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DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA

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REPORT OF ACTIVITIES

April to October 1974

1975

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GEOLOGICAL SURVEY
PAPER 75-1 PART A

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The following reports were submitted after October 23, the date on which editing of this publication began

INTRODUCTION

The role of the Geological Survey of Canada is to provide a comprehensive inventory and understanding of the geological framework of Canada interpreted in terms of all national activities that make use of or are affected by geology. These activities include not only the search for energy sources and mineral deposits but also the geological aspect of those activities concerned with land use, urban development, increasing yields in forestry and agriculture, engineering projects and the conservation of our natural environment, to name only a few. Expanding populations and the ever growing demands for energy and natural resources have heightened the need for a more precise knowledge of the geology of Canada and for a greater comprehension of geological processes for long range planning and as a basis for enlightened decisions by government and industry.

The formal objectives of the Geological Survey comprise the geological aspects of the authorized programs of the Department of Energy, Mines and Resources and follow seven main thrusts directed towards: ascertaining Canada's energy and mineral resources; facilitating exploration and development; encouraging regional development; promoting effective use of the Canadian terrain; identifying and assessing natural hazards; identifying geological features affecting environmental equilibrium, and disseminating information on Canada's landmass and the resources it contains. In pursuance of these objectives the Survey carries out investigations in geology, resource geophysics, geochemistry, geomorphology and physical geography for the landmass of Canada, including the continental shelves and adjacent ocean floors. In addition to systematic mapping and comprehensive topical studies, these investigations require the formulation of nationally consistent standards for chronology and stratigraphic correlation and are dependent on paleontological, petrological and mineralogical studies. In certain other fields such as geophysics and geochemistry, there is a continuing need for the design, development and testing of methods and equipment appropriate for Canadian needs. New fields embrace shipborne geological and geophysical studies, application of statistics to estimation and prediction of mineral potential, regional limno-geochemistry and researches into geotechnics and the application of geoscience to engineering planning.

The 160 reports that comprise this publication present the results of many of the activities carried out by members of the Survey's staff in support of these objectives. Many of the conclusions presented are based on a preliminary assessment of data collected during the 1974 field season and are subject to re-evaluation in light of more detailed studies.

The papers are arranged in broad scientific categories but these in no way reflect the administrative organization of the branch. Divisional affiliation is given for staff members and for internal use, project numbers are listed. Papers for inclusion in this report were received until October 23, 1974.

1. VOLCANIC ROCKS OF THE APPALACHIAN PROVINCE: ROBERTS ARM GROUP, NEWFOUNDLAND (2E)

Project 730043

H.H. Bostock
Regional and Economic Geology Division

The Roberts Arm Group, Notre Dame Bay, Newfoundland, was selected as a potentially rewarding unit within the Appalachian Province for detailed investigation of physical volcanology, volcanic sedimentation, petrography and chemistry of volcanic rocks, and of the relationships of these features to associated mineral deposits. Study of the group commenced during the 1974 field season with mapping of a part of the northern part of the group at a scale of 1: 25,000 using one traverse team.

The Roberts Arm Group is located within the northern part of the central mobile belt of Newfoundland. On the north it is in fault contact with mafic volcanic rocks of the Lushs Bight Group thought to represent Ordovician oceanic crust. To the east it overlies but may also intertongue with sedimentary rocks of the Middle Ordovician Exploits Group. To the west it is overlain by red beds and felsic to mafic volcanic rocks of the Silurian(?) Springdale Group.

Roberts Arm Group

The Roberts Arm Group consists mostly of green to grey, massive to porphyritic, in large part abundantly amygdular, basaltic to andesitic lavas (4)[1]. Pillowed flows are common throughout but columnar structure is rare. Volcanic breccias (5), largely pillow breccias, are widely present in lenses, locally reaching up to 600 or 700 m thick. Elongation of these lenses is in places discordant with bedding shown by pillow elongation, by intercalated minor sedimentary layers, or by bedding within the breccia lenses themselves. Local abundance of breccia and discordance of breccia lens elongation may reflect deposition of these breccias on slopes adjacent to volcanic centres. Although some of the breccias are fine grained, and a few layers of tuffaceous origin may be present, tuffs are scarce. Lenses of red, purple, brown, green, black, pink and cream cherts and siltstones, and greenish greywacke (3), commonly from a few centimetres to a few metres thick, are intercalated locally. Felsic volcanic rocks (7) consisting mostly of red to brown dacites containing plagioclase or plagioclase and quartz phenocrysts, but possibly including some rhyolite, are concentrated along the northern and western limits of outcrop of the group. Quartz amygdules are common in these rocks, and epidote and calcite amygdules less so. The felsites are typically massive, but in places they are mottled, containing more or less distinctly defined inclusions or patches of more mafic lava. Locally felsic breccias are present, and rarely the rocks exhibit flow banding. In places felsic flows consist of large felsic pillows up to 3 m in diameter with thick (20 cm) altered rims.

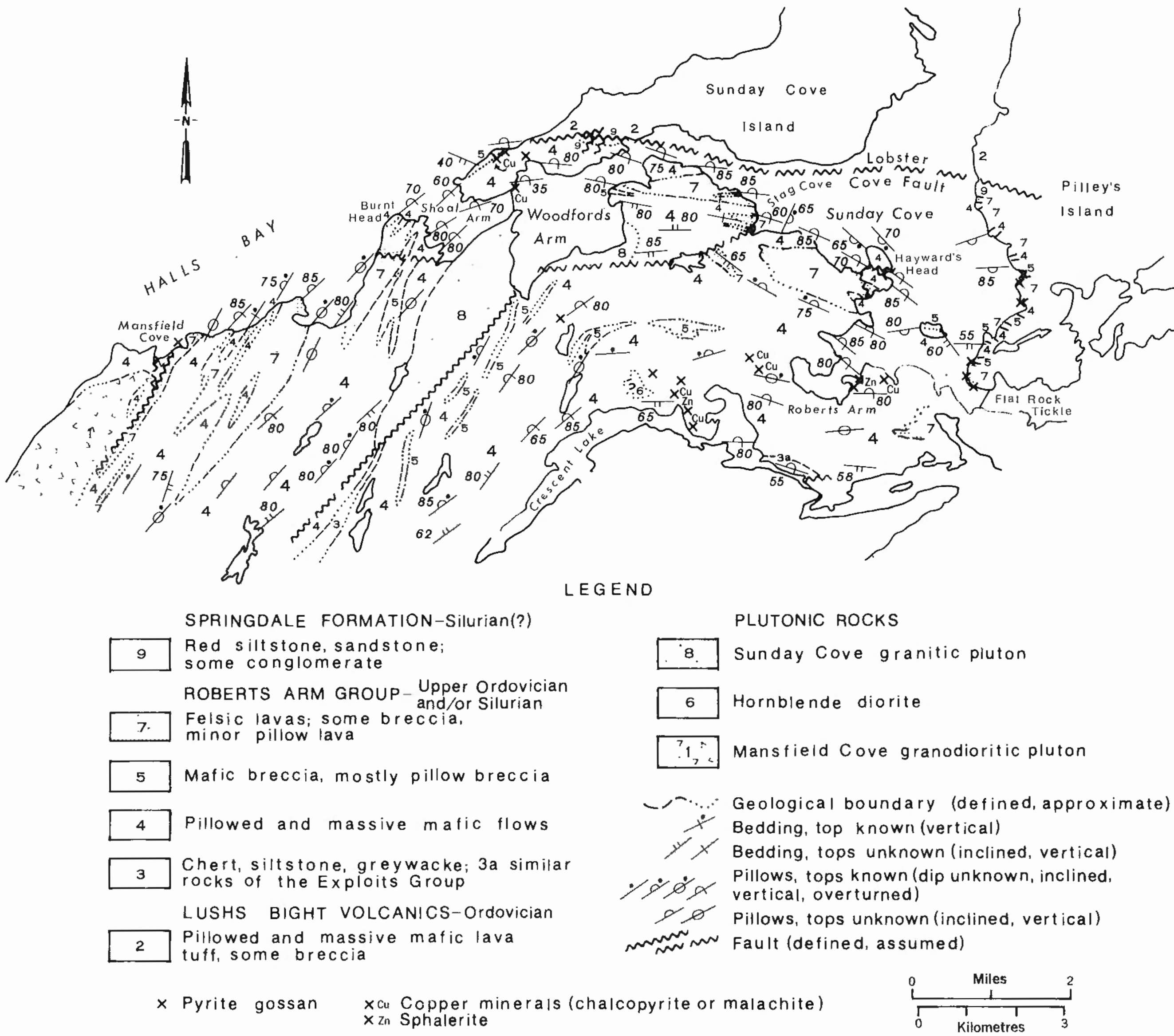
The felsic flows are concentrated about centres that lie (or would have lain if they had not been removed by deformation and erosion) beneath Halls Bay and Sunday Cove. Thin mafic pillow lavas are locally intercalated between the felsic flows, and the two types interdigitate in areas remote from the centres showing that both mafic and felsic volcanism was mostly or entirely submarine. Contacts between felsic and mafic flows are conformable, but in places the two are separated by thin beds of fine-grained sediment, or by volcanic breccia. Mafic and felsic volcanism were therefore concurrent in the northern and western parts of the Roberts Arm Group and individual flows probably succeeded one another without extended periods of quiescence.

Granitic Rocks

South and southwest of Sunday Cove a lower part of the Roberts Arm Group (bounded at its lower limit by a fault) is intruded by the *Sunday Cove granitic pluton* (8). This pluton consists primarily of unfoliated medium-grained, pink-red chloritic granitic rocks which give uniform relatively high scintillometer readings comparable to those obtained from felsites. Such readings are thought to reflect relatively higher potassium content. Remnants of hornblende and locally of biotite probably represent primary mafic minerals. Rocks of more mafic composition, in part of hybrid origin, are present within the pluton along the south shore of Woodfords Arm, and textural variations and zones of inclusions appear elsewhere. The pluton is bordered on the northwest by a partial aureole of dark green amphibole-rich metabasalt which is widest west of Sunday Cove Island causeway. A swarm of northwest-trending mafic dykes that are most prominent about Woodfords and Shoal arms, intrudes the pluton.

Southwest of Mansfield Cove the Roberts Arm Group is in fault contact with the *Mansfield Cove granodioritic pluton* (1). Mafic volcanic rocks similar to the Roberts Arm Group appear in an outlier to the northwest of the pluton and as large inclusions within the pluton. These volcanics are, however, typically more or less highly fractured and locally at least appear more altered than most of the volcanic rocks farther east.

[1] Refers to map-unit numbers on accompanying figure.



The Mansfield Cove pluton consists primarily of strongly to weakly foliated grey-green granodiorite characterized by an abundance of quartz crystals up to 2 cm in diameter. Variants to hornblende diorite are present locally and these in places show lenticular leucogranitic bands parallel to foliation. Pinker, probably more potassic variants, appear less commonly and are the only ones that give scintillometer readings above those typical of basalt. Fine-grained granitic and felsic rocks possibly in part mylonites, are present along the northern contacts of the pluton where the adjacent mafic volcanic rocks are highly brecciated. The pluton is intruded by a variety of mafic dykes which show varying degrees of alteration and disruption.

Structure

Stratigraphic sequence in the Roberts Arm Group is widely indicated by pillow tops and in places may also be deduced from scour and fill structures and from graded beds within minor sedimentary units. These structures indicate that most rocks within the area mapped face northward. At Hayward's Head, however, pillows face southwest, and discordant southeastward facing pillows along the coast to the northwest suggest that there may be a structural break offshore between Stag Cove and Hayward's Head. Preliminary traversing of the Roberts Arm volcanics southwest of the map-area suggests that in this region as well there is structural complexity and a reversal of facing direction over a considerable area.

High-angle faults divide the Roberts Arm Group into at least two major northward-facing, fault-bounded belts. One of these faults truncates a major lens of chert, siltstone, and greywacke, and forms the southeast limit of the Sunday Cove pluton (8). Southwest of Woodfords Arm minor felsites occur almost exclusively to the northwest of this fault (stratigraphically above the Sunday Cove pluton). Dykes of felsite lead northwestward from the pluton toward the main masses of felsite (7) along the northwest margin of the northwestern belt, and are of similar lithology to some fine-grained parts of the pluton. It seems likely therefore that the felsites and the granitic rocks of this pluton are consanguineous.

A second high-angle fault, which follows a lineament southwest of Mansfield Cove, places highly altered granodiorite of the Mansfield Cove pluton (1) against clearly less altered but fractured felsites (7) of the Roberts Arm Group. This fault extends northeastward toward Sunday Cove Island where the more easterly trending Lobster Cove fault has brought penetratively deformed and metamorphosed volcanic rocks of the Lushs Bight Group (2) to the north against unaltered Roberts Arm Group. The latter fault extends eastward across Sunday Cove and Pilley's Islands, and has locally down-dropped, northward-dipping to northward overturned remnants of the Springdale Group (9) along it. Other faults, more closely spaced, probably follow the southeast margin of the Roberts Arm Group where the volcanic rocks overlie and probably intertongue with cherts, siltstones and greywackes of the Exploits Group (3a).

Sulphide Occurrences

Sulphide deposits of two types occur within the Roberts Arm Group. The first and most extensive type consists of disseminated to massive pyrite, with local chalcopyrite and sphalerite, and some galena, in association with the felsic volcanic rocks. The second consists of a variety of occurrences of pyrite and chalcopyrite with or without sphalerite, mostly associated with veins, chiefly of quartz but locally of carbonate, in the mafic volcanic rocks.

Pyrite is disseminated in felsic volcanic rocks producing a gossan zone some 10 feet wide at the shore of Mansfield Cove. On the west shore of Sunday Cove Island a small adit, now collapsed, has been driven along a pyrite-rich bleached zone in mafic volcanic rocks adjacent to the felsites, and disseminated pyrite is found in felsite bodies in road-cuts on the Port Anson road to the east. A minor felsite flow or sill within mafic volcanic rocks along the Port Anson road one half mile southeast of Woodfords Arm contains up to several per cent of disseminated pyrite. A number of large gossan zones resulting from weathering of disseminated pyrite in felsic volcanic rocks are present along the west shore of Pilley's Island. The most economically interesting deposits, including the old Pilley's Island mine, the Henderson showing and the Bull Road showing, occur to the east of the area mapped. These deposits contain pyrite, chalcopyrite and sphalerite with appreciable amounts of galena in the Bull Road showing, and occur within or associated with breccia bodies in the dacites, probably around volcanic centres or pipes (Strong, 1974).

Distribution of felsic volcanic rocks within the area mapped suggests that major centres of felsic volcanism are situated beneath Sunday Cove to the west of Pilley's Island, and beneath Halls Bay to the north and west of Burnt Head. To the extent that similar mineral deposits are likely to have formed in the vicinity of such volcanic centres toward the end of their activity, the most favourable regions for further prospecting for this type of deposit appear to be offshore in these areas.

Small amounts of pyrite and chalcopyrite with and without sphalerite, locally associated with quartz or carbonate veins, are described by Espenshade (1937) in mafic volcanic rocks within a westward-trending zone between Flat Rock Tickle and Roberts Arm, and similar mineralization is present locally in mafic volcanic rocks immediately west of the town. A second, west-northwest trending zone in mafic volcanic rocks immediately north of Crescent Lake, which includes the old Crescent Lake Mine, contains similar mineralization in association with quartz veins (Espenshade, 1937). Minor occurrences of chalcopyrite were found in mafic volcanic rocks just north of Sunday Cove Island causeway, and in pillow breccia near the north shore of the island.

Interpretation

Mapping to date within the Roberts Arm Group has indicated the presence of two major fault-bounded belts within which the volcanic rocks are steeply dipping and northward facing. Felsic volcanic rocks occur along the northern and northwestern margin of the northwestern belt. Similar but thinner fault slices appear to exist along the southeast margin of the group where it partly overlies but may also intertongue with cherts, siltstones, sandstones and greywackes of the Exploits Group. The Roberts Arm Group, along its western margin, is in fault contact with possibly older granodiorite of the Mansfield Cove pluton which may have formed part of a relatively more stable older basement during rotation and faulting of the volcanic rocks to the east (*see* K.L. Currie, this publication, report). Correlation between fault belts is not yet possible but to the extent that each fault belt may represent a more or less equivalent section through the Roberts Arm Group they may collectively provide a picture of the facies changes in volcanic stratigraphy that evolved within the Roberts Arm basin, transverse to the volcanically active margin of a block of sialic basement. Further mapping, together with petrographic and chemical studies, will be directed toward refinement of the structural interpretation and correlation between fault-bounded belts.

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2. GEOLOGY OF THE L'ANSE AUX MEADOWS NATIONAL HISTORIC PARK, NORTHERN NEWFOUNDLAND (2 M/11, 12)

Project 680130

L.M. Cumming
Regional and Economic Geology Division

An area of about 30 square miles around the Norse site at L'Anse aux Meadows (H. Ingstad, 1964 and 1971) has been recently dedicated as a National Historic Park. This area includes most of the islands in Sacred Bay as well as a seven-mile stretch of the mainland which extends from the marine indentation of South Road to Route 436.

Several distinct types of bedrock occur within the Park which are numbered as units 1 to 5 on Figure 2.

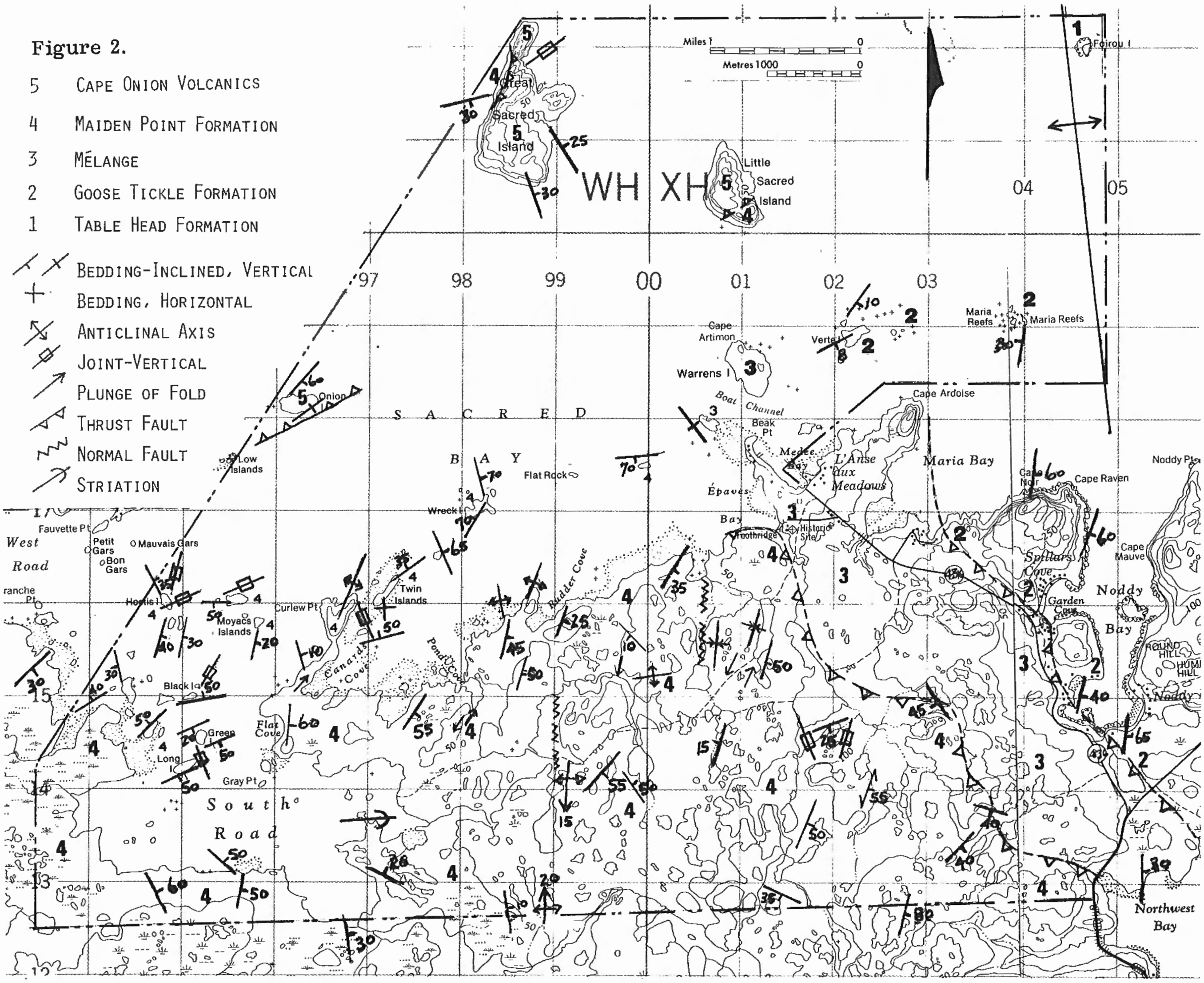
Autochthonous limestones and clastic sediments of the Table Head and Goose Tickle formations respectively (units 1 and 2 on Fig. 2) outcrop on a group of islands in the northeast corner of the Park. These Ordovician strata are exposed along a north-south-trending anticline whose axis extends from Foirou Island to Noddy Bay. Although only the Goose Tickle and Table Head formations are exposed, the entire sequence of autochthonous strata from Goose Tickle to Bradore formations (Cumming, 1971) underlies the Park at depth. These rest on a Precambrian (Grenville) basement.

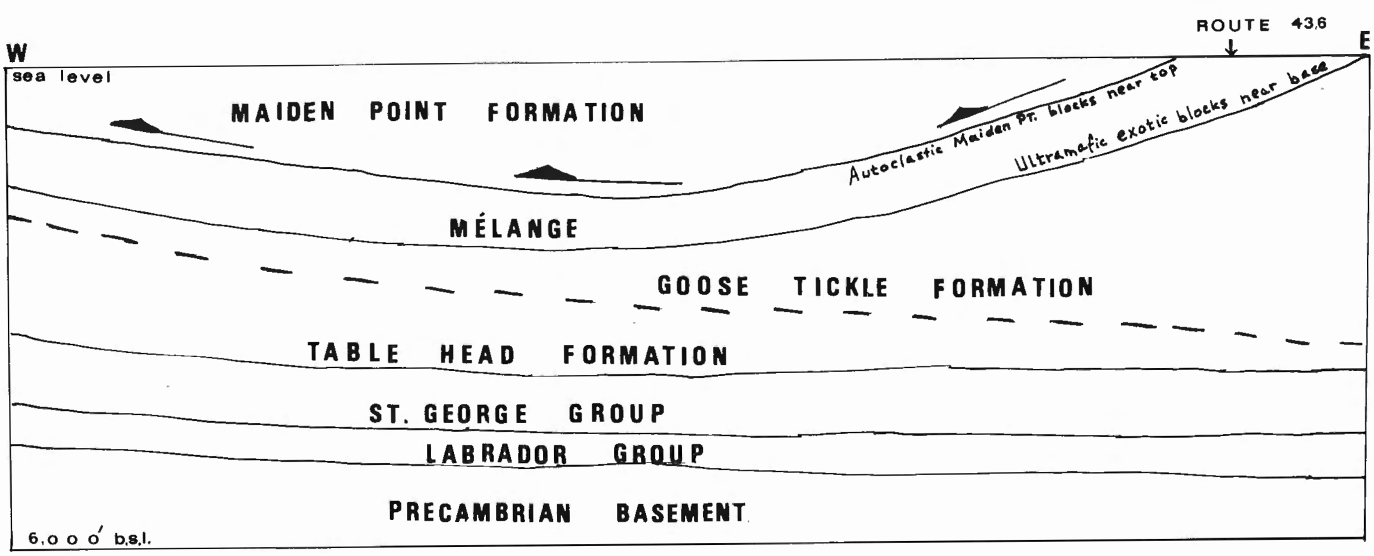
The most widespread formation which is exposed within the Park is the Maiden Point Formation (unit 4, Fig. 2) which consists of greywacke, quartz pebble conglomerate, sandstone and shale (Gillis, 1966; Tuke, 1966). These rocks are part of the allochthonous sequence and are not fossiliferous. Resistant greywacke and sandstone beds within the formation form low ridges throughout the Park (*see* Figs. 1 and 3). A diabase sill intrudes the Maiden Point Formation on the north tip of Wreck Island.

Underlying the Maiden Point Formation is a northwest-trending mélange zone (unit 3, Fig. 2) which is largely restricted in outcrop distribution to the eastern margin of the mainland portion of the Park. This zone of fragmented and mixed rock types has a tectonic origin similar to that summarized by Hsü, 1968 and 1974. Blocks of varying size and lithologies occur within this mélange zone. These blocks are typically set in a cleaved and deformed black shale matrix. Fragmented blocks of the mélange are well exposed in a road-cut

Figure 1. Épaves Bay, aerial view to the southwest of the Norse site at L'Anse aux Meadows; note the escarpment formed at the contact between the less resistant mélange and the more resistant greywacke of the Maiden Point Formation. GSC 202640.

Figure 2.





GENERALIZED GEOLOGICAL SECTION—ALONG SOUTH BOUNDARY OF PARK.

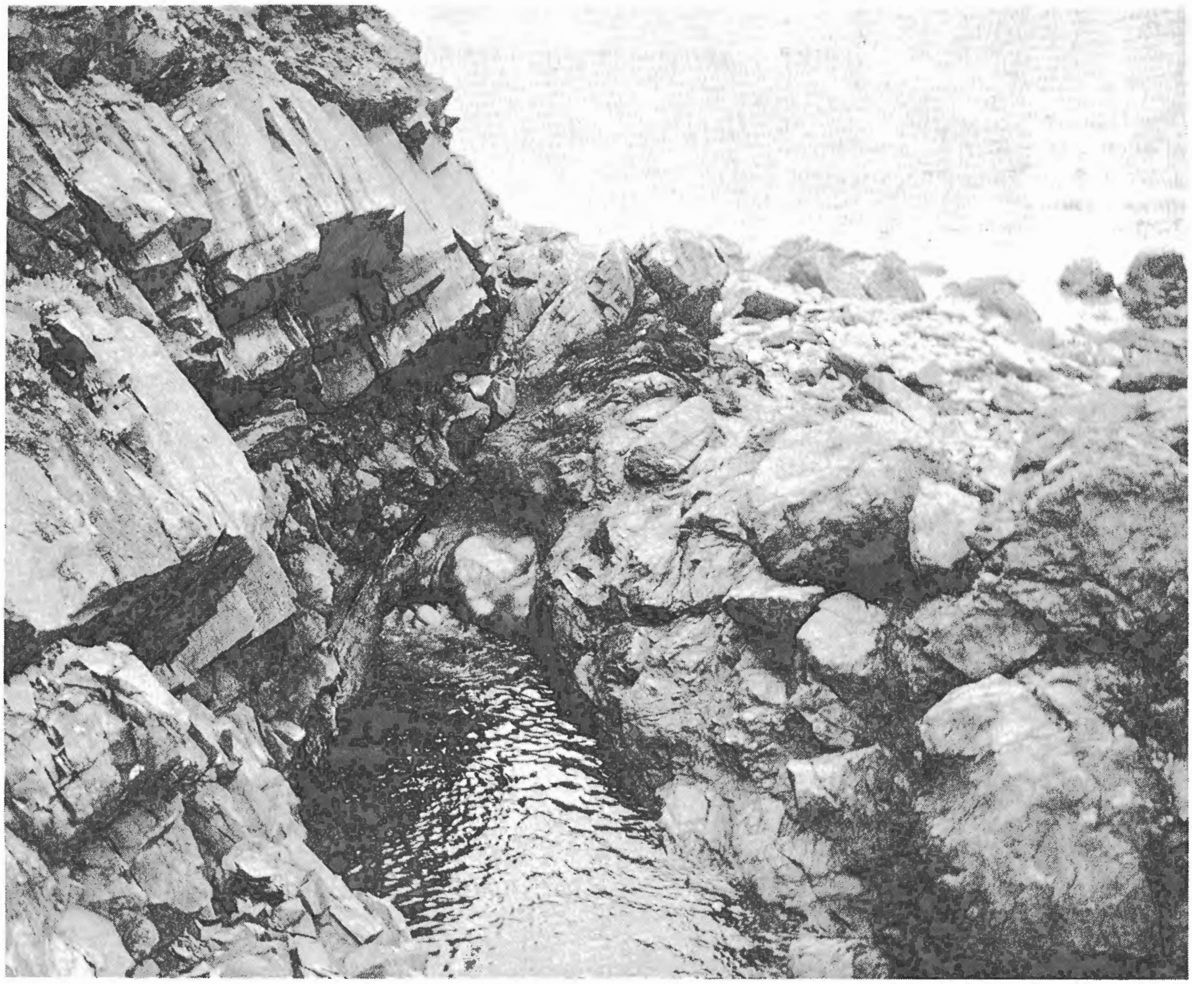


Figure 3. Épaves Bay, view to the west, 0.3 mile west of the Norse site at Black Duck Brook; massive greywacke beds of the Maiden Point Formation at the left dip 40 degrees south and are underlain by "block rock" of the mélange. GSC 202635.

on Route 436, 0.8 mile north of the Quirpon junction and also along Épaves Bay (*see* Fig. 3), especially at low tide. At Straits View (*see* Fig. 4) an exotic block of serpentinite has soapstone developed along northeast-trending shear zones within the block. No continuous sedimentary section was found in the mélange, rather it is a heterogeneous deposit in which exotic blocks of igneous and sedimentary rocks are mixed at random.

Basaltic volcanic rocks showing pillow structure (unit 5, Fig. 2) are well displayed on Onion Island, Great Sacred Island (Fig. 5) and Little Sacred Island in the northwest corner of the Park. These occurrences are part of a northeast-trending belt of Lower Ordovician volcanic rocks (the Cape Onion Slice Assemblage of Williams, Smyth and Stevens, 1973) which extends from Milan Cove to Cape Onion. Similar basaltic rocks occurring near the east side of the Park have been described in detail by Daly (1903).

The L'Anse aux Meadows Norse site is located near the western margin of the mélange at the Maiden Point Formation-mélange contact (*see* Fig. 6). Slag, lumps of bog-iron and a smithy have been found at the site (A.S. Ingstad, 1970, p. 148). Disseminated pyrite cubes and nodules are common in the matrix of the mélange and provide a ready source of iron for transportation by groundwaters, which by biological precipitation produced bog-iron concentrations in the lowland areas underlain by mélange.

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Figure 4

Aerial view looking southeast over Garden Cove and the village of Straits View; highway route 436 is in the foreground. Note the block of serpentinite (350 feet long) on the right and also the smaller block of volcanics (60 feet long) on the left. Both of these exotic blocks occur within the mélange zone whose matrix is intensely deformed black shale. GSC 202646.

Figure 5

Basaltic pillow lava, northern tip of Great Sacred Island. GSC 202633.

Figure 6. Archaeological digs at the L'Anse aux Meadows Norse site, August 1, 1974. The grassy lowlands at the site are underlain by mélange. The bedrock ridge in the background is underlain by greywacke of the Maiden Point Formation. GSC 202643.

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Project 740023

Harold Williams[1] and A.F. King[1]
Regional and Economic Geology Division

Earliest geological studies in the Trepassey map-area were made by Jukes (1843), and by Murray and Howley (1881a, b) between 1864 and 1881. Apart from geological compilations of the Island of Newfoundland by Baird (1954) and by Williams (1967), the only published regional geological map of southeastern Avalon Peninsula was compiled by W.D. Bruckner (*in* King and Brückner, 1974) based on his own observations, on detailed studies by Memorial University of Newfoundland M.Sc. candidates (Misra, 1969a, b; Koh, 1969), and on more recent work by Anderson (1972).

Approximately 60 per cent of the Trepassey map-area was completed during 1974 suitable for publication at 1 inch to 2 miles and the remainder will be completed during the 1975 field season.

All rocks are of late Precambrian age and they comprise two contrasting assemblages. (1) An igneous assemblage consisting of chiefly terrestrial felsic and mafic volcanic rocks, volcaniclastic rocks, representing the southward continuation of the Harbour Main Group and the Holyrood Plutonic Series as defined in the Whitbourne map-area to the north (McCartney, 1967). (2) A sedimentary assemblage consisting of clastic rocks that overlies and flanks the southward prolongation of the igneous assemblage, representing correlatives and lithofacies variants of the Conception and Cabot Groups to the north (Rose, 1952; McCartney, 1967). Lithostratigraphic subdivisions of the sedimentary assemblage and their distribution are shown in the accompanying figure.

Seven map-units are recognized within the Conception Group which is about 4 km thick. Six are of formational status and their delineation represents the first formal subdivision of the entire group. The Cabot Group ($2\frac{1}{2}$ km thick) is divided into three formations. Present boundaries between groups and formations are provisional and subject to revision pending the completion of field studies. The new stratigraphic names herein included will be formally described in a final report to be prepared in a year or two.

The Mall Bay and Gaskiers formations and the Shag Rock sequence are restricted to the vicinity of St. Mary's Bay where they comprise about one quarter of the map-area. They are separated from other formations of the Conception Group by a northeast-trending fault zone east of Holyrood Bay. Much of the middle part of the Shag Rock sequence, especially surrounding Holyrood Pond, resembles the Drook formation (modified after Misra, 1969b). Coarser upper parts of Shag Rock may therefore correlate with the Briscal so that most of the Shag Rock sequence may be equivalent to the combined Drook and Briscal formations.

The Drook and succeeding formations comprise a conformable marine succession that lies directly upon the Harbour Main volcanics north of Chance Cove. The relationship is conformable and the apparent absence of the Mall Bay and Gaskiers formations above the volcanics suggests that the Mall Bay and Gaskiers are offshore equivalents of the volcanic rocks. This suggestion is supported by the enormous amount of volcanic debris, like the Harbour Main, within the Gaskiers tillite. The continuity of the Drook and younger formations without stratigraphic overstep or significant thickness or facies variation implies that they were once continuous across the older igneous assemblage that forms the exposed core of the map-area.

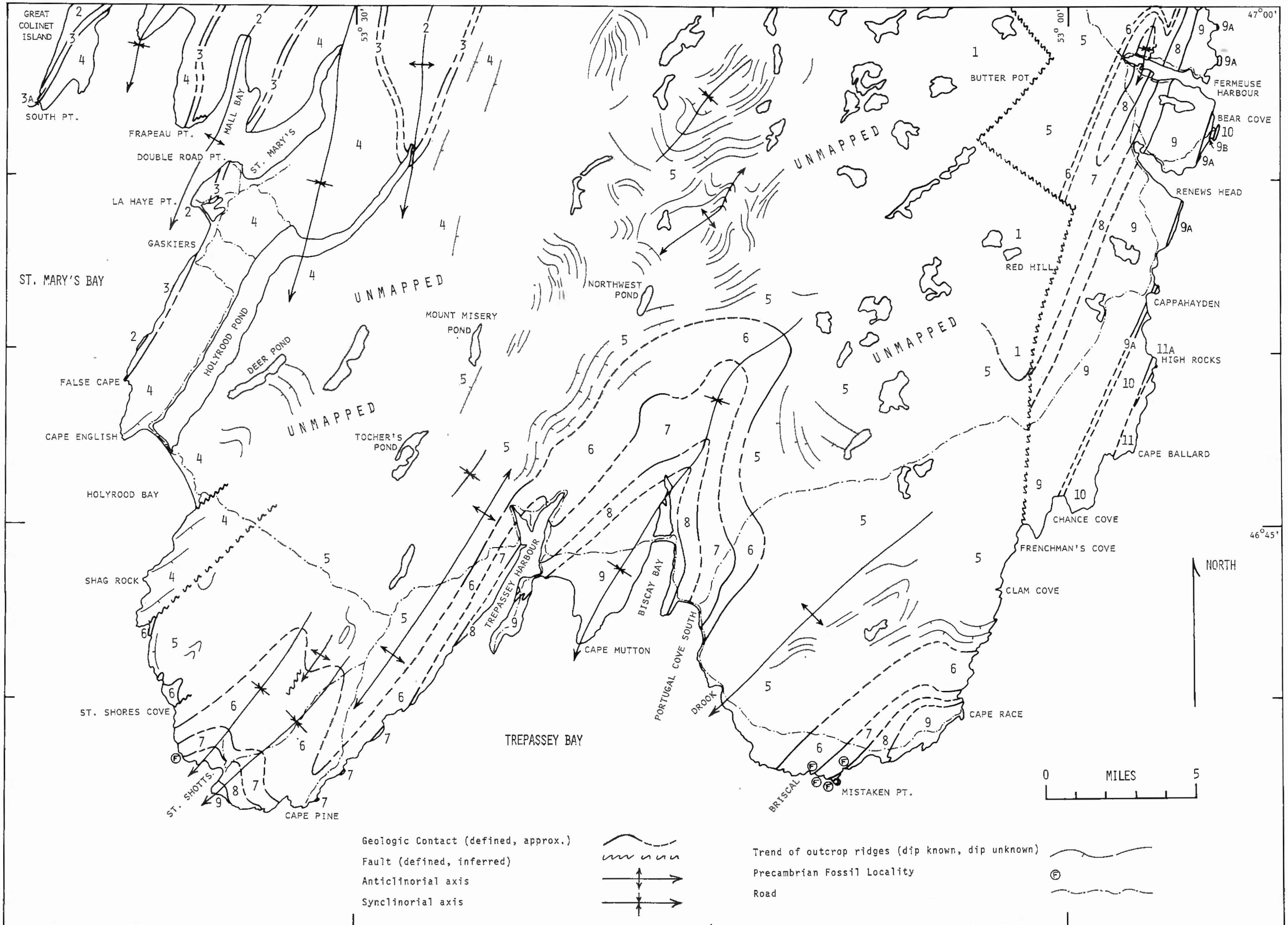
The Cabot Group overlies the Conception Group with conformable and gradational contact. The relationship is well displayed at Cape Race, Long Cove (2 miles east of Mistaken Point), Trepassey Harbour and St. Shotts. The contact is drawn where the thicker sandier beds of the Trepassey Formation grade upward into grey shales.

The Conception Group is undivided outside of the map-area but provisional correlations are suggested as follows: (1) Trepassey Formation is equivalent to gradational beds between the Conception Group and St. John's Formation on the east side of Middle Cove, (2) Mistaken Point Formation corresponds with alternating red and green beds of the 'Torbay Slate' (Rose, 1952) and the Hibbs Hole Formation (Hutchinson, 1953; McCartney, 1967) and (3) the Gaskiers Formation is correlated with tillite at Portugal Cove, Red Head, and Bacon Cove (Bruckner, 1969; King and Brückner, 1972, 1974; Anderson, 1972).

The Gaskiers Formation was referred to as "tilloid" by McCartney and Henderson (*in* McCartney, 1967) and interpreted as "tillite" by Bruckner and Anderson (1971). In six sections studied during the field season, twenty or more thin-bedded 'glacio-marine' siltstone units occur throughout the formation. Convolute and ripple lamination, grading, and oriented fragments all indicate local transport and deposition of finer material by bottom currents. Distorted bedding showing décollement-like slump folds indicates a paleoslope inclined to the south. The coarse unsorted tillite units contain a small percentage of striated pebbles and cobbles. Some are granites and quarzites foreign to the Avalon Peninsula of Newfoundland.

Precambrian fossils are well-preserved at a number of stratigraphic levels toward the top of the Mistaken Point Formation. These consist of a variety of forms that occur consistently on ripple-marked bedding surfaces and beneath thin tuffaceous laminae (Anderson and Misra, 1968; Misra, 1969a; Anderson

[1] Department of Geology, Memorial University of Newfoundland, St. John's, Newfoundland.



GREAT COLINET ISLAND
SOUTH PT.
FRAPEAU PT.
MALL BAY
ST. MARY'S
DOUBLE ROAD PT.
LA HAYE PT.
GASKIERS
ST. MARY'S BAY
HOLYROOD POND
DEER POND
FALSE CAPE
CAPE ENGLISH
HOLYROOD BAY
SHAG ROCK
ST. SHORES COVE
ST. SHOTTS
CAPE PINE
UNMAPPED
MOUNT MISERY POND
TOCHER'S POND
NORTHWEST POND
BUTTER POT
RED HILL
FERMEUSE HARBOUR
BEAR COVE
RENEWS HEAD
CAPPAHAYDEN
HIGH ROCKS
CAPE BALLARD
CHANCE COVE
FRENCHMAN'S COVE
CLAM COVE
CAPE RACE
MISTAKEN PT.
BRISCAL
DROOK
PORTUGAL COVE SOUTH
BISCAY BAY
CAPE MUTTON
TREPASSEY HARBOUR
TREPASSEY BAY
47°00'
46°45'
53° 30'
53° 00'
NORTH
0 MILES 5
Geologic Contact (defined, approx.)
Fault (defined, inferred)
Anticlinorial axis
Synclinorial axis
Trend of outcrop ridges (dip known, dip unknown)
Precambrian Fossil Locality
Road

LEGEND

PRECAMBRIAN (HADRYNIAN)

CABOT GROUP (9-11)

11 CAPE BALLARD FORMATION: Thick-bedded grey sandstone, quartz granule conglomerate, grey shale, minor purple shale; 11a, High Rocks member, red wavy-bedded sandstone and shale

10 GIBBETT HILL FORMATION: Thick-bedded light grey sandstone with alternating units of thin-bedded dark grey sandstone and siltstone

9 ST. JOHN'S FORMATION: Grey to dark grey shale with thin isolated lenses of sandstone and siltstone; 9a, Renews Head member, dark grey thin-bedded sandstone, minor shale; 9b, Fermeuse member, evenly laminated fissile grey siltstone

CONCEPTION GROUP (2-8)

8 TREPASSEY FORMATION: Medium- to thin-bedded grey sandstone and shale, graded sandstone beds with shale tops

7 MISTAKEN POINT FORMATION: Medium-bedded grey to pink sandstone and green to purple and red shale, minor thin tuff horizons. Contains Precambrian fossils toward its top

6 BRISCAL FORMATION: Thick-bedded coarse greenish grey sandstone with units of laminated grey siltstone and shale

5 DROOK FORMATION: Parallel bedded olive green to grey argillaceous chert, siliceous siltstone and silicified tuff. Locally includes grey sandstone and shale

(ST. MARY'S BAY AREA)

4 SHAG ROCK SEQUENCE (undivided): Thick-bedded grey sandstone, thick tuffaceous sandstone units, green to grey siliceous argillite and siltstone, minor purple argillite

3 GASKIERS FORMATION: Grey tillite with thin alternating units of graded laminites with 'dropstones'. Red tillite overlain by red mudstone at top. Minor red mudstone at base; 3a, South Point member, red agglomerate

2 MALL BAY FORMATION: Green siliceous siltstone and argillite, grey sandstone, chert, thick-bedded tuffaceous sandstone, green siliceous tuff and agglomerate

HARBOUR MAIN GROUP (1)

1 Red and green pyroclastic rocks, green altered basalt, minor siliceous siltstone and sandstone; includes undifferentiated Holyrood Granite

Note: New stratigraphic names herein used are provisional and will be described formally in a final report to be completed in a year or two.

in King and Brückner, 1974). Three new occurrences were discovered during the field season as well as a previously undescribed amoeboid-like form with internal ribbed character. The latter is possibly biogenic and occurs on bedding surfaces at the base of the Mistaken Point Formation and at the top of the Briscal Formation about one mile west of Mistaken Point.

The Cabot Group continues northeast of the map-area for about 50 miles to Tor Bay (Rose, 1952). The St. John's Formation is equivalent to black shales and slates of the Carbonear Formation in the Conception Bay area (Hutchinson, 1953). The Gibbett Hill formation is correlated with grey sandstones at the base of the Signal Hill Formation (Rose, 1952; King, 1972). Coarse quartzose sandstones toward the top of the Cape Ballard Formation are lithologically similar to grey sandstones and conglomerates above the Signal Hill conglomerate at Flat Rock (King, in prep.). Red wavy-bedded sandstones of the High Rocks member at the base of the Cape Ballard Formation are similar to rocks at Ferryland Head and sandstones of the upper Signal Hill and Black Head formations farther north (Rose, 1952).

The St. John's Formation contains *Aspidella terranovica,* Billings 1872, toward its top, e.g. at Clear Cove near the entrance to Fermeuse Harbour. This form is thought to be inorganic and the result of water or gas escape during diagenesis (Hsu *in* King and Bruckner, 1974).

The rocks of the map-area are folded about northeasterly trending axes. The major folds are upright with gentle to moderate dipping limbs and gentle southwesterly plunge. The Gaskiers Formation can be traced from Great Colinet Island eastward across major southwest-plunging folds, the most prominent of which is the False Cape anticline. The fold style of the Conception and Cabot groups is further portrayed by the delineation of the Drook and overlying formations from St. Shotts to Cape Race. The position of the present coastline closely follows this structural pattern. Irregular fold patterns expressed by the morphology of ridges in the north-central part of the map-area may be controlled by structural irregularities in underlying more competent rocks, e.g., Harbour Main volcanics or Holyrood Granite. Smaller folds are abundant throughout the map-area and show divergent plunges in either a northeast or southwest direction. Steeply dipping axial plane cleavage is especially prominent in argillaceous formations such as the St. John's and Trepassey.

Faults trend northeast and parallel fold axes. Faults at Holyrood Bay and south of Shag Rock extend inland for many miles. The most prominent fault in the map-area separates the Harbour Main from the Cabot and Conception groups north of Frenchman's Cove.

A positive linear aeromagnetic anomaly trends east-northeast across the northwest part of the area near Gaskiers (Geol. Surv. Can., Aeromagnetic Map 7325G). It can be traced across the Whitbourne map-area to the north as far as Tors Cove where it continues offshore. This feature has been interpreted as a near-surface mafic dyke like the "Great Dike" of mainland Nova Scotia (Papezik *et al.*, in press). A less pronounced magnetic anomaly occurs locally above the Gaskiers tillite.

No metallic mineral deposits are known within the map-area. Gravel and sand deposits occur almost everywhere (Henderson, 1972).

The stratigraphic and sedimentologic relationships in the map-area suggest a model involving chiefly terrestrial volcanic centres, which while active, were progressively denudated and covered by clastic sediment. A proximal volcanic terrane during deposition of the lower Conception Group is indicated by the presence of agglomerate and tuff associated with the Gaskiers tillite at South Point and volcanic fragments in rocks at the base of the Drook north of Chance Cove. Local tuff horizons in the Mistaken Point and higher formations indicate continued local eruptions. Restricted arkosic beds throughout the Conception (within the Gaskiers and Briscal formations, and Shag Rock sequence) imply unroofing of a granitic terrane, possibly associated with the volcanism. Asymmetrical wave ripples with well-developed bifurcated crests, distorted beds, and slump folds indicate sedimentary transport to the south and southeast during Conception time. The Cabot Group was deposited by currents that flowed to the south and southwest. The St. John's Formation possibly represents pro-delta deposition encroached by sheet sands (Gibbett Hill and Cape Ballard) of a southwestward prograding delta system.

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4. GEOLOGY OF THE TERTIARY ROCKS NORTH OF LATITUDE 49°, WEST COAST OF VANCOUVER ISLAND

Project 690075

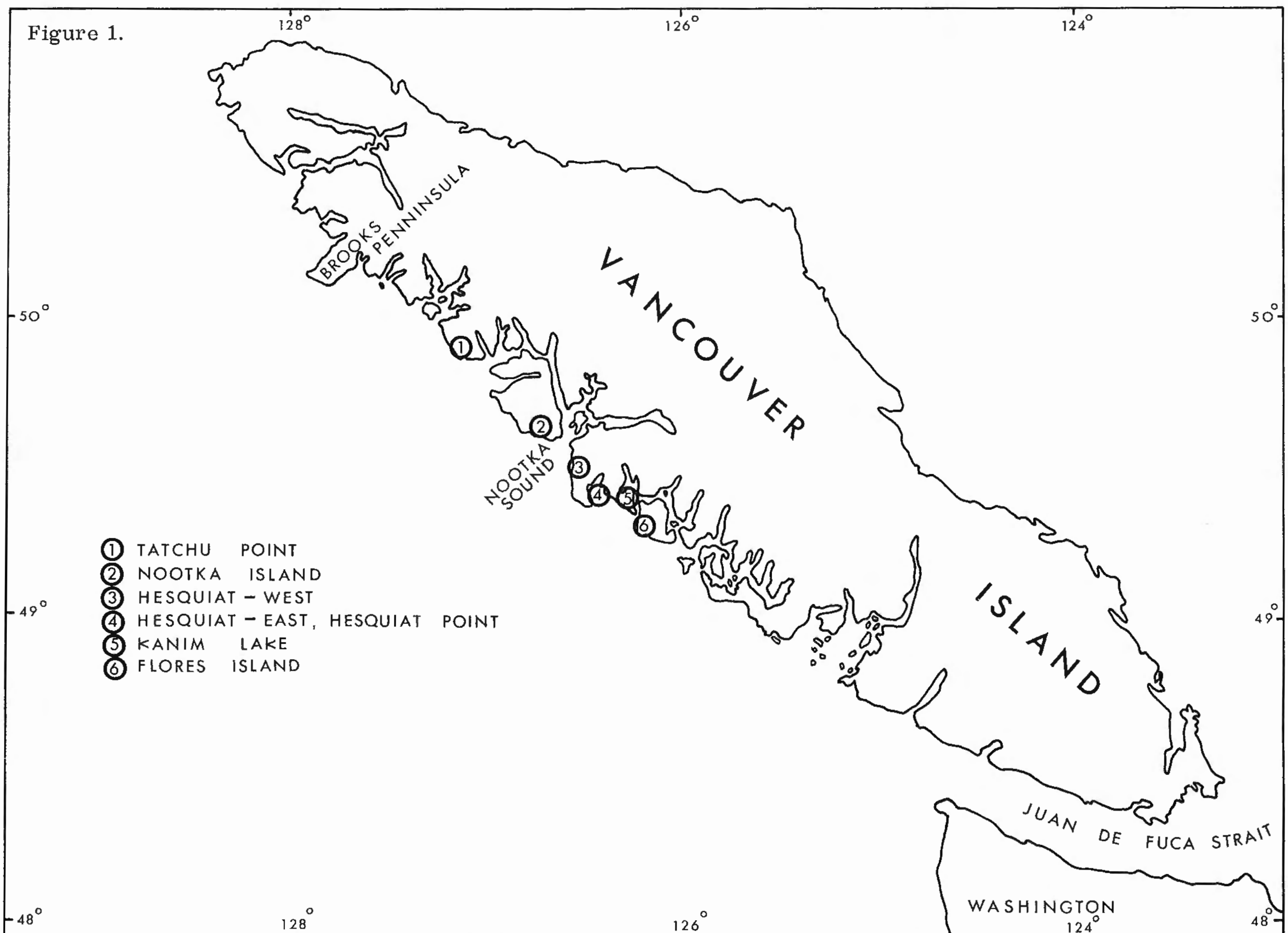
B.E.B. Cameron
Regional and Economic Geology Division, Vancouver, B.C.

Tertiary subaerial exposures north of latitude 49° have now been sampled and described in detail. Microfaunal analyses from sequences totalling 32,000 feet are not yet complete, but several generalizations can be made concerning the geologic history of the area.

1. Basal Tertiary Contact

In all areas studied, the Tertiary rests unconformably on rocks of Mesozoic age, which in most cases are volcanics of the Bonanza Group (J.E. Muller, pers. comm.). As much as eight feet of relief has been observed on this erosional unconformity. A sandstone and minor conglomerate unit overlies the unconformity and ranges in thickness from 60 to approximately 400 feet. Microfaunal analyses in and bounding this unit indicate a Late Eocene age. The unit is diachronous, however, and appears to be oldest in the west Hesquiat area (area 3, Fig. 1; - the type Escalante Formation of Bancroft, 1937). Depositional environments are variable and range from neritic to upper bathyal, apparently depending on the local topographic relief of the depositional site, or on the effects of differential uplift and erosion. In several areas, very well preserved Jurassic foraminifers have been recovered from the basal Tertiary rocks and demonstrate submarine erosion prior to Tertiary deposition.

Figure 1.



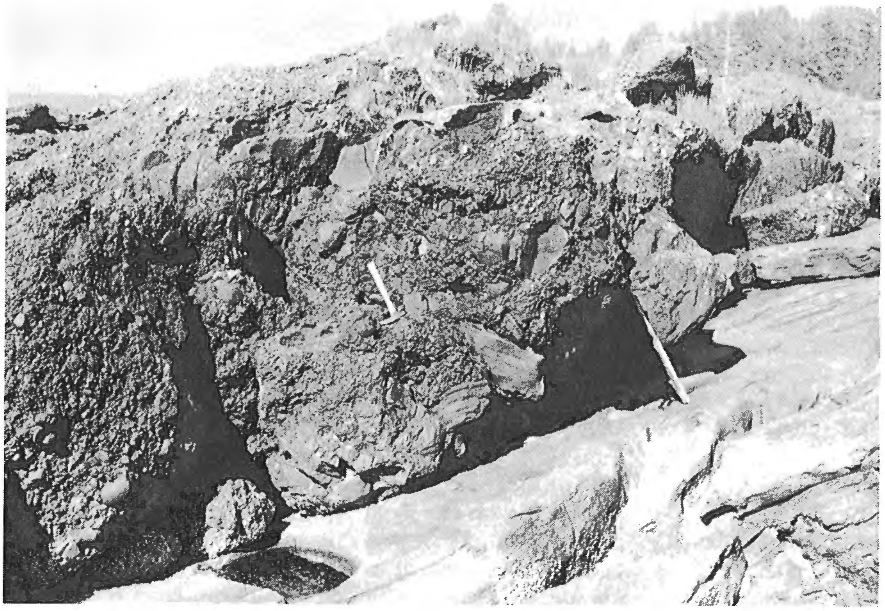


Figure 2.

Reworked angular blocks of Jurassic or Lower Cretaceous and older Tertiary sandstones into younger Tertiary strata.

2. Upper Sequences

Sequences overlying the basal sandstone unit consist of fine shales and siltstones in some areas and massive conglomerates and sandstones in others. These sequences are herein considered to represent distal and proximal, respectively, facies of an Upper Eocene to Oligocene bathyal water fan complex. Several clastic entrants into the depositional basin are apparent. The major sediment channel is located in the west Hesquiat area (area 3, Fig. 1), and secondary entrants are represented in the Tatchu Point area (area 1, Fig. 1), east Hesquiat area (area 4, Fig. 1), and Flores Island (area 6, Fig. 1). Characteristic of the proximal facies are lenticular and intraformational conglomerates, graded sequences, load and flute clasts, penecontemporaneous folds, unconformities, and churned sequences (Cameron, 1973). Many of the massive conglomerates carry large angular blocks of Jurassic or Lower Cretaceous sandstone, reworked blocks of sandstone from the basal Tertiary unit (Fig. 2), and reworked mollusc faunas. Uplift and erosion of the older Tertiary units must have accompanied deposition of younger parts of the succession.

Lithologic correlation of these units is impossible due to very rapid facies changes. Their facies equivalents are well represented by distal sequences exposed on Nootka Island (area 2, Fig. 1), Hesquiat Point (area 4, Fig. 1), and parts of Flores Island (area 6, Fig. 1), which comprise cyclically deposited laminated shale, shaly siltstones, and fine-grained sandstones. The rich foraminiferal faunas recovered from the distal facies indicate deep bathyal depositional environments.

3. Microfauna and Facies Effect

Extensive study of microfaunas has resolved many of these correlation problems and helped to interpret the complex structural history. In addition, certain microfaunal assemblages are indicative of particular lithologic associations within the fan complex. In distal shale and siltstone facies a characteristic microfauna consists of a rich assemblage of calcareous planktonic and benthonic foraminifers, representing up to 50 species. These assemblages are open marine, indicative of bathyal water deposition and remote from the influence of coarse sediment influx. Shales and siltstones within predominantly coarse clastic sequences are generally limited in microfauna or carry a specialized, entirely agglutinated (arenaceous) fauna. In the context of stratigraphic traps for hydrocarbons, this association could be used to indicate proximity to potentially porous clastic tongues or wedges.

4. Tectonic History

A further complicating factor of the Tertiary geology on the west coast of Vancouver Island, is the tectonic history. Two tectonic features are evident, northwest-southeast normal faults, and southwest and south predominantly dextral transcurrent faults. The basal sandstone-conglomerate unit was uplifted and eroded along northwest-southeast normal faults contemporaneously with deposition of the upper sequences. This is apparent from the reworked basal Tertiary rocks throughout the upper sequence and the repeated exposures of the basal erosional contact westerly.

Uplift on these faults continued throughout the deposition of the upper sequence and new faults with similar trends appeared most westerly. Subsequently the entire sequence was uplifted and disrupted by abundant predominantly dextral southwest and south-trending transcurrent faults. Each of these faults appear to have horizontal displacements of from 30 to 100 feet, and locally to 500 feet. Collectively however, they have the effect of increasing the breadth of the outcrop belt southwesterly by duplication of many parts of the sequence.

In summary, the exposures of Tertiary rocks indicate great complexity in depositional and tectonic history. Detailed analyses of the enclosed microfaunas provide a key to interpreting facies equivalents, clastic trends and entrants, and the effects of tectonic events.

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Project 730036

J.E. Muller
Regional and Economic Division, Vancouver, B.C.

Introduction

Reconnaissance geological mapping of the Canadian part of the Victoria map-area (92B) was almost completed during the 1974 field season, leaving the Cape Flattery (92C) part of the project to be completed in 1975. Most of the area was mapped about 60 years ago by C.H. Clapp, who described and interpreted the geology in two Geological Survey Memoirs dealing with the Victoria-Saanich map-areas (1914) and the Sooke-Duncan map-areas (1917), the latter in collaboration with H.C. Cooke. The detailed work of these authors has long been a classic reference for the geology of Vancouver Island and descriptions of the geological formations contain much valuable detailed information. Although most formation names introduced by Clapp are still valid, some revision of age assignments and stratigraphy are required. Undated references to Clapp's work in this report refer to these two memoirs. More recent work within and adjacent to the area is that of Fyles (1955), Yole (1969), and the writer with J.A. Jeletzky (1970).

The stratigraphy and structure of southern Vancouver Island is most complex, bringing together a variety of Paleozoic, Mesozoic and Tertiary volcanic, intrusive, sedimentary and metamorphic rocks. The whole assemblage was deformed and faulted more than once, and most severely in early Tertiary time. The resulting geological collection of similar-looking, mainly basic, crystalline rocks and greywacke-argillite sequences, almost totally lacking in distinct marker-beds or sediments of known age, present a major challenge to the geological investigator. Yet it is a key area that promises to yield important data on the geological history of the Pacific Margin.

Wark Diorite and Colquitz Gneiss

These two intimately related units are confined to the area between Leech River and San Juan faults. They occur in alternating northwest-trending belts and have indistinct gradational contacts with one another. Wark Diorite is hornblende diorite and hornblende quartz-diorite, locally with minor biotite, varying from fine to coarse grained and in many instances with distinct mineral alignment. Agmatite, comprising dark diorite with crosscutting veins of leuco quartz-diorite, is also common. Clapp, writing in an age of exclusively magmatist petrological concepts considered the Wark to be an intrusive batholith. From a modern viewpoint it was more likely formed by recrystallization of basic volcanic rocks, probably mainly Paleozoic Sicker volcanics, but possibly also Karmutsen basaltic lavas.

Colquitz gneiss is light coloured gneissic quartz diorite and granodiorite with minor hornblende and biotite, commonly replaced by chlorite and epidote. Large fresh cuts show irregularly swirling, pinching and swelling light-dark banding and lamination. Locally the gneiss includes lenticular bodies of recrystallized limestone. Clapp's conclusion that Colquitz gneiss intrudes Wark Diorite was probably based on the quartz diorite veins in agmatitic diorite. The gneiss may well be derived from stratified greywackes, tuffs and cherts that form the bulk of Sicker sediments. A zircon-age and associated K-Ar age of similar rocks in the Westcoast Complex near Tofino (Wanless and Muller, in press) indicates that the original age of those rocks is 260 m.y., and that metamorphism occurred 192 m.y. ago. A similar Paleozoic age of parent rocks and early Mesozoic metamorphism of the Wark-Colquitz complex is not unlikely.

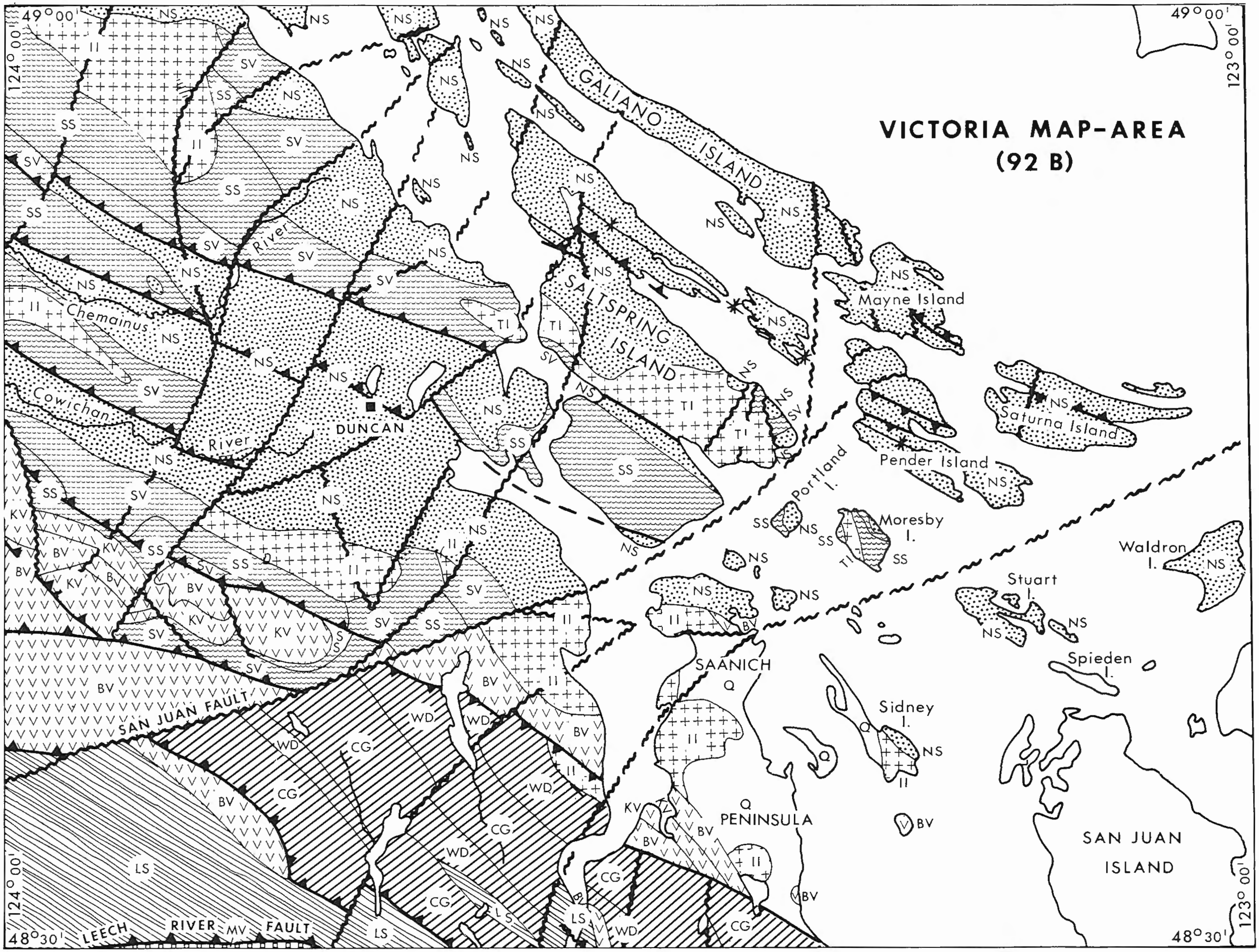
Sicker Volcanics

Sicker volcanics and overlying Sicker sediments occur in several northwest-trending outcrop belts, north of the San Juan Fault system. Nanaimo Group sediments, occupying the lower parts of northeast-dipping half-grabens, separate the Sicker Group belts and these are further broken by northeast-trending faults.

The rocks are mainly massive, dark-coloured tuffs, volcanic breccias, and massive to amygdaloidal lavas. Well banded siliceous tuffs form the transition to Sicker sediments. Many lavas are coarsely porphyritic with hornblende pseudomorphs after augite and plagioclase phenocrysts. Secondary epidote and actinolite indicate a low greenschist grade of metamorphism. The volcanics have been partly altered to chlorite-sericite schist, apparently as a result of strong deformation in fault zones.

Sicker Sediments

The formation, which overlies the Sicker volcanics, is not well exposed, nor has time permitted the study of part-sections in detail. Fyles (1955) and Yole (1969) established the general sequence above the volcanics to be a lower unit, 600 feet thick, of thin-bedded cherty tuff, and an upper unit of about 2,000 feet of "grey to black feldspathic tuffs and argillaceous sediments". The upper part of the unit consists of interbedded grey crinoidal limestone and black chert. Fyles and Yole estimated this unit to be about 1,000 feet thick, but indicate that it grades laterally into chert without limestone. In Victoria map-area, the bulk of Sicker sediments consists of a turbiditic, very well bedded greywacke-argillite sequence, correlative with the 2,000-foot clastic unit of Fyles. Ribbon-chert and banded tuff are also common, but crinoidal limestone occurs as rare and areally small lenses.


VICTORIA MAP-AREA
(92 B)
49°00'
124°00'
123°00'
48°30'
GALIANO ISLAND
SALTSPRING ISLAND
Mayne Island
Saturna Island
Pender Island
Portland I.
Moresby I.
Waldron I.
Stuart I.
Spieden I.
Sidney I.
SAN JUAN ISLAND
SAANICH
PENINSULA
DUNCAN
Chemainus
River
Cowichan
River
SAN JUAN FAULT
LEECH RIVER FAULT
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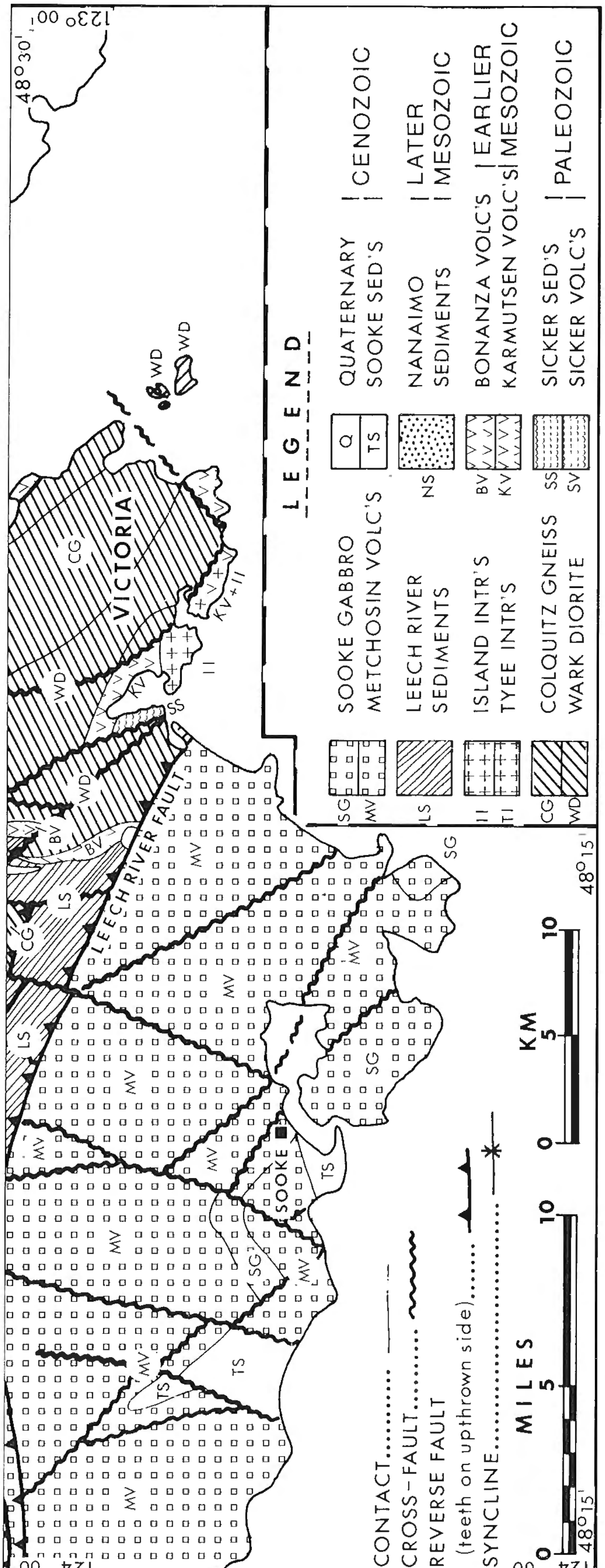

The limestone is best exposed in the large quarry west of Cobble Hill. Dykes and sills of dark coloured feldspar porphyry, in some instances with flower-like feldspar clusters one inch in diameter, are very common in Sicker sediments. Sills of medium- to coarse-grained diabase are likewise widespread and were mapped separately by Clapp.

Fyles and Yole both reported on brachiopod faunas and fusulinids from the limestone, indicating Early Permian age. However, a microfauna extracted from a sample of limestone in the hills south of Cowichan River indicates, according to B.E.B. Cameron (*in* Muller, 1971), a "tentative Pennsylvanian" age. On San Juan Island, which consists for the largest part of a greywacke-argillite sequence probably correlative to Sicker sediments, Danner (1966) has also reported Permian fusulinids from limestone in Cowell quarries.

Tyee Intrusions

Clapp described "Tyee porphyrites", intrusive into Sicker rocks and most typically exposed on Maple Mountain and Saltspring Island. They are quartz-feldspar porphyries, commonly with many conspicuous glassy quartz eyes. According to Clapp, plagioclase, though less conspicuous, predominates by far over quartz in phenocrysts and groundmass, orthoclase is hardly detectable in the matrix and mafic minerals are accessory. This composition is identical to that of known Jurassic quartz-feldspar porphyry of northern Vancouver Island (Muller *et al.*, in press) but the rock's characteristic schistose to gneissic laminated texture, resembling that of ignimbrite, is entirely different. Outcrops near Erskine Point on Saltspring Island show schistose porphyry interdigitating with schistose and slaty Sicker sediments. The contacts are sharp and almost parallel with schistosity. They show the rocks to be truly intrusive rather than ash-flows. Along Burgoyne Bay on Saltspring Island the porphyry is massive and unsheared and grades into medium-grained light coloured quartz monzonite. Similar, generally much altered granitic rocks are exposed on the south coast of this island east of Fulford Harbour.

Conversion of granitoid rocks together with enclosing sedimentary and volcanic rocks to a well-foliated schist-gneiss complex is unknown with respect to any Mesozoic intrusion of Vancouver Island. The Tyee gneissic rocks do not remotely resemble either the rocks of the Wark-Colquitz complex or the gneissic rocks of the Leech River Formation. Tentatively they are considered as late Paleozoic intrusions affecting only the Sicker Group and distinct in age and location from Island Intrusions. Zircon dating is in progress. Granitic intrusions south of Ladysmith and north of Cowichan River likewise only intrude Sicker group rocks. Although they may correlate to the Saltspring-Maple Mountain intrusion they are not known to have the characteristic gneissic phases and have conservatively been classed with Island Intrusions.

Karmutsen Volcanics

Karmutsen volcanics are widespread over most of Vancouver Island but are least abundant of all volcanic formations in the map-area. They occupy a northwest trending string of small areas in the upper Koksilah River drainage, one of which forms Waterloo Mountain and some small coastal exposures on Saanich Peninsula, e.g. Gordon Head. The formation was identified by its characteristic lithology of pillow lavas, pillow breccias and amygdaloidal basaltic flows. Elsewhere the age is known to be Upper Triassic Karnian.

The Quatsino and Parson Bay formations that generally overlie the formation are almost nonexistent in the area and for mapping purposes had to be included with the Karmutsen volcanics. The limestone of Cordova Bay, Brentwood (Butchard Gardens) and Bamberton are probably Quatsino limestone. The first named, where least recrystallized, is a microcrystalline limestone similar in lithology to the Quatsino and is invaded in like manner by diabasic sills. It is in contact (though faulted) with Karmutsen-like pillow lavas. Two limestone occurrences, less than 30 feet thick, near Fellows Creek, north and east of Waterloo Mountain, are probably correlative with Sutton limestone, a thin limestone-member at the top of the Late Triassic Norian Parson Bay Formation. This limestone contains much quartz sand as well as many imprints of very large bivalves, probably the same *Megalodonts* discovered by D. Carlisle (pers. comm., 1970) in uppermost Triassic limestone beds near Sproat Lake. Perhaps intense traversing of creek beds would reveal more such small occurrences of Triassic sediments. Generally, there can be no doubt, however, that the several thousand feet thick sedimentary sequence of Quatsino and Parson Bay formations, that elsewhere on Vancouver Island separates Karmutsen and Bonanza volcanics, is virtually missing in Victoria map-area, although still present with moderate thickness south of Cowichan Lake.

Bonanza Volcanics

Bonanza volcanics, like Karmutsen, have been identified only by lithology. They underlie a considerable area north of San Juan Fault in the upper Koksilah and San Juan River drainage and smaller areas near Shawnigan Lake and on Saanich Peninsula. Poorly schistose volcanics that appear to underlie Leech River schist on Survey Mountain and Mount Finlayson and similar rocks of Gonzales Hill in Victoria have been included in the formation.

The most typical lithologies are massive andesitic to dacitic tuffs and flows, commonly with feldspar and hornblende phenocrysts in a feldspathic matrix. They are dark green to maroon on fresh surfaces and weather to whitish hues. In general they are similar to Sicker volcanics, but less metamorphosed, and distinct in colour and appearance from basaltic Karmutsen volcanics. Maroon breccias, tuffs and tuffaceous siltstones can also readily be assigned to this formation, although some red siltstones were seen interbedded with Karmutsen pillow lavas.

Schistose volcanic rocks, named Malahat volcanics by Clapp, have been included in the Bonanza volcanics. Apart from schistosity they are similar andesitic to dacitic lavas, tuffs and breccias with minor black argillite. The stratigraphic position of Malahat volcanics below Leech River Formation, now considered to be of Jurassic-Cretaceous age, also agrees with the known Early Jurassic age of Bonanza volcanics. Thus Malahat volcanics, considered "Carboniferous?" and Sicker volcanics, dated "Lower and Middle Jurassic?" by Clapp, are in reversed positions in the present stratigraphic sequence.

Island Intrusions

Island Intrusions, locally called Saanich granodiorite by Clapp, occur in two small batholiths, one on Koksilah Ridge south of Duncan and one, broken by many cross faults, occupying the greatest part of Saanich Peninsula and extending across Saanich Inlet to Mill Bay. Extensive sills of dacite porphyry, exposed on both sides of Saanich Inlet and on Mount Jeffrey west of Bamberton, are also included. As mentioned earlier the intrusions south of Ladysmith and north of Cowichan River are also provisionally classed with Island Intrusions.

The rocks are light coloured, medium-grained biotite-hornblende granodiorite, grading inward to quartz monzonite and towards the margin to quartz diorite. Two K-Ar determinations of the age of the Koksilah intrusion by R.K. Wanless have yielded the dates 141±6 m.y. and 158±7 m.y. These are within the Early to Middle Jurassic time-span known to be the age of many other Island Intrusions farther north.

Leech River Formation

The formation is exposed in a wide, eastward narrowing belt of uplands directly north of Leech River Fault. As the lithologies of Bonanza volcanics are similar to those of Sicker volcanics, so those of Leech River sediments are similar to Sicker sediments. They are mainly turbiditic greywacke-argillite sequences that have been metamorphosed to schist and slate. Schistose coarse-grained greywackes are well exposed on the Malahat Highway, showing equally prominent bedding and cleavage. Axial plane cleavage and rodding in the direction of fold axes are generally distinct, and their attitudes vary only gradually over large areas. The difference between these schists with those of the Sicker sediments is in the much greater consolidation, mainly by silicification, of the latter. Sicker schists are hard, with blocky fracture and with smooth joint planes perpendicular to bedding and schistosity, whereas Leech River schists are platy to flaky, poorly jointed and friable. Metamorphism of Leech River rocks increases from north to south and is highest in the widest part of the belt near Bear Creek reservoirs. There the main rocks are garnet-biotite-quartz-feldspar schist and gneiss locally with staurolite and andalusite, with minor hornblende-plagioclase gneiss, derived from basic volcanics. A light coloured muscovite-quartz-feldspar gneiss appears to have formed by partial melting and mobilization and is in part intrusive. At least in one place, on a spur of the Walker Creek logging road, a pegmatite has been blasted out that exhibits muscovite books to over one inch in diameter and tourmaline up to 5 inches long.

A further analogy to Sicker sediments is the occurrence of ribbon cherts, placed by Clapp in Malahat volcanics (Bonanza volcanics of this report), but more suitably considered as part of the Leech River Formation. These presumably oceanic deposits were formed either by radiolarians or chemical precipitation or excess silica in seawater due to volcanic eruptions. They occur in part as rhythmic sequences of about 2-inch chert beds alternating with thin seams of argillite, or as scattered chert lenses in predominant argillite. Both modes are well exposed on Malahat Highway just east of Sawluctus Island in Finlayson Arm and the best exposure of ribbon chert is at the base of two hydro towers just east of the highway.

Clapp, following G. M. Dawson, considered Leech River schist to be of Carboniferous age on the basis of lithological similarity to known Carboniferous Cache Creek Group rocks of British Columbia. The misleading similarity of schistose Leech River and Sicker sediments on Vancouver Island, however, has been pointed out. Sutherland Brown (1966) first suggested that the formation might be of Jurassic-Cretaceous age. As fossils are still unknown, one can only tentatively correlate Leech River sediments westward with the Pacific Rim sequence of western Vancouver Island (Muller, 1973) and eastward with the Jurassic-Cretaceous Nooksack Group of Washington. More distant are the Franciscan deposits of California and the great late Mesozoic greywacke-argillite sequences of western Alaska. All are poor in fossils but have over large areas yielded enough faunal evidence to suggest late Jurassic to early Cretaceous age. All have been seriously deformed, some into completely disorganized mélanges, others into more regular schistose complexes. The writer believes that, in the absence of faunal evidence, correlation of Leech River schists to these late Mesozoic formations offers the best structural-stratigraphic hypothesis.

Nanaimo Group

Nanaimo Group sediments underlie most of the Gulf Islands, part of the coastal area between Ladysmith and Crofton, and a large area around Duncan with northwestward extensions into Cowichan and Chemainus River valleys. They are conglomerate, sandstone, siltstone and coal forming cyclic deltaic to marine deposits of Late Cretaceous age that have been described in some detail in an earlier publication (Muller and Jeletzky, 1970).

Metchosin volcanics and Sooke Intrusions

Eocene basic volcanic and intrusive rocks underlie the entire area south of Leech River Fault. The geology of these rocks, as described by Clapp and Cooke, has not been revised to any extent. The lithology of pillow basalt, aquagene breccia and basaltic lavas is strikingly similar to that of Triassic Karmutsen volcanics. Unlike the Karmutsen, this formation contains some bedded cherts and cherty tuffs, but low-grade metamorphism of the two formations with introduction of epidote, quartz, prehnite and pumpellyite is similar. Definite dating of the rocks as Lower Eocene, equivalent to the Crescent Volcanics of Olympic Peninsula, is based on gastropods and foraminifera from tuffs near Albert Head.

The Sooke intrusions vary from olivine-pyroxene gabbros to hornblende quartz diorite (called granite by Cooke in Memoir 96) and are intrusive into Metchosin volcanics.

Sooke Formation

Conglomerate and sandstone of the Sooke Formation overlie Metchosin volcanics conformably and are mainly known from small coastal exposures. The extent in valleys of Kirby, Muir and Tugwell creeks shown on the Sooke Sheet by C. H. Clapp is somewhat doubtful. The valley walls are mainly composed of Pleistocene till, gravel and silt. Boulder conglomerate, exposed in a few places in the creek bottoms could be either of late Tertiary or Pleistocene age. However, the absence in these valleys of any protruding bluffs of volcanic rocks may indicate the presence of soft sediments beneath the thick Pleistocene cover. Sooke sediments are Oligocene to Miocene according to the macrofauna and late Miocene to early Pliocene according to the microflora.

Structure

It is evident that rocks of the Victoria map-area have been deformed during more than one period of deformation. Clearly the isoclinally folded Sicker rocks of Saltspring Island, unconformably overlain by and faulted against much less deformed and essentially unmetamorphosed Nanaimo Group rocks, were subject to deformation before as well as after deposition of the Upper Cretaceous sediments. The first deformation produced tight folding of the Paleozoic rocks along northwest-trending axes, most pronounced in the Coronation Mountain to Saltspring Island belt and not so evident in outcrop belts farther southwest. If Tyee intrusions, that were foliated with enclosing Sicker rocks, are indeed older than Jurassic Island Intrusions, the folding and consequent foliation may have occurred in latest Paleozoic or earliest Triassic time, preceding outflow of Karmutsen and Bonanza volcanics. However, the fact that the massive non-bedded volcanic rocks do not exhibit intense folding like Sicker sediments may be attributable to their great competence and does not necessarily indicate that they postdate that early deformation.

Early to Middle Jurassic plutonism of the Island Intrusions probably included further metamorphism and granitization of Sicker Group rocks, resulting in the Wark diorite - Colquitz gneiss complex. The most pervasive Eocene deformation produced isoclinal folding in Lower Cretaceous(?) Leech River sediments that were compressed between a northern block of Vancouver Island rocks, bounded by San Juan Fault and a southern block of Metchosin volcanics bounded by Leech River Fault.

Leech River Fault is well defined, although locally splayed into two or more parallel strands. It bounds Leech River Formation and Metchosin volcanics from its western end at Sombrio Point to Langford where the sediments taper out and Metchosin volcanics are probably faulted against Wark diorite. South of the fault the relatively unstructured Metchosin volcanics dip about 30 degrees north towards the fault and are broken by faults trending at high angles to the main fault. To the north the conditions along San Juan Fault are much more complex. West of Victoria map-area the fault follows San Juan River valley but is splayed into several parallel faults. Bonanza volcanics and older crystalline rocks bound the fault to the north. Within Victoria map-area splay faults fan out northeast, east and southeastward, and the main fault almost loses its identify. The most important branch probably crosses Saanich Peninsula at Patricia Bay and forms the obvious geological discontinuity between Canadian Gulf Islands and San Juan Islands. It also separates Sicker group rocks to the north from Wark-Colquitz rocks to the south. The fault is marked by wide zones of crushed granitic and volcanic rocks, and north of Patricia Bay by an overturned unconformity of Nanaimo Group sediments on Saanich granodiorite.

Southwestward thrust of the northern block resulted in its breaking up into several panels, parallel to the old northwest Sicker folding trend. By reversed faulting and northeastward tilting a series of northeast-dipping half grabens were formed containing Nanaimo Group sediments and in most instances exposing strips of Sicker rocks along the up-tilted edges. In addition, many cross-faults, striking at high angles to the reverse faults, cut the panels with considerable horizontal and vertical (mainly left-lateral) offset.

Between the two faults Leech River sediments and underlying Bonanza volcanics, perhaps originally deposited on a Wark-Colquitz "basement", were compressed to low- and high-grade schists and even partly granitized. The time of this event is well defined as it clearly post-dates outflow of lower Eocene volcanics and predates Refugian (late Eocene to early Oligocene) sediments overlying Leech River schist near Port Renfrew. In addition a K-Ar dating by R.K. Wanless of Leech River quartz-biotite schist has yielded an age of 40±2 m.y., indicating late Eocene.

It is tempting to equate the events in the early Tertiary orogeny to those supposed to occur in a subduction zone. Vancouver Island rocks north of San Juan Fault represent the continental plate, Metchosin volcanics are the oceanic plate, and Leech River rocks are oceanic sediments being squeezed between the converging plates. If this premise is correct Victoria map-area offers an excellent opportunity to examine the structure of a fossil subduction zone.

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6. STRATIGRAPHY AND STRUCTURE OF THE WESTERN MARGIN OF THE SHUSWAP METAMORPHIC COMPLEX, VERNON (82L) AND SEYMOUR ARM (82M) MAP-AREAS, BRITISH COLUMBIA

Project 720037

Andrew V. Okulitch
Regional and Economic Geology Division, Vancouver, B.C.

Introduction

Completion of field mapping of rocks bordering and lying within the Shuswap Metamorphic Complex was carried out from June to September. Work was divided between the Vernon-Shuswap Lake and Clearwater-Vavenby areas. In the former, the resolution of a number of stratigraphic and structural problems was attempted. Sampling was carried out for geochronological studies, both paleontological and radiometric. In the Clearwater-Vavenby area, detailed mapping was done between the Raft and Baldy batholiths (Campbell, 1963; Campbell and Tipper, 1971) from Clearwater Station east into regions of intrusive and high grade metamorphic rocks.

Vernon-Shuswap Lake Area

The essential aspects of stratigraphy and regional correlations are unchanged from studies reported previously (Campbell and Okulitch, 1973; Okulitch, 1974), and reference should be made to those reports in what follows. A number of detailed studies have clarified relationships among certain members of the succession, although revision might be anticipated pending results of geochronological studies.

Radiometric analysis of granitoid gneiss observed southeast of Vernon and east of Kelowna (unit nm) has yielded highly discordant results (R.K. Wanless, pers. comm., 1974) tentatively suggesting a thermal event (metamorphic or intrusive) at 254 m.y. ($^{207}Pb/^{206}Pb$ from zircons). This event pre-dates most known events in the Shuswap Complex and is supported by results of research by Medford (in press) in adjacent areas, but evaluation of the regional significance of such data must await further work.

Radiometric analysis (R.K. Wanless, pers. comm., 1974) of granitoid gneiss immediately east of Adams Lake has given a presumed time of crystallization 366 m.y. ($^{207}Pb/^{206}Pb$ from zircons) and makes possible the extension of unit Dns from Seymour Arm to Adams Lake. The lithology of this unit and the concordancy of the radiometric data strongly suggest an intrusive origin. Similar rocks outcrop near East Barrière Lake and in the Shuswap Range. Their extent to the north is unknown but not believed to be great. This pluton therefore appears to be a batholith at least 50 miles long whose present form is tectonically controlled. Whether it is a 'basement' to the Eagle Bay Formation (unit PM_{EB}) or whether it intrudes part of that succession is uncertain, although limited evidence suggests the latter.

In the southwestern part of the Vernon map-area, unconformable relationships between the Cache Creek Group (unit PP_{CC}) and the underlying Chapperon Group (unit P_C) (Jones, 1959), were neither confirmed nor disproved. Structural analysis supports the interpretation that both groups were tightly folded prior to deposition of the Nicola Group (unit uT_{RN}). Such deformation is presumably related to Permo-Triassic folding of the Cache Creek Group in the Nicola and Bonaparte Lake map-areas (Campbell and Tipper, 1971). The unconformable relationships observed by Jones (1959) indicate a Pennsylvanian or older age for the Chapperon Group.

In the Shuswap Range, north of Sicamous, unit PM_{EB} was observed in fault contact with unit ns (Monashee Group of Jones, 1959), although some evidence of a metamorphic transition remains. Conclusive tracing of unit PM_{EB} into the higher grade terrane of the Shuswap Complex in this area would therefore seem impossible.

Relationships between unit PM_{EB} and the northwesterly adjacent Fennell Formation (Campbell and Tipper, 1971) are not well exposed. The two successions appear to be intimately related being at least in part the same age and sharing the same deformational history. As noted by Campbell and Tipper, the contact is commonly a fault, perhaps because of movement between successions of differing rheological properties.

Investigation of the complex stratigraphic and structural relationships near and east of Vernon was not completed but preliminary results indicate that argillite and greenstone correlative to the Nicola Group and the Sicamous Formation unconformably overlie limestone of the Cache Creek Group. These low grade metamorphic rocks are closely juxtaposed against sillimanite schist and gneiss of unit ns by presumably westerly directed low angle faulting and/or recumbent folding. The contact is marked locally by a cataclastic zone of unknown extent.

Clearwater-Vavenby Area

Mapping of sedimentary and volcanic rocks of low metamorphic grade east of Clearwater established structural and lithologic correlation with those of unit PM_{EB} (Eagle Bay Formation) in the Vernon map-area. Much of the succession is phyllitic, including siliceous, sericitic, argillaceous and chloritic varieties. Foliated micaceous quartzite, siliceous tuff, greenstone, limestone and minor conglomerate comprise the remainder. With the exception of limestone, units of distinct lithology are lacking, rendering delineation of major structures difficult. Several limestone units are present and are likely repeated by polyphase deformation so that they cannot be reliably correlated over great distances.

In some areas a fault forms the contact with easterly adjacent gneiss, schist and granitic rock of the Shuswap Complex. Elsewhere the contact is obscured by granitic rocks probably related to the Cretaceous Raft and Baldy batholiths. Similar intrusive rocks are also found in abundance within the complex. The presence of granitoid gneiss similar to that of unit Dns suggests possible correlation which can only be confirmed by radiometric analysis.

To the west, the contact with the Fennell Formation is apparently not exposed but available data indicate that the Fennell and successions to the east have a similar history of deformation and that they are of similar metamorphic grade although the intensity of deformation and of metamorphism becomes progressively lower from east to west.

No fossils have yet been collected from the succession although a number of samples are awaiting analysis for microfauna. In view of the intensity of deformation, favourable results are unlikely. Based on comparison with the Eagle Bay Formation (also *see* Okulitch and Cameron, in press), and with units to the west and northwest, this succession is believed to be Paleozoic in age. It is most likely pre-Late Mississippian, unless younger rocks are infolded, and may include rocks as old as Early Cambrian and possibly of the Windermere (late Proterozoic) Kaza Group (Campbell and Tipper, 1971). Bedding-cleavage relationships indicate westerly and southwesterly overturning suggesting that older parts of the succession lie to the east and northeast of the Mississippian or younger Fennell Formation.

Four phases of deformation have affected the succession, and display style and orientation similar to those described in the Mount Ida Group (Campbell and Okulitch, 1973; Okulitch, 1974). All but the last (northerly trending fracturing and kinking) preceded intrusion of Cretaceous plutons and all apparently followed deposition of the Fennell Formation. On the basis of data obtained in the Vernon and Bonaparte Lake map-areas most, if not all, the phases occurred in post-Late Triassic time. The regional structural pattern, although not clearly delineated, is a composite of interference between northeasterly trending second phase and northwesterly trending third phase structures, affected by accommodation of these to emplacement of the Baldy Batholith. Foliation dips toward the north and south contacts of the Raft Batholith and the effects of its emplacement on rocks at the exposed structural level has not been detected.

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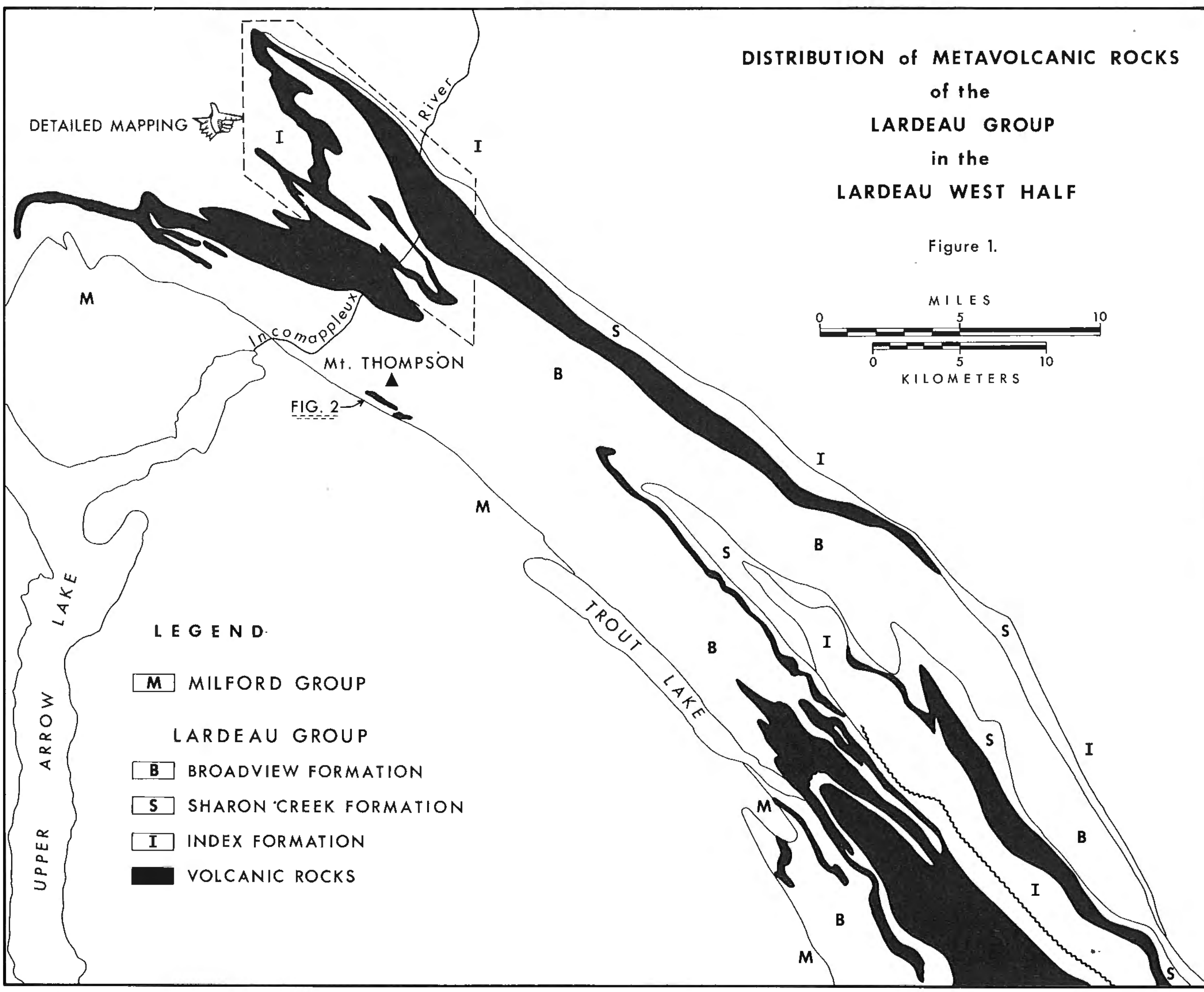
LARDEAU GROUP, LARDEAU MAP-AREA, WEST HALF (82K WEST HALF), BRITISH COLUMBIA

P.B. Read[1]

Brief periods of field work during the summers of 1972 to 1974 were devoted to: (1) tracing metavolcanic horizons of the Lardeau Group to outline the structure of the group throughout the map-area; (2) studying in detail the stratigraphy of the group northwest of Incomappleux River; (3) timing of the first phases of deformation affecting the group; and (4) resolving correlation problems arising from detailed mapping of Fyles (1964), and Read (1973), and regional mapping of Wheeler (1966, 1968).

Southwest of Trout Lake and near Mount Thompson, a metavolcanic unit of the Broadview Formation is truncated by the unconformity at the base of the Milford Group (Fig. 1). Southwest of Mount Thompson, the unconformity truncates foliation developed during the earliest phase of deformation affecting the Lardeau Group (Fig. 2a). As reported by Wheeler (1966), conglomerate at the base of the Milford Group contains clasts of the underlying Broadview Formation with the earliest foliation varying in orientation from clast to clast (Fig. 2b).

North of Incomappleux River, a graded bedding indicates the stratigraphic interval from upper Index to Broadview formations is upright and substantiates the facing assumed by Fyles and Eastwood (1962, p. 14), for the detailed stratigraphy of the Lardeau Group. Stratigraphically below the metavolcanic member of the upper Index Formation, metasedimentary rocks coarsen in grain size from east to west over a distance of about 15 km. To the east, phyllite and phyllitic limestones dominate but grade westward through arenaceous limestone, calcareous meta-sandstone and into phyllitic grit and phyllite. In this area, grits typical of the Broadview Formation develop through a horizontal fac-



[1]Consulting geologist, 4490 Angus Drive, Vancouver, B.C. V6J 4J3.

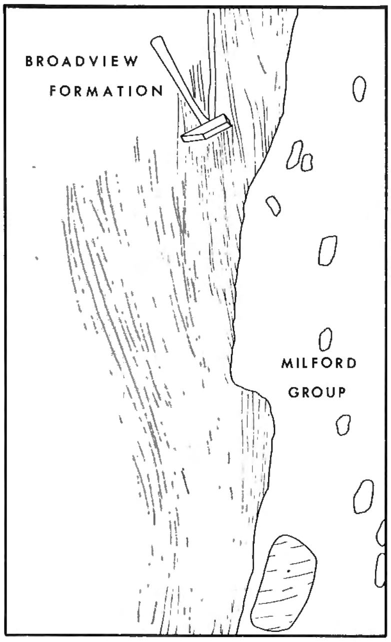


Figure 2a.

Unconformity at the base of the Milford Group located 3 km west of Mount Thompson. Earliest foliation developed in the Broadview Formation is truncated at unconformity.

Figure 2b. Basal conglomerate of Milford Group 2.5 km southwest of Mount Thompson. Clasts of Broadview have a pre-Milford foliation which varies in orientation among clasts.

ies change. This change suggests the lower contact of the Broadview Formation is stratigraphic and not tectonic. Upright facing of the Lardeau Group and apparent absence of major tectonic slides within the group, limit its deposition to post-Badshot Formation (Early Cambrian) and pre-Milford Group (Early Late Mississippian).

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8. A PRELIMINARY STUDY OF THE UPPER JURASSIC BOWSER ASSEMBLAGE IN THE HAZELTON WEST HALF MAP-AREA, BRITISH COLUMBIA (93M-W 1/2)

Project 720038

T.A. Richards and O.L. Jeletzky
Regional and Economic Geology Division, Vancouver, B.C.

Field work in the Hazelton west half map-area was begun in the summer of 1974 with emphasis on the area lying east of the Bulkley and Skeena rivers and south of the Babine River. Most of the area, with the exception of the lowlands, with its scattered exposures of the Cretaceous Skeena Group is underlain by rocks informally known as the "Bowser Assemblage" (*see* Fig. 1).

The "Bowser Assemblage" is of Late Jurassic age (Oxfordian to Kimmeridgian (?)), and comprises three approximate time-stratigraphic map-units that show great lithological variation. The oldest of these (the lower Oxfordian "Trout Creek facies") is exposed only on the southern flanks of Mount Blunt and Mount Thoen, but is more extensive in Hazelton east half map-area, and in the Smithers map-area to the south (H.W. Tipper, pers. comm.). It includes marine and nonmarine clastics and some intercalated volcanics and volcanogenic sediments. Above this lies a marine black shale, which grades into the Upper "Bowser Assemblage". The latter is a succession of fluvial, deltaic and marine clastics. Six interfingering facies have tentatively been defined. These include channel and overbank deposits, lower flood plain (including coastal swamps, and bars as well as possible tidal channels), a shoreline coquina facies, a delta platform and prodelta slope facies (Fig. 3).

The Cretaceous Skeena Group consists of mostly alluvial deposits of probable braided stream origin in the southeast and coal swamps in the west. Augite porphyry volcanics underlie the clastics to the east. Acid volcanics along the Bulkley River are probably of Cretaceous age. The clastics and the volcanics are considered to be part of the Red Rose and Brian Boru formations that underlie the Rocher Deboule Range (Sutherland Brown, 1960). Intrusive rocks are assigned to the Upper Cretaceous Bulkley Intrusions.

Lower Bowser Assemblage
(Trout Creek Facies)

This assemblage is composed of four informal units. The lowest is a sandstone of unknown thickness outcropping on the south ridges of Mount Thoen and Mount Blunt. These rocks are medium-grained, winnowed, crossbedded and ripple-marked sands which are locally conglomeratic. The sands grade upwards into approximately 100 feet of finely plane-laminated argillaceous siltstone and fine sandstone showing minor burrowing, local fine crosslamination, possible mudcracks and well preserved plant remains. Overlying are 150 - 200 feet of fine impure sands and silts typified by numerous belemnites and pelecypod coquinas. Tuff, crossbedded feldspathic greywacke, siliceous limestone and volcanic cobble conglomerate overlie the shell-bearing beds.

Black Shale Facies

The black shale facies is at least 500 feet thick and may be more than 1,000 feet thick, consisting mostly of rusty weathering fine silty argillite containing small (1 inch diameter) carbonate nodules and thin (6 inches to 2 feet thick), fine-grained, grey limestone lenses and bands. In the upper part subgreywacke sand members 1 - 15 feet thick are characterized by the lack of internal structure with the exception of local common rip-up clasts up to 6 inches in diameter. Fossils are uncommon but belemnites, thin-shelled pelecypods and ammonites (tentatively identified as *Amoeboceras* and *Rasenia* (?) were found. An Upper Oxfordian to (?) Lower Kimmeridgian age is indicated. This facies coarsens upwards gradually into a pebble-cobble conglomerate with rare pelecypod fragments.

Upper Bowser Assemblage

This assemblage (Figs. 2 and 3) covers most of the Hazelton east half map-area, and is tentatively subdivided into six major facies. To the south, the assemblage is predominantly composed of meandering stream deposits showing overbank and channel facies and well developed "fining-upward" cycles. To the north, these facies interfinger with coastal environments (swamps, barrier bars, etc.) and pass gradually into a sandy shoreline facies. Farther north, the section is entirely marine and is marked by a delta front and a prodelta facies. The alluvial-deltaic sequence appears to be prograding northward (Fig. 2).

The channel facies is dominated by medium- to coarse-grained subgreywacke to lithic arkosic sand. Typically the rocks are thick bedded and crossbedded members whose bases show erosional scour. Conglomerate units up to 30 feet thick (but with thick grit lenses) are found in the south (Mount Seaton) but are rarely more than 1 to 2 feet thick in the north. Clasts in the conglomerate consist mainly of aphanitic acid volcanics and intermediate feldspar porphyries probably derived from the Lower Jurassic volcanics of the Hazelton Group. Biotite-hornblende tonalite and granodiorite, possibly derived from the Topley Intrusions to the south, are common in the more southerly conglomerates but are rare to absent in the north. Argillite to siltstone of both intraformational and extraformational origins is also common. Vein quartz and chert (?) are very rare. The general decrease in

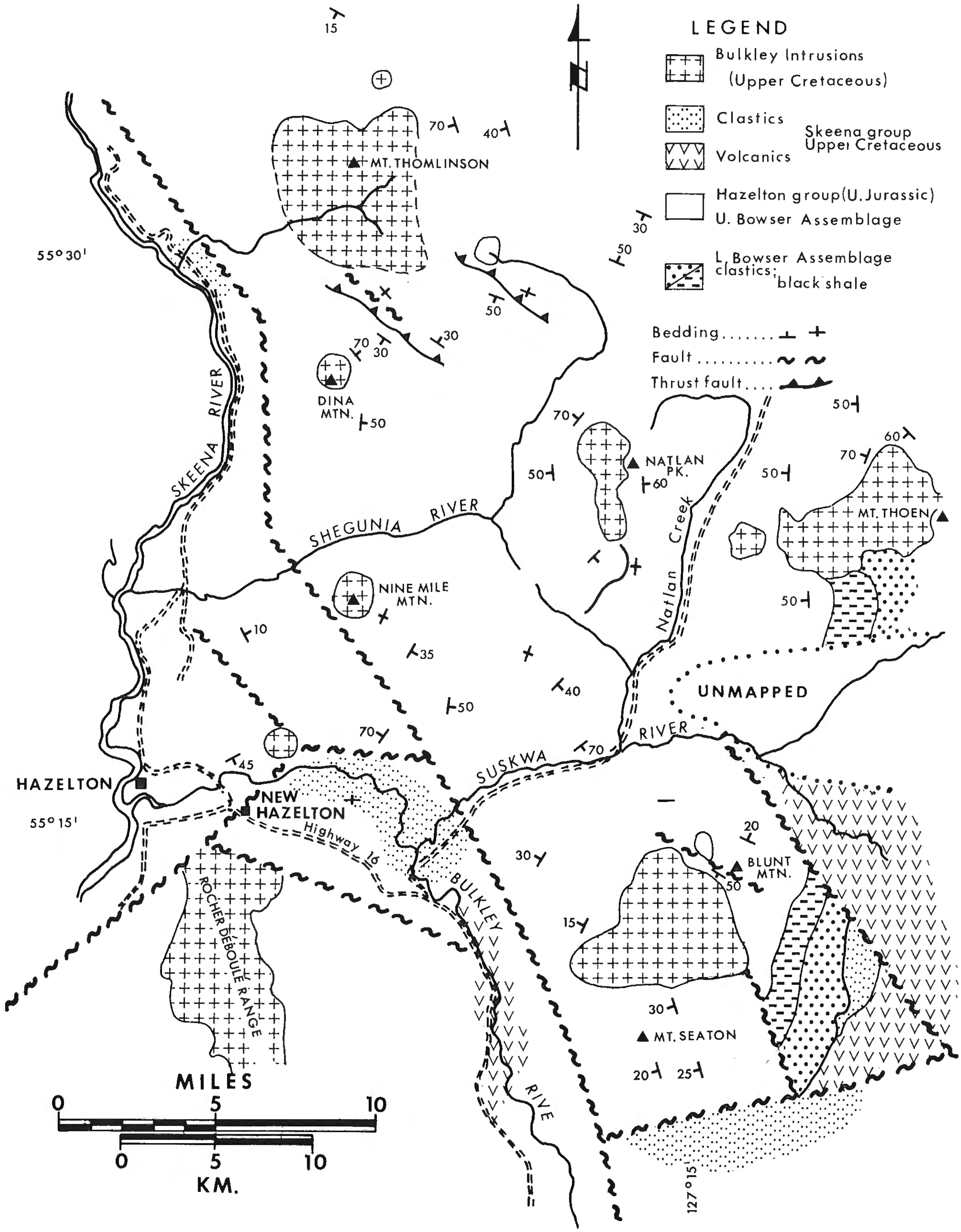

Figure 1. Preliminary geological map of the southern part of Hazelton west half (93M - west ½) map-area.

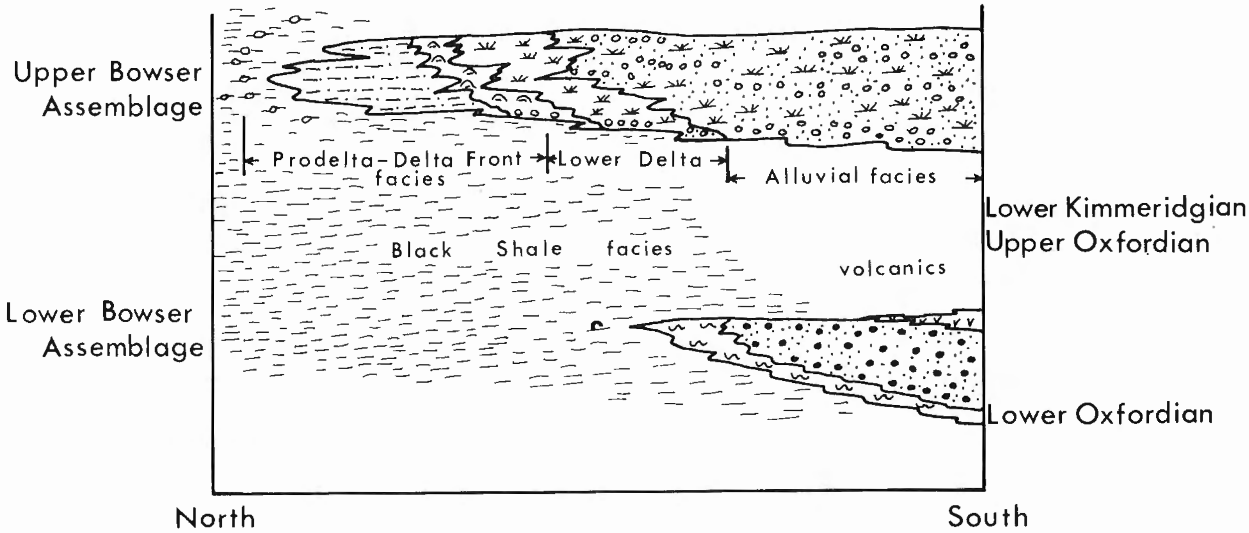

Figure 2. Schematic north-south cross-section of the Upper Jurassic Bowser Assemblage in the Hazelton map-area (93M).

LEGEND FOR FIGURES 2 and 3

LOWER and UPPER CRETACEOUS

SKEENA GROUP

Brian Boru Formation: feldspar-augite porphyry flows, agglomerate tuff, minor dacite and rhyolite.

Chert pebble conglomerate, sandstone, siltstone and coal.

UPPER JURASSIC

UPPER BOWSER ASSEMBLAGE

Channel-Overbank Facies: volcanic pebble conglomerate, sandstone, siltstone, mudstone, minor marl and coal.

Delta Facies including coastal swamps, barrier bars and distributary channels: sandstone, siltstone, mudstone, minor coal, marl and conglomerate.

Shoreline Coquina Facies: pelecypod coquina beds, sandstone, siltstone.

Delta Front Facies: greywacke to subgreywacke, siltstone, argillite with rare pelecypods.

Prodelta Facies: siltstone, argillite, minor greywacke.

Black Shale Facies

LOWER BOWSER ASSEMBLAGE

Coquina Facies: sandstone, siltstone, pelecypod coquinas, minor conglomerate and tuff.

Channel Facies: conglomerate, sandstone, siltstone, mudstone.

INTRUSIVE ROCKS

UPPER CRETACEOUS

BULKLEY INTRUSION

Diorite to quartz monzonite

POST DEPOSITIONAL FAULTING

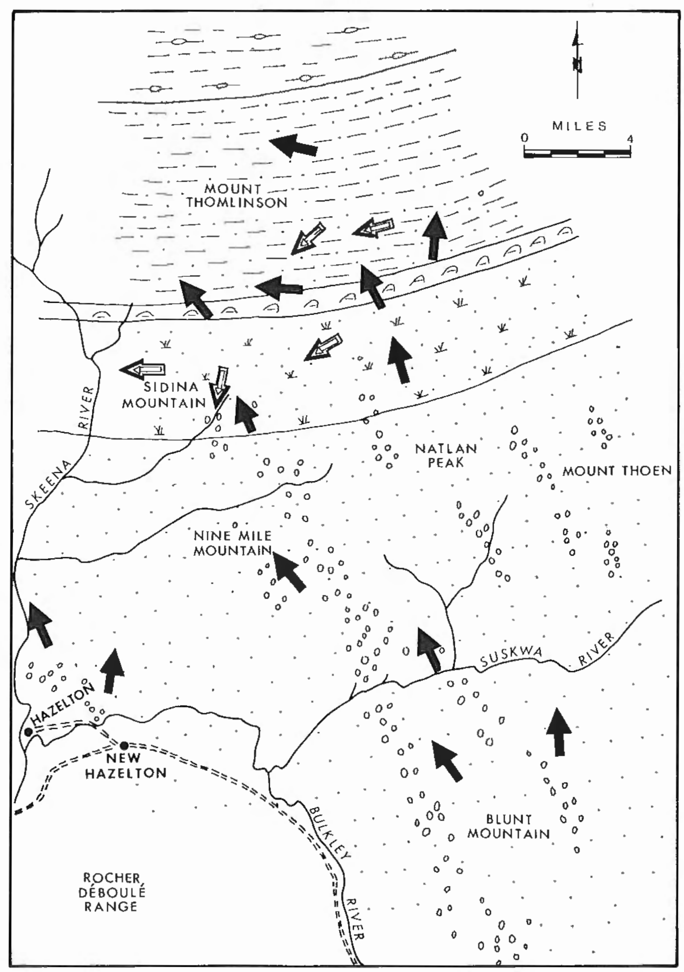

Figure 3. Facies distribution of the Upper Jurassic, Upper Bowser Assemblage in the Hazelton W½ map-area (93W½).

thickness of conglomerate beds northward is accompanied by a decrease in clast size from a mode of 1 - $1\frac{1}{2}$ inches to $\frac{1}{2}$-$\frac{3}{4}$ inches in the north. The sand and conglomerate are interbedded with carbonaceous muds and silts. Fining-upward cycles of an order of 50 - 100 feet thick were observed, in which a conglomerate or conglomeratic sandstone (with a scoured base and abundant trough crossbeds) grades upward to a medium or fine sand or mud rich in plant material. Trough crossbeds, some festooned, up to 2 feet in amplitude, are the most common sedimentary structure in the coarse sandstone, whereas finer sands are finely crosslaminated, or ripple-drift laminated. Paleocurrents are strongly directed northerly.

The channel facies grades into overbank facies and any separation of the two is strictly arbitrary on the basis of relative amounts of sand and mud. Delicately plane-laminated fine sands, silts and muds, commonly carbonaceous, are typical of this facies. The thin laminae of fine sand show fine, almost isolated, ripples. Mudcracks, some burrow structures and rootlets are present. Plants are well preserved and "ferns" of several types were noted. Thin, laterally extensive, 2 inch to 2 feet thick marl beds may indicate shallow lakes in the flood plain environment. Rare coal seams are seldom more than 1 - $1\frac{1}{2}$ feet thick. Also included in this facies are olive, spheroidally weathering sands which are believed to represent levee deposits. Little structure is visible but rootlets and plant fragments are common. Medium- to coarse-grained pebbly sands of the subgreywacke channel facies interbedded with the overbank deposits are interpreted as crevass-splay deposits.

The transition from alluvial to marine sedimentation is marked by a relatively narrow (Fig. 1) belt of channel and overbank, coastal swamp, tidal channel and sand bar deposits 5 to 10 miles wide. The sands and silts are generally finer-grained and channel facies with fining-upward cycles rarer than to the south. A lithology first seen in this facies is a medium-grained well winnowed arkosic sandstone displaying very low angle tabular crossbedding, giving a general southwest to west paleocurrent direction. Lenticular units of this sand are thick (to 30 feet) showing a general coarsening upwards from carbonaceous mud or coal to fine ripple-marked crossbedded sand. Coastal swamp deposits are common, showing muds with a diverse floral assemblage and coal beds to 18 inches. Some thin (6 to 12 inches) pelecypod coquinas are interbedded with the fine to medium sands. Trough and tabular crossbeds are abundant. It appears that the southwesterly directed paleocurrent direction measured in the low angle tabular crossbeds is almost diametrically opposed to the north-northwest direction measured from the tabular crossbeds in the alluvial sands. Asymetrical ripple-marks are extremely common in the arkosic sands and silt, and are continuous where large bedding surfaces are exposed. Continuous, fine mud drapes over the ripple-marks are not uncommon. Rarely, megaripples with a wavelength of approximately 10 feet and an amplitude of 8 to 12 inches were noted.

The shoreline coquina facies consists of beds and lenses of thick shelled pelecypod coquinas 2 inches to 3 feet thick, occupying a narrow belt separating delta platform from transitional deposits. The coquinas have as a matrix pebbly grit to fine-grained dirty sands with minor intercalated finely laminated silt. Pelecypods are apparently in situ in many places and seem similar to oyster banks, although layers with fragmented shells are common. Cutting across this facies are tongues of pebbly sandstone and conglomerate of the alluvial type which are probably distributary channels. Thicknesses of up to 10 feet were noted for these beds.

The delta front facies is composed of rusty weathering tabular beds of greywacke to subgreywacke and plane laminated fine sands, and sandy silts. Sedimentary structures typical of this facies are small scale crossbeds and fine ripples. The sands show little internal structure. Articulated and rarer disarticulated pelecypods are common. The finer silts are bioturbated. Coarse, scouring greywackes with up to 6 inch rip-up clasts are probably submarine channel deposits.

Wispy laminated, fine, black silty mudstone and argillaceous siltstone with scattered pelecypods are the dominant lithologies of the prodelta facies. Interbedded with these are subgreywacke to greywacke beds in 1- to 25-foot-thick units which cut as much as 3 feet into the underlying argillites. The sands are generally graded and contain large amounts of angular, platy rip-up shale clasts to a maximum diameter of 1 foot. Imbrication is common. The thick units are commonly composite and a submarine channel origin is considered likely. This facies is exposed north of Mount Thomlinson to the Babine River.

Cretaceous Skeena Group

Augite porphyry, tuff, flow, breccia and agglomerate underlie chert and quartz-vein pebble conglomerate, sandstone and siltstone on the south end of Mount Blunt. The sands are muscovite-bearing and contain rare broad-leaf flora. Along the Bulkley Canyon are finely bedded rusty tuffs and breccias tentatively correlated with the Brian Boru Formation. On the lower Bulkley Canyon and on Sediesh Creek, along the Skeena River, are acid volcanic, siliceous-pebble conglomerate, sandstone, siltstone and coal that have been correlated with the Red Rose Formation.

Paleocurrent Data

Approximately 600 paleocurrent measurements were taken, most from crossbeds, a few from asymmetrical ripple-marks and rare ones from current lineation. For twenty-two localities, rose diagrams are shown in Figure 4, all from the Upper Jurassic "Bowser Assemblage".

Two main current directions are apparent. The most prominent is a north-northwest to north-northeast direction in alluvial (mostly channel) deposits, but also detectable in the transitional marine beds. In the transitional marine beds, there is a strong southwesterly component, particularly common in the

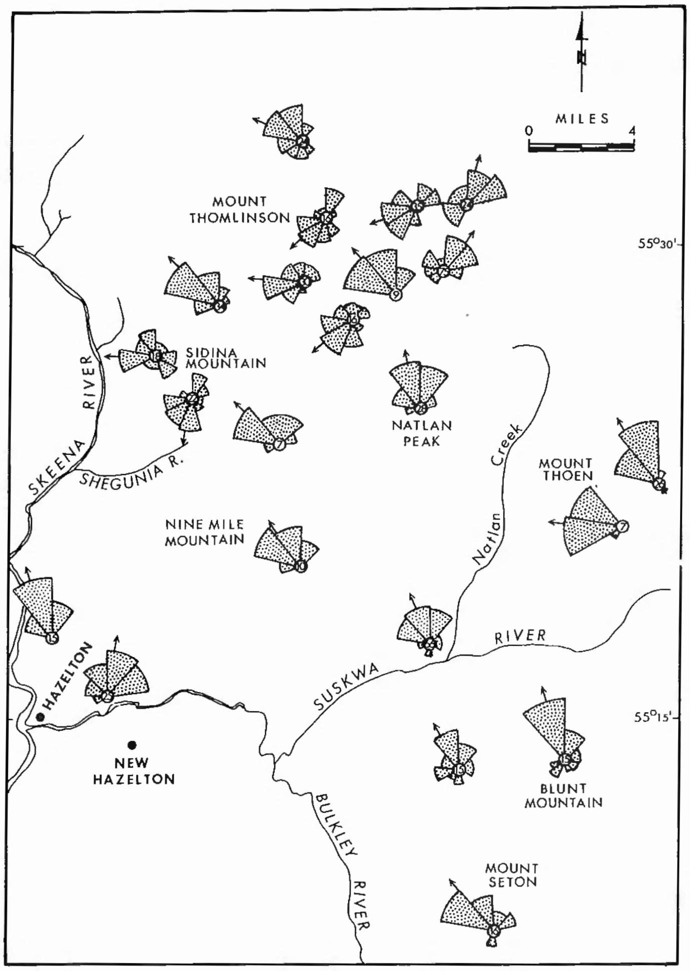

Figure 4. Paleocurrents from the Upper Jurassic Bowser Assemblage in the Hazelton W½ map-area (93W½).

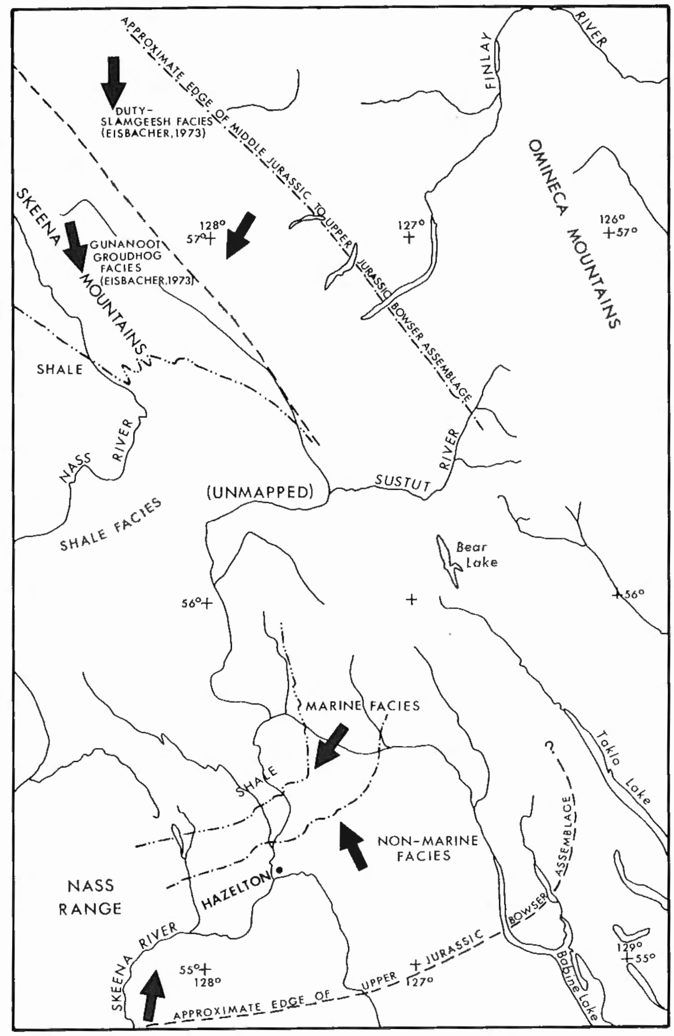

Figure 5. Paleogeography of the Bowser Assemblage.

lenticular sand-bar members. This suggests a strong marine, possibly long shore drift component. Farther north in the submarine channel deposits, a northerly paleocurrent direction is again indicated.

Only scanty paleocurrent data was obtained from the Cretaceous and Lower "Bowser Assemblage". These indicate a pattern as yet indistinguishable from the Upper "Bowser Assemblage". A tentative paleogeographic restoration including data from Eisbacher (1973) is given in Figure 5.

Intrusive Rocks

All intrusive rocks of the area mapped are assigned to the Upper Cretaceous Bulkley Intrusions except for a small plug north of Mount Thomlinson, which is of Tertiary age. Age dates indicate a range of 70 to 84 million years, and 54 million years for the Tertiary plug. The granitic rocks are exposed as stocks ½ to 15 square miles in area and form cores to each of the mountain massifs within the Hazelton Mountains. Two types are apparent: a quartz-saturated mesocratic hornblende-biotite diorite and syenodiorite, and a mesocratic to leucocratic biotite-hornblende monzonite to quartz monzonite. Within the more acid phases are quartz-feldspar-biotite porphyries rich in potassium feldspar. These also occur as dykes and sills in the adjacent sediments. The major stocks (Blunt, Thoen, Natlan and Thomlinson) are composed of the acidic phases whereas Nine Mile, Sidina and satallitic stocks to Blunt and Thomlinson, the more basic.

Each stock is encircled by hornfelsed sediments in a zone as much as 2,000 feet wide. Hornfelses are in general of two types. Around the more basic bodies the sediments are dense, conchoidally fracturing hornfels, with little visible development of new minerals. Adjacent to the larger, more acid stocks, the rocks have been strongly recrystallized with development of garnet, hornblende, actinolite, epidote, biotite and cordierite.

The intrusions are epizonal and commonly have parts of their roof preserved. Blunt and Thomlinson stocks are steep sided; the smaller, more basic Sidina and Nine Mile stocks are probably cylindrical.

Economic Geology

Metallic mineral prospects in the area are closely related to the Bulkley Intrusions. Each of the major stocks (Blunt, Thomlinson and Thoen) has copper and/or molybdenite prospects occurring in veins and pegmatites within the generally unaltered intrusion, and to veins and replacements in the adjacent sediments. Silver mineralization is well known around Nine Mile Mountain and in small tetrahedrite-sphalerite-galena-pyrite veins on Mounts Thoen and Natlan. In general, much of the mineralization seems to be related to the upper parts of the intrusive bodies.

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9. COAST MOUNTAINS PROJECT: PEMBERTON (92J WEST HALF) MAP-AREA, BRITISH COLUMBIA

Project 630016

J. A. Roddick and G. J. Woodsworth
Regional and Economic Geology Division, Vancouver, B. C.

Work during the 1974 field season was devoted largely to Pemberton (west half) map-area. As in other areas of the Coast Mountains, Pemberton west half and adjacent parts of Vancouver (92G) and Pemberton east half map-areas are underlain mainly by plutonic rocks. Gneiss, migmatite, and regionally metamorphosed sedimentary and volcanic rocks form discontinuous northwest-trending belts in a matrix of plutonic rocks, dominantly quartz diorite (Fig. 1). Numerous exposures of unmetamorphosed volcanic rocks appear to be remnants of a formerly more extensive volcanic cover.

Stratified Rocks

Metavolcanic rocks greatly predominate over metasedimentary strata, and are most abundant in the belt extending from Lillooet Lake to Meager Creek and in the belts on either side of Rainbow Mountain. The Lillooet - Meager Creek belt consists largely of greenstone, volcanic breccia and tuff, with lesser argillite and very minor dacite and limestone. The western end of this belt, south of McParlon Creek, is predominantly a peculiar andesitic feldspar porphyry. The pendants on either side of Rainbow Mountain are composed largely of greenstone mostly derived from volcaniclastic rocks. Rusty-weathering pyritic argillite is more common in the eastern of these two belts. Small discontinuous limestone bodies occur in both pendants.

Metasedimentary rocks occur in three main areas. The belt along upper Jervis Inlet consists of black slate and argillite, with minor interlayered dacitic to andesitic volcanic breccia and flows. The narrow belt just south of Stanley Peak is largely argillite with interbedded greywacke and volcanic conglomerate. A few miles farther south, hornblende schist is the dominant lithology; garnet-biotite schist and coarsely crystalline limestone are also present. Near Mount Overlord, the rocks are predominantly fine-grained greywacke and tuff, with minor finely crystalline limestone.

The ages of most pendants are unknown. Metavolcanics along the east margin of the map-area north of Lillooet River are the northwest continuation of the Late Triassic Pioneer Formation (Roddick and Hutchison, 1973). Fossils collected from the Jervis Inlet belt have been identified by T.E. Poulton, Queen's University, as *Trigonia* of probable Early Cretaceous age. Strata at the head of the Lillooet River are lithologically similar to those 30 miles northwest in the Mount Raleigh area for which an Early Cretaceous age is probable (Woodsworth, 1974). No recognizable Jurassic strata have been found in the map-area, and it is possible that most pendants contain only Late Triassic and/or Early Cretaceous rocks.

Shale, tuff, and andesite of the Taylor Creek Group are restricted to the northeast corner of the map-area and seem to be in fault-contact with orange brown-weathering andesitic flows and breccias that may be correlative with Upper Cretaceous Kingsvale Group rocks farther north and east. The volcanics are in turn in fault-contact with granodiorite to the southwest.

Small remnants of Lower Tertiary (?) volcanic rocks are scattered throughout the southeast part of the map-area. The rocks are mainly of light grey massive andesitic flows and breccias, but some dacite and basalt are present. The northeasterly of three small caps southwest of Lillooet Lake includes a spectacular volcanic conglomerate containing abundant clasts of basic plutonic rock. Dips are difficult to measure but appear to be nearly horizontal. Epidote alteration is locally conspicuous in this unit but otherwise the rocks show no sign of metamorphism.

Young unmetamorphosed and undeformed volcanic rocks form a belt striking north-northwest through the map-area. These are partly or entirely equivalent to the Garibaldi Group (Mathews, 1958) just south of the map-area. The volcanic centre between Meager Creek and Lillooet River consists largely of thick dacitic and andesitic flows and coarse pyroclastic rocks. This centre is important as the source of the Bridge River ash, which has been dated at 2440±140 years B.P. (Nasmith *et al.*, 1967), although the age limits of volcanism are not known. The volcanics just east of the junction of the Squamish and Elaho rivers consist of several thousand feet of dacitic flows and lesser pyroclastic rocks. At the head of the Bridge River, at least five flat-lying basalt flows are interbedded with plutonic-boulder conglomerate and minor siltstone. The sequence is at least 1,000 feet thick and unconformably overlies plutonic rocks. Segments of large basalt flows outcrop in Elaho River Valley and in the valley southwest of Rainbow Mountain. The former flow overlies till, and is itself covered by till.

Plutonic and Migmatitic Rocks

Gneiss and migmatite form northwest-trending belts, and smaller, more irregular bodies. The belts at the head of Lillooet River are very heterogeneous but are dominated by contorted, irregularly layered gneiss and screen gneiss with lesser amphibolite and schist. The overall composition is quartz dioritic. The migmatite body at the head of McParlon Creek is more basic, consisting of quartz diorite and diorite that grades into and contains screens of fine-grained amphibolite. Minor layers of pelitic schist contain the assemblage sillimanite-biotite-garnet-cordierite-quartz, indicating an amphibolite-facies grade of metamorphism.

Migmatites between Jervis Inlet and Elaho River are less heterogeneous, and consist mainly of irregularly layered gneiss, and plutonic rock containing abundant amphibolite screens and schlieren. The average composition is probably quartz dioritic. Contacts between areas of migmatite and plutonic rock may be either sharp or gradational. Contacts between the migmatites and schists at the head of Lillooet River are sharp.

Diorite occurs principally in heterogeneous diorite-gabbro-amphibolite complexes. The diorite contains hornblende as the major mafic mineral and locally grades into gabbro. Amphibolite forms schistose and massive bodies that both grade into diorite and form discrete screens within the plutonic material. Diorite is rare northeast of Lillooet River.

Quartz diorite is the most abundant lithology within the map-area and, in general, is more homogeneous than the diorite complexes, but less homogeneous than most of the granodiorite. Hornblende generally predominates over biotite, but biotite seems to be more abundant in the northern part of the map-area.

The largest body of granodiorite in the map-area underlies the area north of Bridge River. Most of this

Figure 1.

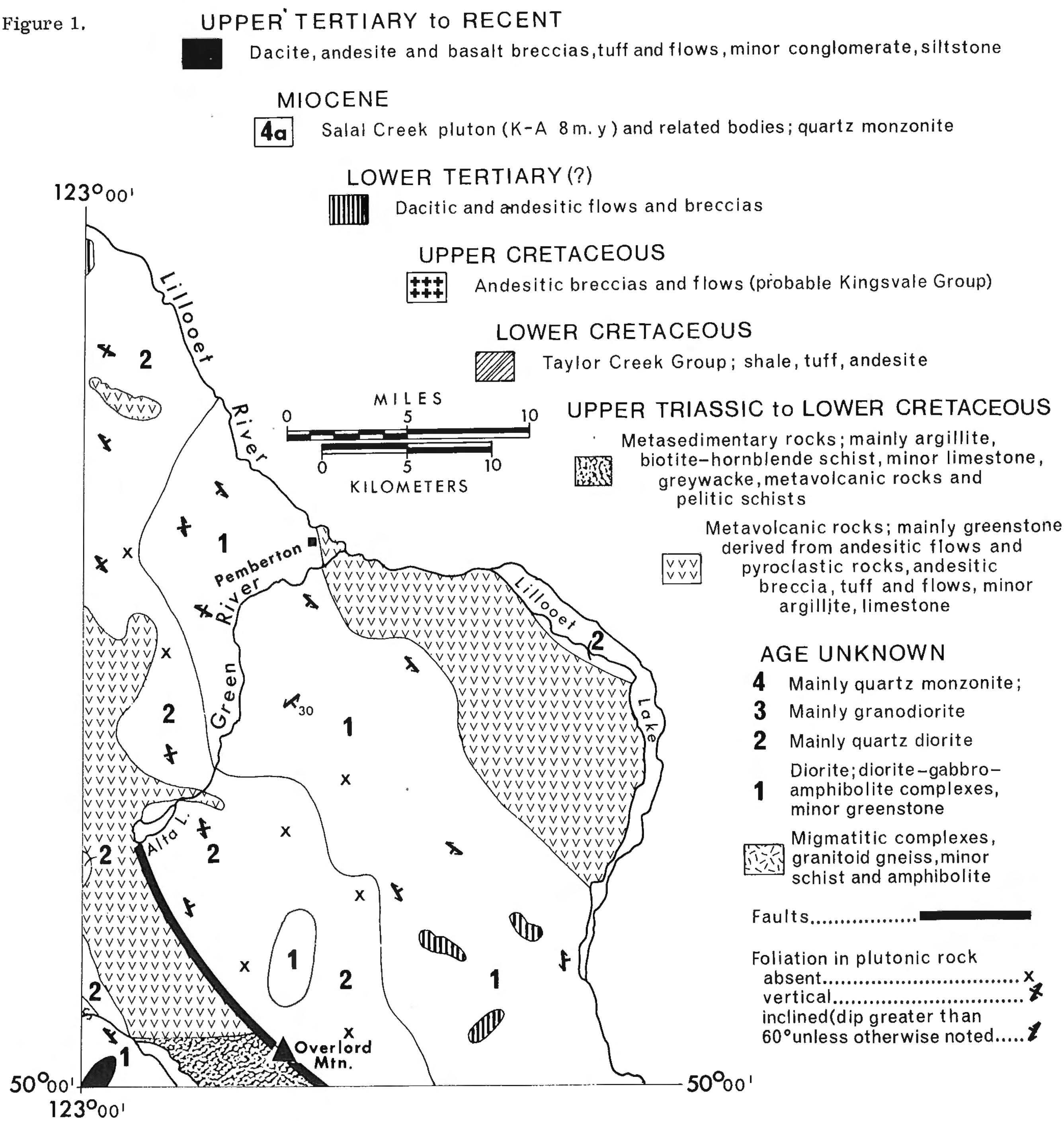
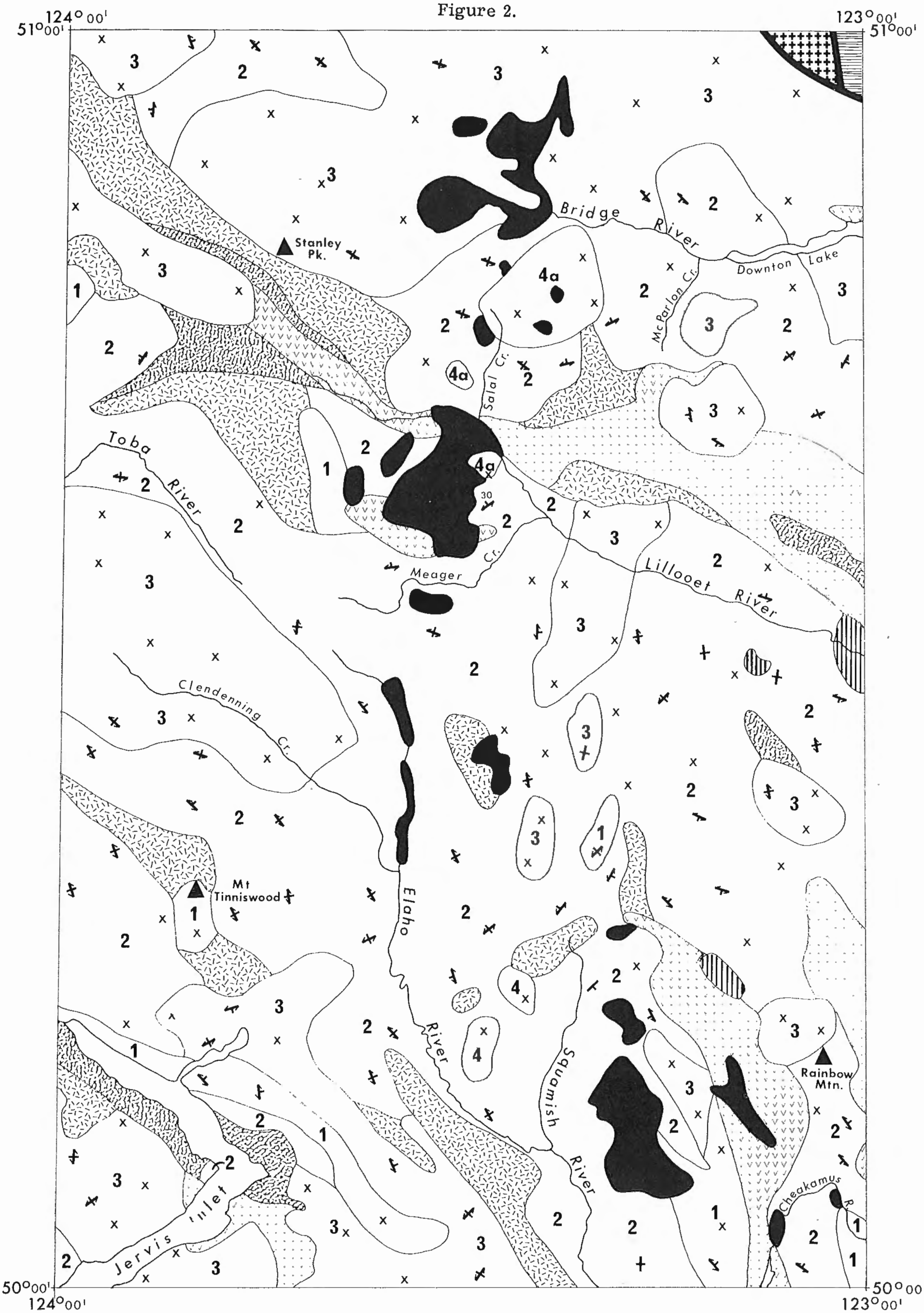


Figure 2.



124° 00'
51° 00'
123° 00'
51° 00'
Stanley Pk.
Bridge River
Downton Lake
McParlan Cr.
Salal Cr.
Toba River
Meager Cr.
Lillooet River
Clendenning Cr.
Mt Tinniswood
Elaho River
Squamish River
Rainbow Mtn.
Cheakamus R.
Jervis Inlet
50° 00'
124° 00'
50° 00'
123° 00'

rock is clean, fresh, and contains few inclusions. The large pluton at the head of Clendenning Creek is a clean, light-weathering, generally massive granodiorite with hornblende generally more abundant than biotite.

Quartz monzonite, locally granite, forms small stocks with sharp margins. These stocks are generally leucocratic and almost free of inclusions. The three bodies between Meager Creek and Bridge River appear to have been emplaced at a very high structural level. A K-Ar age of 7.9 m.y. on biotite from the largest of these, the Salal Creek pluton, is the youngest date yet obtained from plutonic rock in the Coast Mountains. The two quartz monzonite stocks between Squamish and Elaho rivers contain small reddish garnets and appear to have been emplaced at a deeper level.

Structure and Metamorphism

As in other parts of the Coast Mountains, foliation in plutonic rocks generally trends northwest and dips steeply. Some plutons are elongated in a northwest direction, but others, particularly small, massive plutons show a north-south elongation or none at all. Schistosity in pendants is usually parallel or subparallel with contacts. Schistosity is rare in the greenstone belts; the impression is that deformation has been largely concentrated in narrow northwest-trending zones, leaving the intervening areas with well-preserved original textures. The metavolcanic rocks at the head of Lillooet River show, however, a thoroughly penetrative northwest-trending schistosity.

A northeast-striking foliation is locally conspicuous, particularly in a belt trending northeast from near the head of Jervis Inlet, but its significance is not known.

Upper Tertiary to Recent volcanics are concentrated in a north-northwest-trending zone running the length of the map-area. Also localized in this belt are several quartz monzonite plutons of probable Miocene age (unit 4a). This belt thus appears to be the locus of a major fracture system that persisted from at least Miocene to Recent time.

The pendant rocks are everywhere metamorphosed. Most metavolcanic rocks appear to be greenstones composed largely of chlorite, epidote, actinolite, and altered plagioclase. Fine-grained metamorphic biotite is conspicuous in the few thin sections of argillite that have been examined. Small porphyroblasts of andalusite are abundant in the metasediments along Jervis Inlet. Most pendant rocks thus probably belong to the greenschist facies.

Amphibolite-facies metamorphism is evident in the pendant south of Stanley Peak. Hornblende is abundant and sillimanite and garnet occur in pelitic schists. Although possibly younger than the Upper Triassic metavolcanics to the southeast, this pendant has apparently been metamorphosed to a higher grade.

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CARMACKS MAP-AREA, YUKON TERRITORY

Project 700025

D. J. Tempelman-Kluit
Regional and Economic Geology Division, Vancouver, B. C.

Parts of Carmacks map-area (Bostock, 1936) were examined during the first half of the 1974 field season with the object of allowing reinterpretation of the geology in the light of recent studies in adjacent parts of the Yukon Crystalline Platform (Tempelman-Kluit, 1973). Work was done by ground traverses with very limited helicopter support.

For the discussion that follows the reader is referred to Tempelman-Kluit (1974), a preliminary interpretation of Bostock's (1936) work made without the benefit of field work in this area. Although this reinterpretation is generally valid, the distribution of rock units requires revision particularly in the area between the Pelly and Yukon rivers.

Metamorphic rocks including amphibolite, marble and serpentinite found in the northern part of Carmacks map-area (Schist-Gneiss unit) are not equivalent to this unit in Snag map-area. Instead, the schist-gneiss of Carmacks area bears similarities to rocks of the Anvil Range Group (Tempelman-Kluit, 1972), and may be Permian. The unit is continuous with Campbell's (1967) unit 6. No diagnostic fossils were found in the marble associated with the unit although crinoid columnals are found at many localities.

The amphibolite and hornblende gneiss in southern Carmacks map-area and included in the biotite schist is more probably correlative with the amphibolite found in northern Aishihik Lake map-area. The age of this unit is unknown.

Ultramafic rocks although mapped as a single unit belong to three distinct suites. One is serpentinite and serpentinized peridotite interfoliated with the Schist-Gneiss unit and presumably of Permian age. This suite occurs along Pelly River. A second group includes coarsely crystalline magnetite-rich diorite to gabbro found associated with the Triassic massive green volcanics near the mouth of Wolverine Creek. Fresh finely crystalline diabase, a subvolcanic part of the Selkirk Lavas, comprises the third suite included in the ultramafic rocks. They are found mainly near Minto.

The massive green volcanic unit that trends northwest diagonally across Carmacks map-area shows a remarkable variety of textures and includes augite porphyry, fine-grained tuff, tuff breccia and agglomerate (Figs. 1a, b, c, d). The unit ranges from massive greenstone to well foliated amphibolite and rocks in the north are more metamorphosed than those in the south. Because it generally lacks primary layering, the internal structure of the unit has not been worked out, but the rocks are faulted against hornblende granodiorite in the southwest. In the south, this fault is a brittle fracture zone with much shearing in the walls. Farther north its brittle nature is masked and the fault is welded by later metamorphism.

The Pelly Gneiss and hornblende granodiorite (Klotassin Suite) have nebulous migmatitic relations over wide areas in central Carmacks map-area. This fact and the similar composition of the two units suggests strongly that the hornblende granodiorite was derived from the Pelly Gneiss by partial melting during metamorphism at or close to the level presently exposed.

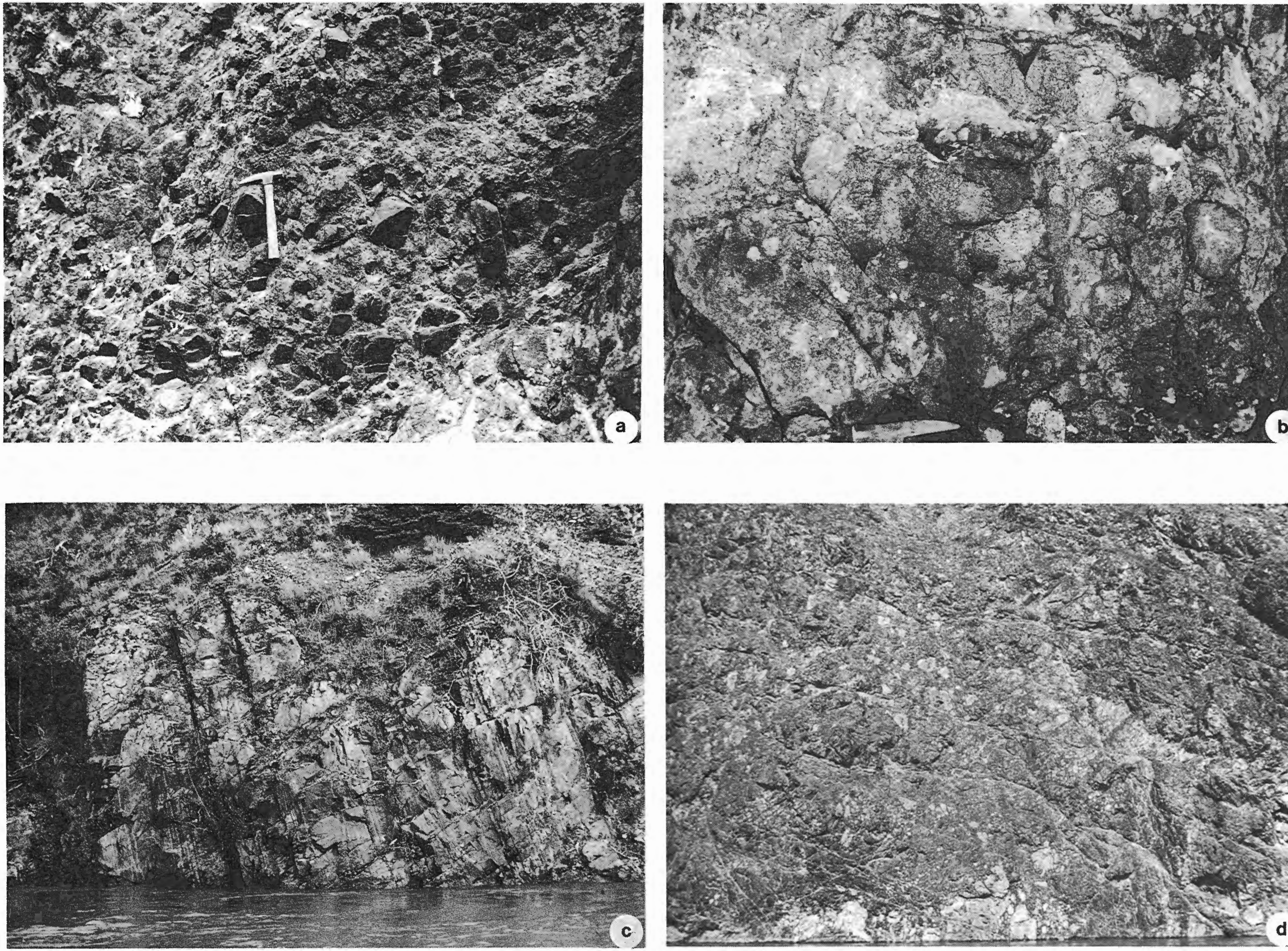
Syenite found in central Carmacks area is gradational with, and apparently a phase of, hornblende granodiorite that constitutes the Klotassin Batholith.

Sandstones of the Lower Jurassic Laberge Group are poorly exposed in most of the area, but the belt of these rocks is cut by steep dipping faults that break relatively open symmetrical folds. A number of new collections of ammonites and pelecypods from old and new fossil localities have been made, but as these have not yet been studied, no account of their stratigraphic implications is given.

Within a radius of ten or fifteen miles of Carmacks, the basal 500 feet or more of the Carmacks Group consists of light coloured tuff, tuff breccia and tuffaceous sediments, overlain by massive brown basalt that is found elsewhere in the Carmacks Group (Fig. 1e). Such extensive and thick development of tuffs does not occur elsewhere within the Carmacks Group.

The Selkirk volcanics are fresh Pleistocene lavas that are spectacularly exposed in stream cuts near the mouth of Pelly River (Fig. 1f). Nodules of pale green olivine enclosed by partly devitrified glassy basaltic rinds were discovered in tuff extruded from the small volcanic centre opposite the mouth of Wolverine Creek (Fig. 1g). A number of these have been collected for study.

No new mineral occurrences were discovered. The writer briefly examined some of the drill core at the United Keno Hill Minto property. The mineralization, host rocks and lack of extensive alteration here are identical to those seen at the Williams Creek and Hoochekoo Bluff properties. Concentrations of mafic minerals within granodiorite of the Klotassin Suite are host to chalcopyrite and bornite at all properties. These schlieren are remnants of poorly digested Pelly Gneiss with the granodiorite. The copper was probably emplaced hydrothermally during late stages in formation of the granodiorite from the Pelly Gneiss.


a
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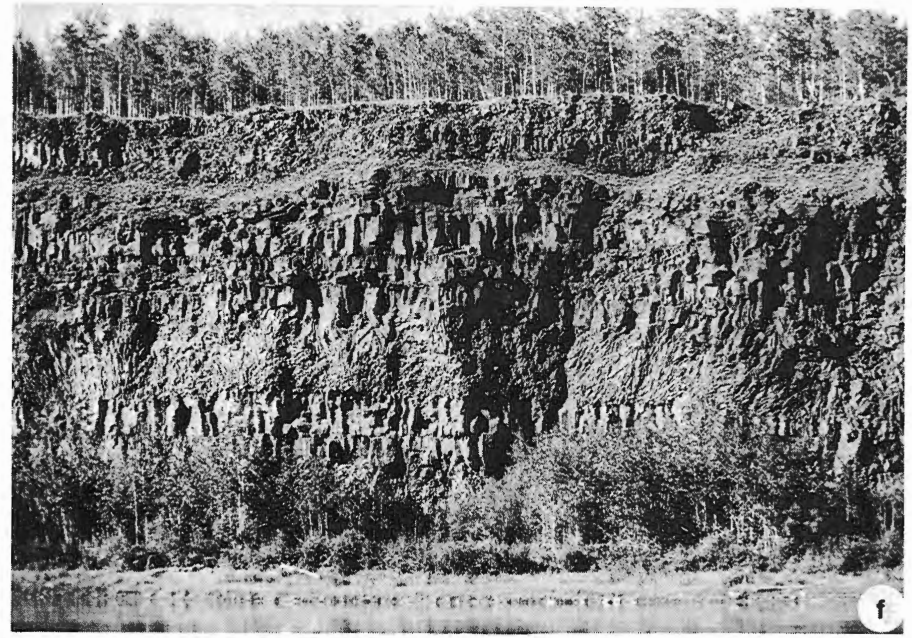

Figure 1

(a) Altered tuff breccia in the massive green volcanic unit (Triassic) near Victoria rock.

(b) Agglomerate with rounded boulders of granodiorite and a variety of volcanic rocks; a part of the massive green volcanic unit. This exposure is just downstream from the mouth of Williams Creek.

(c) Regularly laminated and thin-bedded pale green fine-grained tuff of the massive green volcanic unit. The exposure is near Minto.

(d) Tuff of the massive green volcanic unit just downstream from Minto.

(e) Flat-lying tuff and tuffaceous sandstone that make up the lower 600 feet of the Carmacks Group here. This view westward from Tantalus Butte shows the exposure north of Murray Creek.

(f) Exposures of stream-cut columnar basalt of the Pleistocene Selkirk Lavas along Yukon River. Nine cooling units with varying column characteristics and of different thickness can be seen here.

(g) Olivine nodules in tuff that mantles the small volcanic cone opposite the mouth of Wolverine Creek. One of the nodules is enclosed by partly devitrified glass, the other two are incorporated directly in the tuff and lack such rinds. Note the match for scale.

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Project 730037

D. J. Tempelman-Kluit, G. Abbott[1], S. Gordey[1], and B. Read[2],
Regional and Economic Geology Division, Vancouver, B. C.

Quiet Lake and Finlayson Lake map-areas (105F, 105G) are of particular interest because they straddle Tintina Trench, the locus of a major transcurrent fault, whose tectonics are critical to reconstructions of the geology of the northern Cordillera. Field work in parts of these areas during the latter half of the 1974 field season was aimed at gaining a clearer insight into the stratigraphic and structural relations of rock units in and near the fault zone. The work, carried out by ground traverses with limited helicopter support, is the second season in a continuing project to study the region between Tintina and Shakwak trenches. Figure 1, an index of the accompanying cross-sections shows where field work was concentrated. Wheeler *et al.* (1960a and 1960b) have mapped the distribution of rocks in the region at reconnaissance scale and the reader is referred to their maps for the discussion that follows:

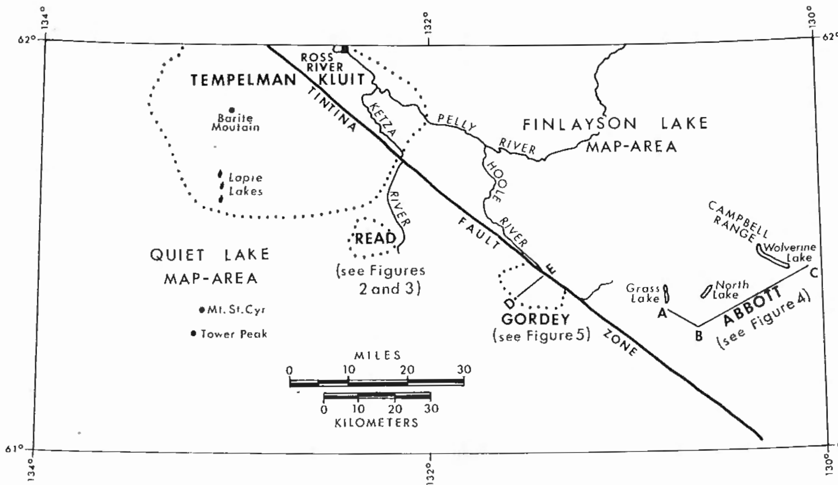


Figure 1. Index map of Quiet Lake and Finlayson Lake map-areas showing where field work was concentrated in 1974.

Green argillite and fine-grained, thin-bedded, crosslaminated, greenish, argillaceous quartzite mapped as units 1b and 1a in east central Quiet Lake map-area lie unconformably below the lower Cambrian carbonate rocks (unit 1c). The argillite and quartzite closely resemble the upper part of the "Grit Unit" northeast of Tintina Trench in Selwyn basin, and these rocks are therefore probably Proterozoic. The same argillite and quartzite is found, with its metamorphosed equivalents, west of Lapie Lakes where it is included with younger strata in unit 2 of Wheeler *et al.* (1960a).

Metamorphic rocks in central Quiet Lake map-area included in units A and C can be traced into the Proterozoic argillite and fine-grained quartzite and into the overlying impure carbonate rocks of Early Cambrian age. The metamorphic complex may also include equivalents of the Cambro-Ordovician phyllite (unit 2), but these rocks have not yet been recognized in the complex. The metamorphic complex in the western part of Quiet Lake map-area probably includes no equivalents of younger strata. Unit B, a marble, may be the metamorphic equivalent of carbonate rocks of Proterozoic age.

Lower Cambrian rocks in the Ketza River area are the subject of detailed study by B. Read. Figure 2 is a generalized section of these rocks. Figure 3 shows the facies relationships within, and the stratigraphic relationships of the Lower Cambrian strata as determined by Read. Several unique features of the succession merit emphasis. The clean orthoquartzite generally found at the base of the Lower Cambrian

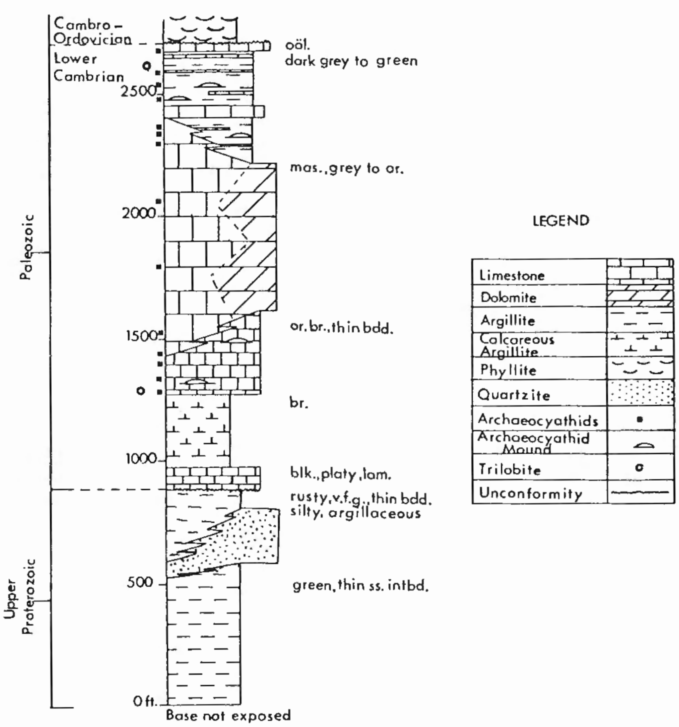


Figure 2. Generalized Lower Cambrian Section in the Ketza River area.

[1]Queen's University, Kingston.

[2]University of Alberta, Calgary.

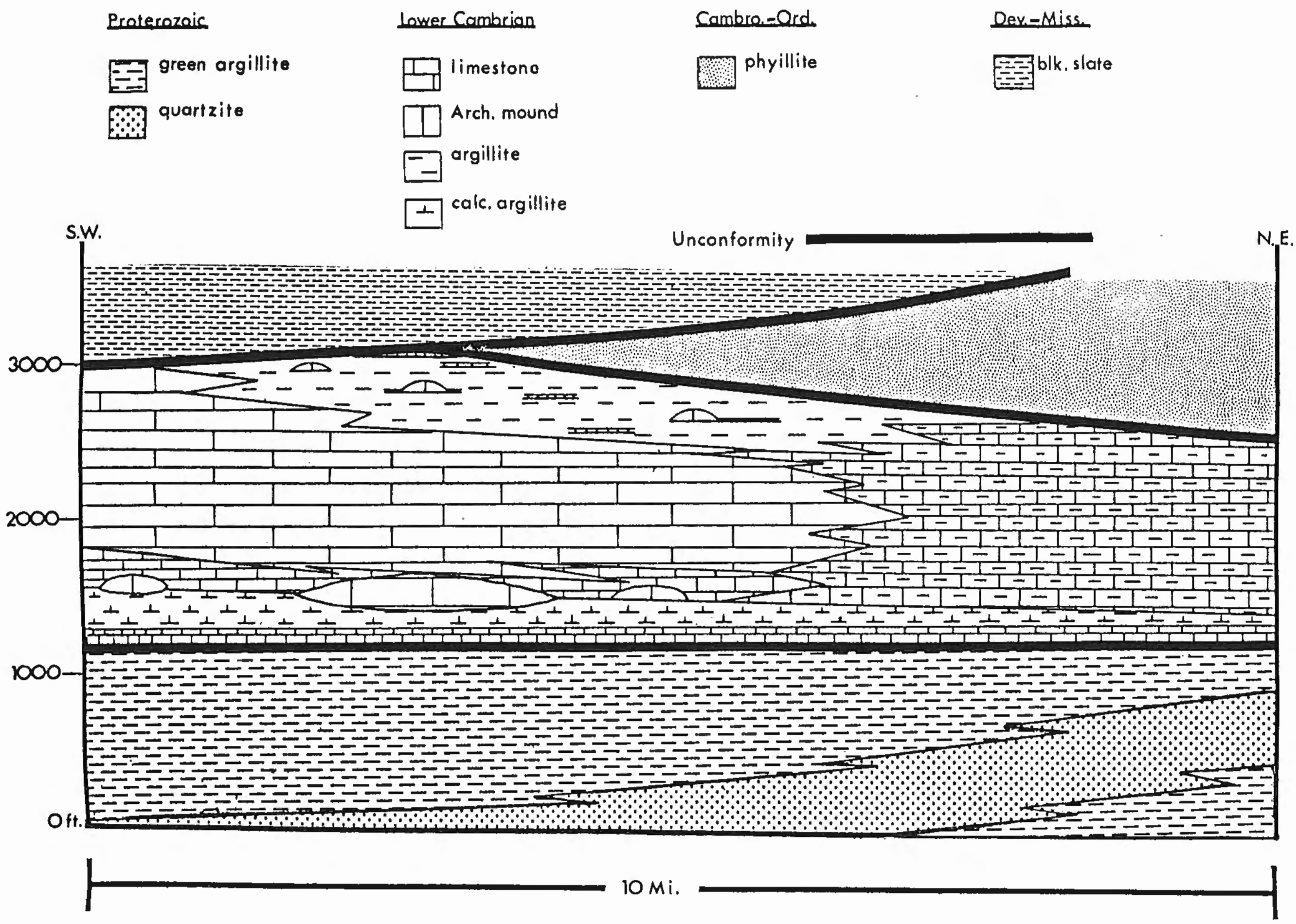


Figure 3. Facies relationships of lower Cambrian rocks in the Ketza River area.

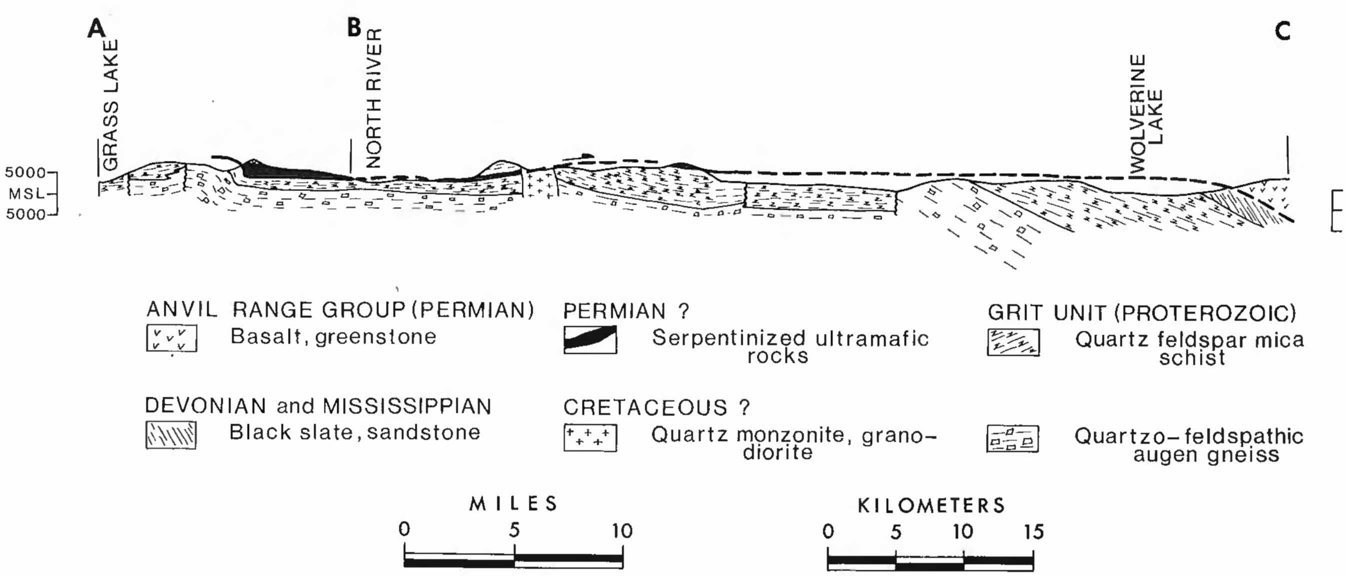
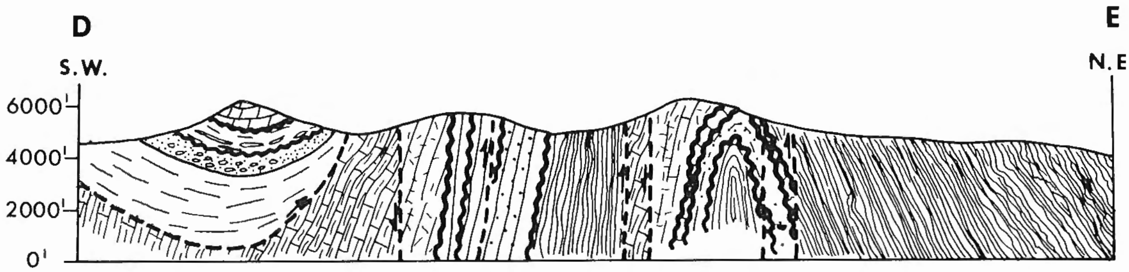


Figure 4. Diagrammatic cross-section of the Finlayson Lake metamorphic complex (*see* Figure 1 for location).

61° 22' 20" N ; 131° 32' 35" W to 61° 26' 20" N ; 131° 25' 00" W

(No Vertical Exaggeration)



LEGEND

Triassic

Medium bedded, calcareous, cross laminated siltstone and very fine grained sandstone

Mississippian (?) or Earlier

Thin-bedded, poorly bedded, black, siliceous, fine to coarse grained greywacke ; pebbly very coarse-grained greywacke ; black well-cleaved argillite ; minor siliceous volcanic tuff ; black, brown, or gun-blue weathering

Middle Devonian

Well bedded, medium-bedded dolomite ; massive dolomite ; black, thin-bedded limestone

Silurian

Platy, well-laminated black dolomitic siltstone ; tan-weathering

Interbedded, thick-bedded, black graptolitic slate, and grey medium-grained quartz

Upper Cambrian (?)

Agglomerate poorly laminated, loc lly cherty tuff ; dark-brown weathering

Silver-grey weathering phyllite

Very well cleaved, locally calcareous argillite ; phyllite ; orange weathering

Fault .... — — — —

Unconformity .... ∿∿∿∿

Figure 5. Diagrammatic cross-section.

elsewhere in the Cordillera is absent in Pelly Mountains. Furthermore, although trilobites are rare, those found suggest to W. H. Fritz (*see* this publication, report 144) that only the lower part of the Lower Cambrian is exposed in the Ketza River area and that the upper part, seen in most sections elsewhere, was either not deposited or eroded. The thickness of carbonate rocks over which Archeocyatha are found, nearly 1,500 feet, is considerably more than generally noted elsewhere in the Cordillera.

Although the rocks are strongly deformed and metamorphosed and lack fossils, the Lower Cambrian strata west of Lapie Lakes conform broadly to the scheme outlined in Figure 2. Unit 2 as mapped west of Barite Mountain includes about 2,000 feet of calcareous phyllite and impure limestone that is considered Lower Cambrian. The thin-bedded limestone and limy phyllite that forms the resistant outcrops at the Lapie canyon bridge (also mapped as unit 2) is also thought to be Lower Cambrian.

Volcanic rocks mapped as unit 6 are not all part of one stratigraphic unit. Those near Tower Peak and Mount St. Cyr belong, with their associated ultramafic rocks (unit D), to a suite that may be correlated with the Anvil Range Group. Similarly, rocks included in unit 6 in the northeast corner of Quiet Lake map-area are part of the Anvil Range Group. However, the volcanic rocks mapped as unit 6 northeast of the Seagull

Fault are part of a distinctly acid terrestrial suite that appears to be a facies of unit 5 with which the rocks are closely related and homotaxial. The acid suite northeast of Seagull Fault is gradational, and deformed with the strata on which it rests, whereas the basic volcanics near Tower Peak may be allochthonous.

Granitic rocks in western Quiet Lake map-area are intrusive at the level of their present exposure and have sharp contacts and marginal zones up to 2 miles wide where irregular dykes and sills are abundant. The metamorphism of rocks surrounding the plutonic rocks is a relatively high temperature - low pressure type and results from the intrusive episode though it is not thermal metamorphic in the restricted sense. Metamorphic aureoles are narrow and have sharp gradients. Metamorphism has obliterated the minor structural elements of the rocks.

Main structural features of the area mapped are briefly outlined by Wheeler *et al.*, 1960a. The zone of phyllitic rocks southwest of the Tintina, mapped as unit 2, is cut by a number of steep-dipping faults of which the St. Cyr Fault is an example. Thrust faults close to the Tintina Trench, like the Porcupine Thrust had northeast directed movement, but thrusts with movements in the opposite sense are found east of Lapie Lakes. Some of the thrust faults are folded and apparently cut by younger thrust faults.

Abbott examined part of the metamorphic complex in central Finlayson Lake map-area in a traverse from Grass Lake to Wolverine Lake (*see* Fig. 4). Units A and C of Wheeler *et al.*, 1960b, are lithologically like the "Grit Unit". Unit A, comprising brown weathering quartz-feldspar-muscovite-biotite-chlorite schist overlies unit C, a more recessive weathering homogeneous quartzo-feldspathic gneiss. Feldspar augen occur in both units, but are more common in unit C. Their development is a function of the bulk composition and degree of metamorphism. Foliation dips gently and is axial planar to recumbent, small sub-isoclinal folds. Fold axes and mineral lineations trend eastward west of North Lake and southeast of the east of the lake. The orientation of minor structures is consistent over large areas and local abrupt changes reflect young faults. Serpentinized ultramafic rocks form massive to weakly foliated sheets and pods parallel with the regional foliation. Locally these sheets are enclosed by the metamorphic rocks, but more commonly they cap ridges and are overlain by amphibolite and chlorite schist correlated with the Anvil Range Group. The ultramafic bodies southeast of North Lake are the remains of a single flat lying sheet. Along the northeast shore of Wolverine Lake black slate (Devono-Mississippian) overlies the metamorphic rocks and is overlain by basalt of the Anvil Range Group. A large slide, shown in the cross-section (Fig. 4) along the base of the serpentinite sheet is not inconsistent with the data. Such a thrust may have served to bring the Anvil Range Group over the metamorphic complex into the Campbell Range where they now rest.

S. Gordey began a study of the structural style southwest of the Tintina Fault zone near Hoole River. His results are summarized in the diagrammatic cross-section of Figure 5.

Although only small, relatively high grade, showings of transgressive mineralization have so far been discovered in the Pelly Mountains the region holds promise for occurrences of stratabound mineralization. The stratigraphy is grossly like than that of Selwyn basin and specifically strata that are equivalent to those that host the deposits in the Anvil Range are widespread. Because the metamorphic rocks in west-central Quiet Lake map-area are equivalents of the "Grit Unit" and Lower Cambrian they are particularly important in exploration for lead-zinc. The occurrence of metamorphosed impure Lower Cambrian limestone in this metamorphic and intrusive complex, and the presence of tungsten at several localities makes this region important prospecting ground for that metal. Barite occurs in narrow veins within rocks of unit 4 at many localities, but no stratabound barite is known in these rocks. However, an occurrence of bedded barite was discovered in rocks of unit 5 at N 61°56′ 45″, W 132°58′ 00″. No sulphide minerals were noted at this locality. Many bright orange gossans are seen in the acid volcanic suite (unit 6) northeast of the Seagull Fault. Although pyrite is widespread in these rocks, no valuable mineralization is known.

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12. TASEKO LAKES (92C) AND SMITHERS (93L) MAP-AREAS, BRITISH COLUMBIA

Projects 610011 and 690009

H.W. Tipper
Regional and Economic Geology Division, Vancouver, B. C.

To obtain a fuller understanding of the geology of the Taseko Lakes and Smithers map-areas, further work was undertaken within these and adjoining map-areas (Quesnel Lake 93A, Quesnel 93B, Prince George 93G, and McLeod Lake 93J). From new exposures in road-cuts and in logging areas more detailed stratigraphic information obtained permitted some re-interpretation of earlier views. The primary aim of the 1974 field season was to collect fossils to facilitate better regional correlations.

The Cache Creek Group was re-studied at several localities along its belt of exposure from Big Bar Creek in the south to Nechako River in the north. A few fusulinid fossil localities suggest that Upper and Lower Permian beds are present along the belt, but fossil localities are not sufficiently abundant to date the rocks everywhere.

Massive grey limestone, commonly oolitic, exposed along Canoe Creek and in the Springhouse Hills (Taseko Lakes map-area) have a Late Permian (Guadalupian) fauna near its base and, although other stages of the Permian may be represented, these limestone masses are tentatively considered to be Late Permian in age. Northward and eastward, there is some evidence of thinning of the unit or replacement with an interbedded sequence of thin limestone beds (10 to 150 feet), ribbon chert, shale, and greywacke. So far there is no evidence for the presence of Late Permian beds on the eastern margin of the belt.

Interbedded limestone, shale, ribbon chert, and greywacke with basic volcanic breccias near the base form a heterogeneous unit that underlies the massive Upper Permian limestone or is partly correlative with it. The volcanics of this unit comprise the main volcanic members of the group but in this part of the Cache Creek belt are nowhere prominent. The age of this unit is not fully known.

Underlying the aforementioned unit near Soda Creek (Quesnel area) is a thick section of shale with minor ribbon chert and tuff. Eastward the shale is replaced by ribbon chert and, here and there, fairly massive limestone masses correlative with the Lower Permian limestone of Quesnel Lake (Campbell, 1961) and Bonaparte Lake (Campbell and Tipper, 1971) map-areas.

The Cache Creek Group is complexly deformed. The more incompetent beds, shale and ribbon chert, are isoclinally folded in places, whereas the thick limestone units appear to be structureless or in fairly broad north-trending folds. In a few places there is a suggestion that Lower Permian beds are thrust westward onto Upper Permian beds. This deformation apparently occurred in pre-Upper Triassic time but any interpretations are made difficult by poor exposure, and more particularly, by Tertiary block faulting that has disrupted the structural pattern and dropped younger Mesozoic and Tertiary assemblages into the Permian terrain.

In central British Columbia, the Cache Creek Group is a belt of rocks bounded on the northeast by the Pinchi Fault and on the southwest by the Fraser Fault. Northeast of the Pinchi Fault and southwest of the Fraser Fault, Cache Creek rocks are not exposed. Along the Pinchi Fault from a point on Quesnel River about 20 miles southeast of Quesnel to the mouth of the Blackwater River 30 miles northwest of Quesnel, Cache Creek Group rocks on the southwest side of the fault are, in places, in contact with Cambrian-Precambrian Cariboo and Kaza groups on the northeast side. Upper Triassic rocks (Nicola Group in part) rest unconformably on the Cariboo and Kaza groups with the apparent absence of Mississippian and (?) younger Slide Mountain Group that is present farther to the northeast. No Upper Triassic rocks were found on the Cache Creek rocks. Lower Jurassic (Pliensbachian and Toarcian) sediments overlie the Upper Triassic rocks unconformably northeast of the fault and apparently rest discordantly on Cache Creek rocks (on Dragon Mountain) southwest of the fault. Repeated activity on the fault since Triassic time or earlier is necessary to readily explain the anomalous relations on either side of the fault.

Some success in interpreting a stratigraphic succession in the Mesozoic rocks of Quesnel Trough was achieved using new information in conjunction with information previously obtained by R.B. Campbell (1961), and the writer. Four general assemblages can be recognized. The oldest, resting unconformably on Paleozoic or earlier rocks comprises black shale, calcareous shale, phyllite, and minor black argillaceous limestone and grey limestone of Late Triassic (Karnian to Norian) age. The next younger assemblage is mainly volcanic and characterized by dark green basaltic augite porphyry flows, breccia, and tuff with minor limestone and tuffaceous shale of Norian age that overlies the first assemblage with apparent conformity or interfingers with it. The third assemblage comprises Lower Jurassic Hettangian sediments and Sinemurian purple and maroon andesite and augite basalt that rest disconformably on Triassic rocks. The youngest assemblage is a succession of Lower to Middle Jurassic (upper Pliensbachian, Toarcian, and lower to middle Bajocian) finely banded shale and siltstone, calcareous brown shale, blue-grey thick-bedded siltstone, coarse light to dark green greywacke with rare boulder conglomerate along the western margin of the basin (Dragon Mountain and Beaver Valley of Quesnel area). Marine fauna, although not abundant, are sufficiently well-preserved to adequately date these four assemblages. No younger marine beds are known in this part of Quesnel Trough.

The Upper Triassic volcanic rocks (Nicola Group) thin northward and between Quesnel and Prince George occur as more or less isolated and unconnected volcanic centres. North of Prince George in McLeod Lake map-area, Upper Triassic rocks are largely replaced by shales except east of Carp Lake and southward to Merton Lake.

Brief visits to collect fossils were made to Smithers area (93L), Tyaughton Creek (92O), Garibaldi Park (92G), Merritt region (92I), and Queen Charlotte Islands. On Maude Island of the Queen Charlotte Islands, the type section of the Maude Formation and a section of the Kunga Formation were studied and some forty fossil collections date an apparent conformable sequence of Early Sinemurian to Early Toarcian age. When fully studied these collections will assist in interpreting the stratigraphic succession in the Hazelton and Takla groups and in the Lower Jurassic assemblages of Tyaughton Creek area and Quesnel Trough.

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13. OPERATION SAINT ELIAS, YUKON TERRITORY

Project 730035

R.B. Campbell and C.J. Dodds
Regional and Economic Geology Division, Vancouver, B.C.

Introduction

Following a wide-ranging reconnaissance of the Saint Elias Mountains in 1973 (Campbell and Eisbacher, 1974), a comprehensive geological study was initiated in the summer of 1974. The work, restricted to the mountains in Yukon Territory, involved regional mapping and related specific studies. Stratigraphy and structure of Permo-Triassic rocks, including detailed mapping of the "Mush Lake Group", was investigated by J.W.H. Monger and P.B. Read, the latter under contract to the Geological Survey. G.H. Eisbacher worked on the sedimentology and structure of Jurassic-Cretaceous and Tertiary strata. J.G. Souther studied the stratigraphy, structure and evolution of Tertiary volcanic and related intrusive rocks. This report provides a general introduction for separate discussions of each of these studies. Mapping of the surficial geology and studies of the glacial history were the responsibility of V.N. Rampton.

The efforts of the authors were directed primarily toward mapping regions where the geology was mainly unknown; this included Paleozoic (pre-Permian) sedimentary and volcanic rocks of generally low metamorphic grade and a variety of plutons in the Icefield Ranges. They were concerned, also, with the compilation of data on a scale of 1: 250,000 from the other participating geologists and from all available sources. The accompanying map (Fig. 1) is generalized and shows those regions in which the geology was the particular focus of one or other of the individual studies mentioned above. The map emphasizes, also, the main faults which are important elements of the regional structural setting.

Important revisions have been made in the geology of Dezadeash map-area where Kindle (1953) applied the name Mush Lake Group to rocks he believed to be Triassic, and he indicated, also, that rocks overlying the Mush Lake Group near Alsek River, were part of the Jurassic-Cretaceous Dezadeash Group. The rocks of the Mush Lake Group within Dezadeash map-area are now thought to be early and mid-Paleozoic (Read and Monger, following report), and the overlying rocks near Alsek River are also Paleozoic (*see* below).

Rocks in the Icefield Ranges

Locally, rocks in the Icefield Ranges have been mapped and reported on by previous workers (Kindle, 1953; Wheeler, 1963; Muller, 1967), and results of the earlier work with modifications are incorporated in the accompanying map. The results of the complete examination of fossil collections, and of the determination of the radiogenic age of plutonic rocks are not yet available, and field work is incomplete.

Layered rocks, dominantly sedimentary, are generally metamorphosed to low greenschist facies. Higher grade rocks, containing biotite and less commonly garnet, possibly resulted from contact metamorphism superimposed on the lower-grade, regionally metamorphosed rocks following the final phase of widespread penetrative deformation. The higher grade rocks are mostly restricted to a narrow zone extending northwesterly from near the terminus of the Dusty Glacier to the terminus of the Donjek Glacier (*see* Wheeler, 1963), and to an area northwest and southeast of Mount Alverstone. They can be divided into two sequences as shown by Sharp (1972) and Muller (1967): one characterized, if not dominated by, thick, grey carbonate and argillaceous rocks, and the other made up mainly of metamorphosed greywacke and shale with subordinate thin carbonate beds. The former, partly or entirely Devonian, has yielded fossils listed by Muller (1967, p. 28). The latter may overlie the carbonate unit, perhaps unconformably, and at Alsek River contains fossils tentatively identified as Upper Mississippian (B.E.B. Cameron, pers. comm., 1974).

The carbonate unit outcrops in a narrow band northwest from the mouth of Dusty River, along the southwest side of the Duke River Fault (*see* Wheeler, 1963, and Muller, 1967), and in another band along the southern and western edge of the area mapped, from south of the Fisher Glacier to the Klutlan Glacier. It also underlies a large, unmapped area north of the Walsh Glacier. The metamorphosed greywacke and shale sequence lies between the two bands of the carbonate unit and extends from near Bates Lake to near the Steele Glacier.

The Paleozoic stratified rocks of the Icefield Ranges were folded at least twice, and locally, if not generally, the axes of the later folds are at a high angle to those of the earlier. Although extensive exposures are characteristic of the region, macroscopic folds are uncommon, even where prominent marker beds are present. The reasons for this are not understood. Possibly fold hinges are obscured and dislocated by shearing. If the folds are large, and the axes plunge steeply on a regional scale as they do locally, fold hinges may not be obvious in the steep, mountainous terrain.

Plutonic rocks vary from gabbro and diorite to quartz monzonite and syenite. Most are moderately dark hornblende-biotite quartz diorite and granodiorite, but some are melanocratic gabbro or diorite with syenitic phases, and some are leucocratic, biotite quartz monzonite with large pink potash feldspar phenocrysts. Most granitic plutons have sharp, steeply dipping contacts and rather irregular outlines. The rocks probably range from late Paleozoic to Tertiary in age, but any breakdown by age or composition must await results of laboratory studies.

Major Faults

The mid and lower Paleozoic rocks of the Saint Elias Mountains are separated by major faults from Permo-Triassic and Jurassic-Cretaceous rocks along the northeastern margin of the mountains. The Dalton Fault extends southeastward from Jarvis River and is the direct southeasterly extension of the Shakwak segment of the Denali Fault system (Campbell and Eisbacher, 1974). It separates the Paleozoic rocks from the Jurassic-Cretaceous Dezadeash Group and contains pods of Tertiary coal-bearing conglomerate within the vertical fault zone. Tertiary volcanic rocks, presumably equivalent to the Wrangell Lava of eastern Alaska are cut by the fault.

The Duke River Fault (Muller, 1967) diverges from the Shakwak-Dalton Fault near Jarvis River from where it can be traced northwestward to the Klutlan Glacier. At its southern end the fault dips steeply to moderately southwestward; farther north it is mainly vertical. Throughout its length the fault separates the Paleozoic rocks of the Icefield Ranges from Permo-Triassic strata to the northeast; locally it displaces the basal units of the Wrangell Lava, but does not cut higher flows. North of Steele Glacier the lava is deformed into large overturned folds above the trace of the underlying fault, and other, possibly related faults cut the lava (Souther, this publication). Near Klutlan Glacier Permian rocks are thrust over the Tertiary volcanics. The trace of the Duke River Fault apparently extends beneath the Klutlan Glacier westward into Alaska where it may intersect or interconnect with the Totschunda Fault system (Richter and Matson, 1971).

The type and magnitude of movement on the steeply dipping Dalton and Duke River faults is unknown. Indications of Pleistocene or Recent movement on the faults are lacking, but both the Dalton and Duke River faults cut, or are related to deformation within rocks that may be as young as Pliocene. Most of the movement must predate deposition of the Wrangell Lava.

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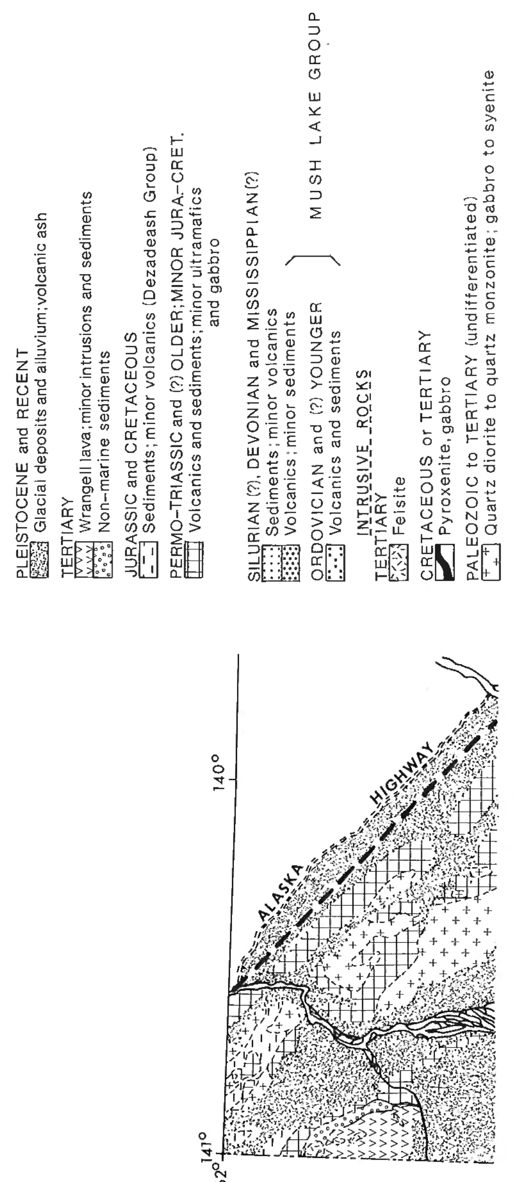
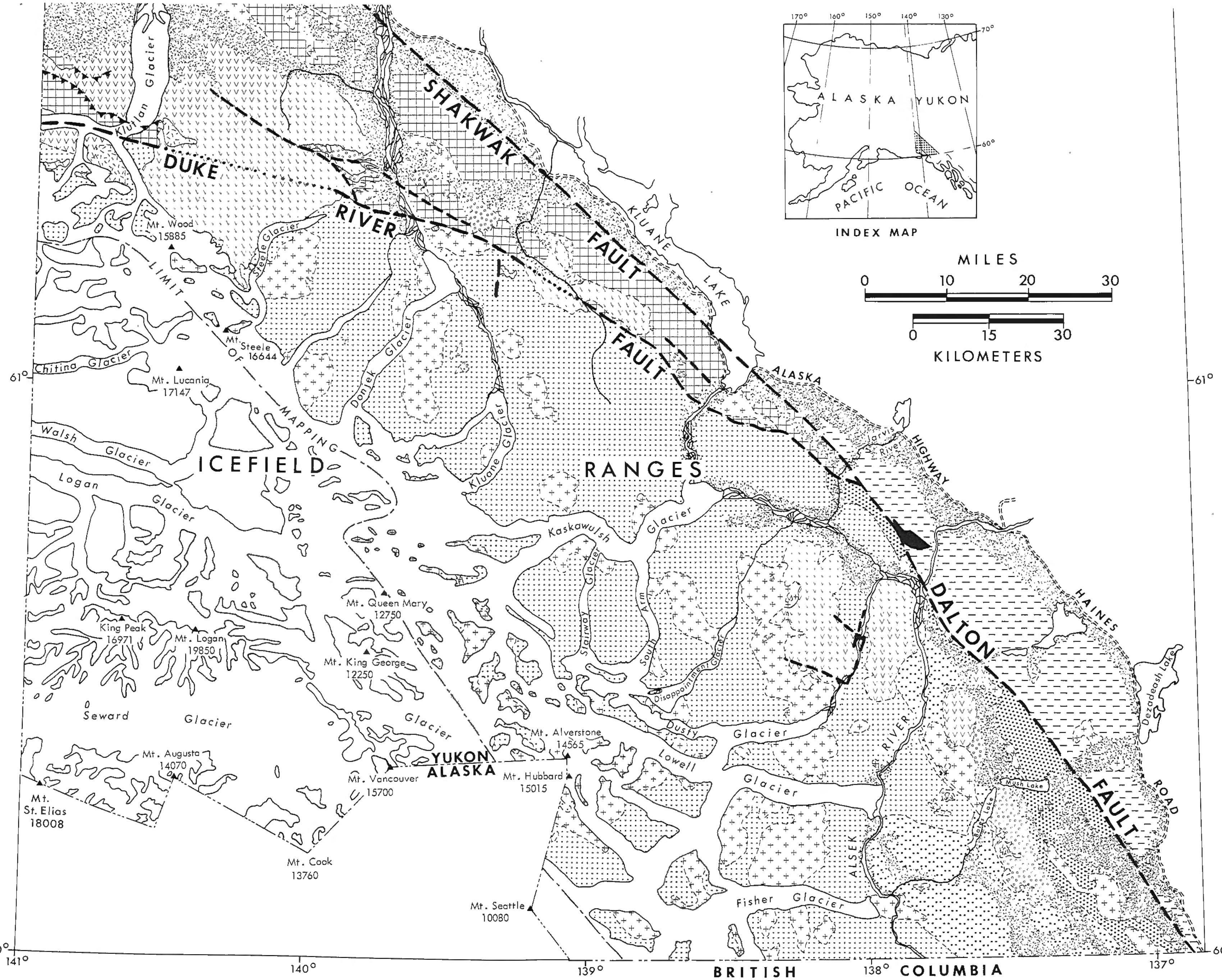


Figure 1
GEOLOGICAL MAP, ST. ELIAS MOUNTAINS YUKON



SHAKWAK
FAULT
DUKE
RIVER
FAULT
DALTON
FAULT
ICEFIELD
RANGES
LIMIT OF MAPPING
KLUANE LAKE
ALASKA HIGHWAY
HAINES ROAD
INDEX MAP
ALASKA
YUKON
PACIFIC OCEAN
MILES
0
10
20
30
0
15
30
KILOMETERS
Kluan Glacier
Mt. Wood
15885
Steele Glacier
Mt. Steele
16644
Chitina Glacier
Mt. Lucania
17147
Donjek Glacier
Kluane Glacier
Walsh Glacier
Logan Glacier
Kaskawulsh Glacier
Stairway Glacier
South Arm
Disappointment Glacier
Jarvis River
Mt. Queen Mary
12750
King Peak
16971
Mt. Logan
19850
Mt. King George
12250
Seward Glacier
Glacier
Mt. Alverstone
14565
Dusty Glacier
Lowell Glacier
YUKON
ALASKA
Mt. Augusta
14070
Mt. Vancouver
15700
Mt. Hubbard
15015
Mt. St. Elias
18008
Mt. Cook
13760
ALSEK RIVER
Mush Lake
Dezadeash Lake
Mt. Seattle
10080
Fisher Glacier
BRITISH COLUMBIA
61°
60°
141°
140°
139°
138°
137°

OPERATION SAINT ELIAS, YUKON TERRITORY: THE MUSH LAKE GROUP AND PERMO-TRIASSIC ROCKS IN THE KLUANE RANGES

Project 720041

P. B. Read[1] and J. W. H. Monger
Regional and Economic Geology Division, Vancouver, B. C.

The project was designed to study the stratigraphy, structure and economic potential of the Triassic and Jurassic (?) Mush Lake Group and underlying Permian rocks, that were thought to form much of the Kluane Ranges in Dezadeash (115A), eastern Mount Saint Elias (Kaskawulsh, 115B), and Kluane Lake (115F - G) map-areas. Field work demonstrated that the distribution of Permo-Triassic rocks in Kluane and Kaskawulsh map-areas is essentially as shown by Muller (1967) and Wheeler (1963). In the type area of the Mush Lake Group, however, rocks mapped by Kindle (1953) as Triassic and Jurassic (?) are of probable Ordovician and Devonian ages. Consequently, separate descriptions are given in this report of the Mush Lake Group of Kindle, here largely restricted to the Dezadeash map-area, and the Permo-Triassic rocks farther north.

Mush Lake Group

The Mush Lake Group (restricted) is separated from younger rocks to the north and northeast by, respectively, the Duke River and Dalton faults (Campbell and Dodds, preceding report, Fig. 1), and extends along strike for at least 70 miles, from Jarvis River in the Kaskawulsh map-area (latitude 60°50') to south of Dezadeash map-area (latitude 60°00').

Stratigraphy

The Mush Lake Group consists of approximately 20,000 feet mainly green, porphyritic and amygdaloidal meta-andesite flows, with intercalated tuff, volcanic breccia, grey phyllite, limestone and chert. Fossils from sediments interbedded with the flows indicate a probable Early to Middle Ordovician age for strata near Field Creek, approximately 12 miles southwest of Mush Lake, and probable Devonian age for rocks north and south of Mush Lake. These rocks underlie massive to thin-bedded limestone and dolomite, grey phyllite and phyllitic greywacke that extend over a vast area of the Icefield Ranges and are at least partly of Devonian age.

Near Field Creek dark green meta-andesite with plagioclase phenocrysts and chlorite amygdules underlie massive light grey limestone (Fig. 1). Towards the southwest, lenses of tuffaceous sediments up to 100 feet thick are intercalated with the flows. Above the limestone is an intensely folded volcanic sequence containing calcareous volcaniclastic rocks.

Between Mush Lake and Beloud Creek, the Mush Lake Group consists mainly of meta-andesite flows with discontinuous pillow lavas and volcaniclastic rocks (Fig. 2). Probable Devonian fossils were obtained from thin, bioclastic limestones low in the section at Sickle Creek, southeast of Mush Lake and 1¼ miles southeast of Johobo Mine. Beneath these limestones are dark grey phyllite and greywacke previously mapped with the Jurassic-Cretaceous Dezadeash Group.

Structure

At least two regionally extensive phases of folding deformed rocks of the Mush Lake Group. Late folds have northwest-striking axial planes with steep dips, and fold axes plunge steeply. Early folds are isoclinal with highly variable attitudes. Near Field Creek, massive grey limestone outlines a large late antiform plunging northwestward and exposing Ordo-

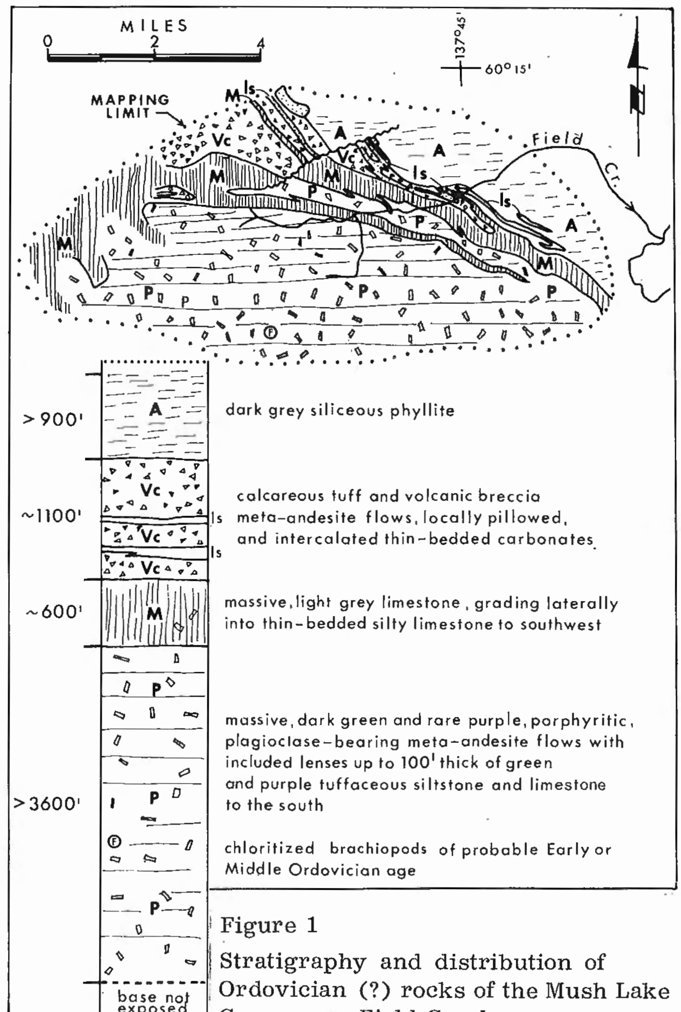


Figure 1
Stratigraphy and distribution of Ordovician (?) rocks of the Mush Lake Group near Field Creek.

[1] Consulting geologist: 4490 Angus Drive, Vancouver, British Columbia.

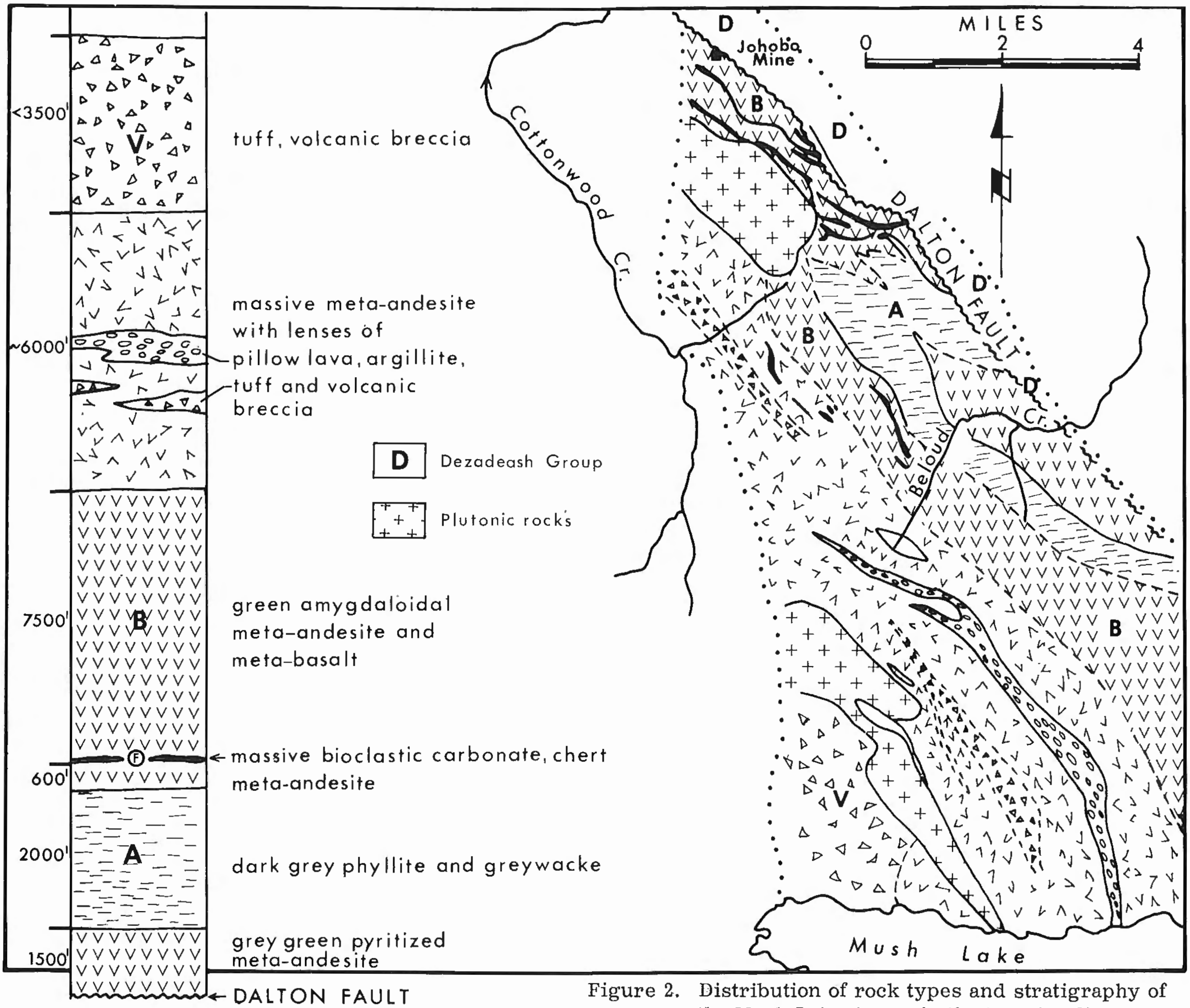


Figure 2. Distribution of rock types and stratigraphy of the Mush Lake Group in the type locality.

vician rocks in the core. Early isoclinal folds in this limestone mostly plunge moderately southeastward. The belt of Mush Lake Group from Jarvis River to Mush Lake forms the northeast limb of a northwest plunging syncline. The anticline exposed at the head of Cottonwood Creek is one of the parasitic folds on the early (?) regional fold.

The folds are cut by northwesterly striking Dalton and Duke River faults, whose latest movements are shown by slickensides to be subhorizontal.

Mineralization

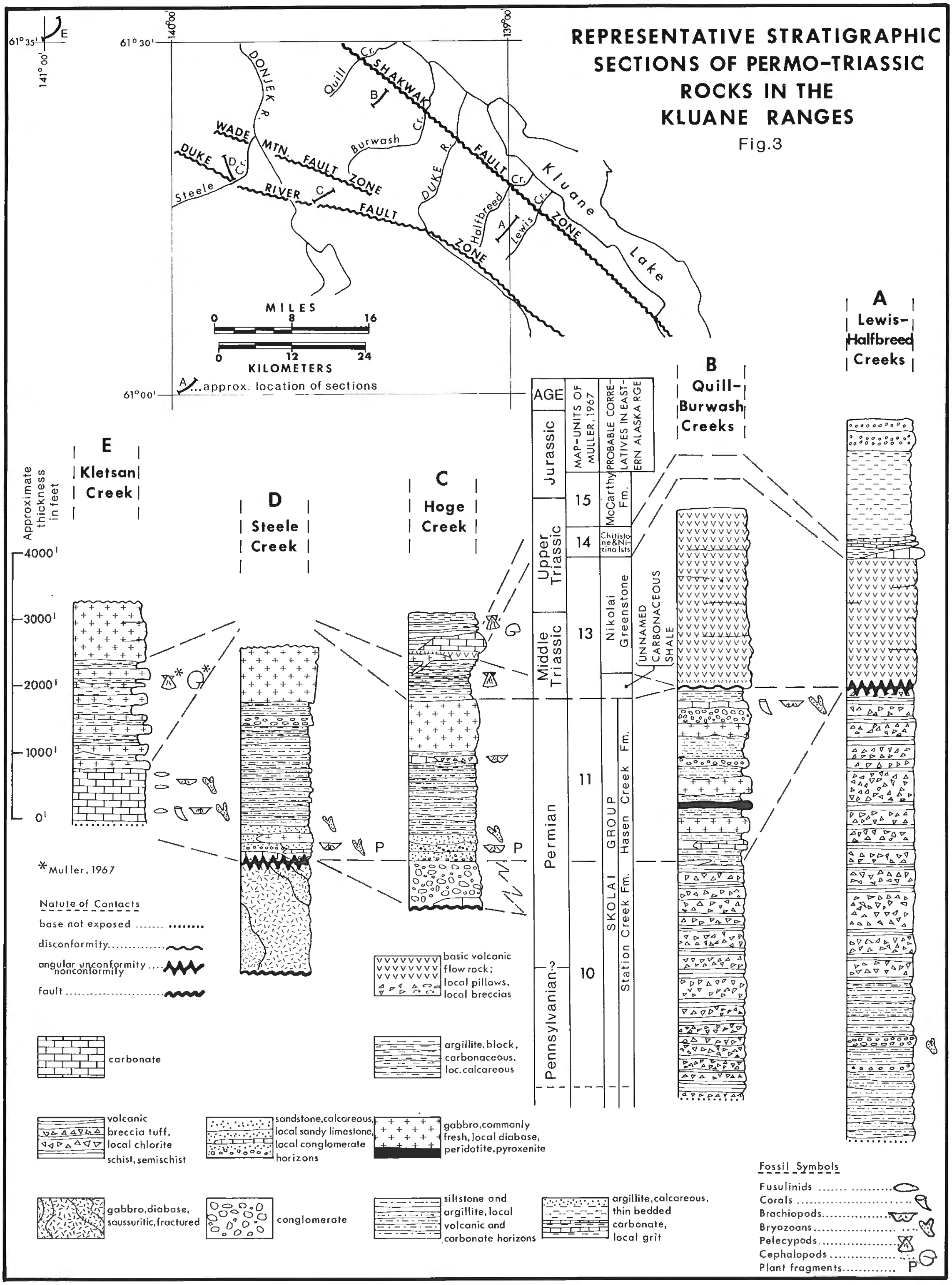
Mineralization is spatially restricted to certain rock types or structures. In the Dezadeash area, most copper showings in the Mush Lake Group lie within 4 miles of the Dalton Fault adjacent to intrusions. The Johobo Mine is within 1,000 feet of the Dalton Fault near the crest of an anticline outlined by sedimentary and volcanic rocks of the group.

Permo-Triassic and (?) older rocks

Permo-Triassic and (?) older rocks in the Kluane Ranges underlie an area extending for 125 miles along strike, from the Alaska boundary in the northwest (latitude 62°05') to Jarvis River in the southeast (latitude 60°50'), (Campbell and Dodds, preceding report, Fig. 1). The area is 35 miles wide in the northwest, and tapers to zero width near Jarvis River. Major faults, the Shakwak-Dalton on the northeast and east, and Duke River to the southwest, separate these rocks from, respectively, metamorphic and granitic rocks of the Yukon Crystalline Platform and Devonian and older (?) strata of the Icefield Ranges.

Stratigraphy

Six main stratified rock units, listed below in order of decreasing age, overlie and are cut by basic intrusive rocks of two and possibly three ages (Fig. 3).


REPRESENTATIVE STRATIGRAPHIC SECTIONS OF PERMO-TRIASSIC ROCKS IN THE KLUANE RANGES
Fig.3
MILES
KILOMETERS
approx. location of sections
SHAKWAK FAULT ZONE
WADE MTN. FAULT ZONE
DUKE RIVER FAULT ZONE
Kluane Lake
A Lewis-Halfbreed Creeks
B Quill-Burwash Creeks
C Hoge Creek
D Steele Creek
E Kletsan Creek
Approximate thickness in feet
AGE
MAP-UNITS OF MULLER, 1967
PROBABLE CORRELATIVES IN EASTERN ALASKA RGE
Jurassic
Upper Triassic
Middle Triassic
Permian
Pennsylvanian-?
McCarthy Fm.
Chitistone & Nizina lsts
Nikolai Greenstone
UNNAMED CARBONACEOUS SHALE
SKOLAI GROUP
Hasen Creek Fm.
Station Creek Fm.
*Muller, 1967
Nature of Contacts
base not exposed
disconformity
angular unconformity nonconformity
fault
basic volcanic flow rock; local pillows, local breccias
argillite, block, carbonaceous, loc. calcareous
carbonate
volcanic breccia tuff, local chlorite schist, semischist
sandstone, calcareous, local sandy limestone, local conglomerate horizons
gabbro, commonly fresh, local diabase, peridotite, pyroxenite
gabbro, diabase, saussuritic, fractured
conglomerate
siltstone and argillite, local volcanic and carbonate horizons
argillite, calcareous, thin bedded carbonate, local grit
Fossil Symbols
Fusulinids
Corals
Brachiopods
Bryozoans
Pelecypods
Cephalopods
Plant fragments

The stratigraphy correlates well with upper Paleozoic - lower Mesozoic stratigraphy described by Smith and MacKevett (1970), and Richter and Jones (1973) from the eastern Alaska Range.

(1) Permian and (?) older volcanic rocks, exposed extensively in the eastern part of the Kluane Ranges and near the Alaska boundary at latitude 61°30' are grey-green fine-grained, well-bedded, crystal lithic tuff and volcanic breccia containing clasts of saussuritic basalt, pyroxene or hornblende porphyry and feldspar porphyry and rare, locally pillowed, flow rocks. Near the Shakwak and Wade Mountain fault zones, these rocks grade locally into chlorite schists and semischists, and they are probably the primary rock for much of the amphibolite and dioritized 'greenstone' associated with granitic rock in the belt between the Generc River and the easternmost Kluane Ranges (part of map-unit 17 of Muller, 1967). Commonly these are the oldest rocks in the area between the Duke River and Shakwak faults (Fig. 3, Sec. B), but between Halfbreed and Quill Creek (Fig. 3, Sec. A), the volcanic rocks are apparently underlain by a sedimentary sequence.

(2) Permian sedimentary rocks exhibit three main lithofacies. Most abundant, but most deformed and extensively cut by gabbro and peridotite, are argillite, siltstone, less-common chert, graded-bedded sandstone, chert pebble conglomerate and thin limestone in the easternmost Kluane Ranges (Fig. 3, Sec. B). Southwest of the Wade Mountain Fault zone is a well-preserved sequence of basal, locally brown to orange crossbedded calcareous sandstone, sandy limestone and minor chert pebble conglomerate, dominant thin-bedded siltstone and argillite, with lenses of volcanic rock and carbonate near the top (Fig. 3, Secs. C, D). In contrast to the eastern section, which conformably lies on Permian and (?) older volcanic rocks, the sequence near Steele Creek lies nonconformably on gabbro and diabase and near Hoge Creek conformably on maroon to green pebble to boulder conglomerate containing clasts of gabbro, pyroxenite, basic volcanic rocks and chert. Near Kletsan Creek (Fig. 3, Sec. E), the Permian section is represented by thick-bedded, crinoidal calcarenite and calcarenitic limestone.

(3) Middle Triassic argillites, characterized by their black colour and carbonaceous content, are locally calcareous and nodular. These rocks are known from southwest of the Wade Mountain Fault zone and near Kletsan Creek, but have not been positively identified in the eastern Kluane Ranges.

(4) Triassic volcanic rocks are mainly red-brown, massive amygdaloidal basalts with pillow lava and breccia near the base of the sequence. Individual flows can rarely be recognized except south of Kletsan Creek on the Alaska boundary (latitude 61°34') where flow tops are marked by breccias and red horizons. Fine-grained amphibolite and dioritized 'greenstone' immediately northeast of the Wade Mountain Fault zone (part of map-unit 17 of Muller, 1967), is a metamorphosed equivalent of this unit. Southwest of the Wade Mountain Fault zone the Triassic volcanic rocks are thin and discontinuous but elsewhere they are up to 3,000 feet thick.

(5) Upper Triassic limestone is commonly massive but is locally thin bedded near its stratigraphic top. Topographically prominent, it makes a useful marker horizon, but in places is a series of lenses rather than a continuous unit.

(6) Upper Triassic and (?) Jura-Cretaceous clastic rocks are mainly argillite, but have a characteristic basal unit consisting of thin limestone beds in argillite. Upward they contain lenses of grit and, rarely, conglomerate.

Basic intrusive rocks in this area are of two, possibly three ages. Massive, fractured, green gabbro, pegmatitic gabbro and diabase nonconformably underlie Permian strata (Fig. 3, Sec. D) as first suggested by Sharp (1943). Intrusive relationships of this gabbro are not known, as it is apparently in fault contact with Devonian strata across the Duke River Fault. Most common are relatively fresh, grey to grey-green, locally columnar jointed gabbro sills, commonly concordant with bedding. In places peridotite sills associated with the gabbro show ambiguous cross-cutting relationships suggesting they are the same age as the gabbro. As these sills cut all rocks up to and including the Triassic basic volcanic unit, but not younger rocks, they are perhaps genetically related to the volcanics. Finally, rusty weathering, dark grey to black basalt and diabase sills cutting Middle Triassic rocks south of Kletsan Creek are possibly feeders to late Tertiary lavas in the area.

Structure

Permo-Triassic and (?) older strata are folded and faulted. Folds commonly trend northwesterly and may be tight or open, and major folds generally have subhorizontal fold axes. Many fault surfaces carry subhorizontal slickensiding, indicating strike-slip movement, and close to such faults, plunges in mesoscopic folds may be steep. Some faults at least are very young. Near Kletsan Creek, Permian strata are thrust over upper Tertiary volcanics and near Steele Creek and Donjek River, faults cutting Permian strata and pre-Permian gabbro can be traced laterally into folds and faults affecting adjacent upper Tertiary volcanics.

Economic Geology

Small malachite and azurite showings are present in nearly all rock units described above, but are particularly abundant in the Triassic volcanic rocks. On the upper canyon of the White River, recent exploratory adits in the Triassic volcanics reveal scattered occurrences of native copper, chalcocite and rarely, bornite. Nickel-copper deposits near Quill Creek, along the contacts between the Permian sedimentary rocks and gabbroic intrusives, are currently being studied as a University of British Columbia thesis project.

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OPERATION SAINT ELIAS, YUKON TERRITORY: DEZADEASH GROUP AND AMPHITHEATRE FORMATION

Project 730035

G.H. Eisbacher
Regional and Economic Geology Division, Vancouver, B.C.

Four weeks were spent by the author on a reconnaissance of the sedimentology and structure of the Upper Jurassic (?) - Lower Cretaceous Dezadeash Group in the area between Kluane Lake and latitude 60° (Fig. 1).

Stratigraphy and Sedimentology

The Dezadeash Group consists entirely of marine flysch. Fossils are scarce and the clastic sediments seem to have been deposited mainly by turbidity currents along the distal portion of a sub-sea fan. Structural complexity and the absence of persistent markers make reliable thickness estimates difficult, but the approximate thickness of 11,000 feet (3,500 m) given by Kindle (1953) is of the right order of magnitude. Beds generally face and are younger toward the west. Older beds along the eastern part of the outcrop belt seem to grade easterly into metamorphic rocks of the Coast Crystalline Complex. Considering the structural pattern described below, it is probable that a zone of high-angle reverse faulting separates the Coast Crystalline Complex from the Dezadeash Group (Fig. 1). Younger parts of the sequence in the west are juxtaposed against Paleozoic rocks along the Dalton Fault (Campbell and Eisbacher, 1974).

In the lower part of the sequence sandstones commonly exhibit graded beds, parallel lamination or crosslamination (A, B, C intervals of the "Bouma sequence"). In the upper part crosslaminated and unlaminated to finely laminated siltstones (C, D of the Bouma sequence) predominate. The central part contains several subaqueous slide masses with well rounded granitic, gabbroic, volcanic, chert and limestone pebbles. In one area north of Kathleen Lakes, blocks of limestone up to five metres in diameter are part of the debris flow units. Several horizons of highly altered (zeolitic?) tuffaceous turbidite beds occur along the north shore of Kathleen Lakes. Paleocurrent diagrams derived from sole marks and crosslamination on turbidite beds indicate northeasterly directed sediment transport for the Dezadeash Group as a whole. Slump folds indicate a northeasterly to easterly facing paleoslope.

Coal-bearing conglomerates along the western outcrop limit of the Dezadeash Group have been previously considered part of the basal Dezadeash Group (Kindle, 1953; Wheeler, 1963). Careful examination showed that these conglomerates are younger slivers of continental clastics (probably Tertiary) within the Dalton Fault zone. Small erosional remnants of Tertiary sandstone and conglomerate overlie parts of the deformed and intruded Dezadeash Group with profound unconformity. Coal deposits were not found within the Dezadeash Group and none should be expected.

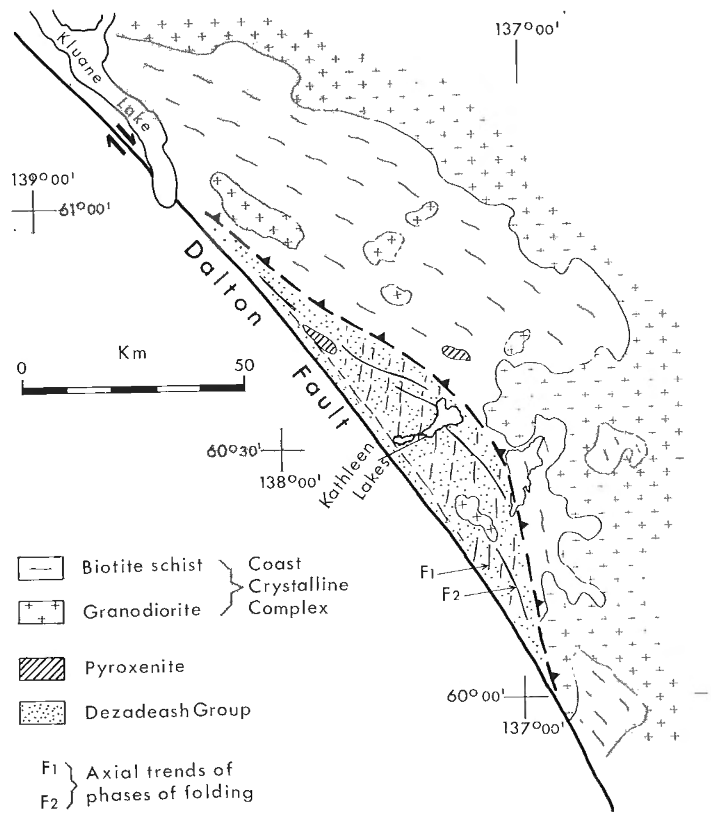

Figure 1. Interpretive sketch map of the Dezadeash Group outcrop area, Eastern Saint Elias Mountains.

Structure

Three major deformational events affected the Dezadeash flysch (Fig. 1):

1) Early north-northeasterly trending, eastward overturned folds on the scale of 10 to 100 m whose axial surfaces can be mapped for 3 to 6 km along trend (F_1).

2) Large scale northwesterly trending anticlines and synclines with predominant overturning to the southwest (F_2). F_1 folds were refolded by F_2 folds. F_2 folds are probably related to strong deformation and metamorphism of the Coast Crystalline Complex (Late Cretaceous - early Tertiary). Regional deformation and metamorphism was followed by the intrusion of granodiorite batholiths.

3) Faulting and shattering of Dezadeash rocks during displacements along the Dalton Fault.

Regional Implications

The Dezadeash flysch filled one of the extensive Upper Jurassic - Lower Cretaceous successor basins of the Canadian Cordillera (Eisbacher, 1974). Structure and sedimentology suggest that the outer deposits of the sub-sea fan and those of the inner shelf-slope assemblage are missing. The outer sub-sea fan facies has probably been metamorphosed to extensive quartz-biotite schists of the Coast Crystalline Complex to the northeast (Fig. 1). The shelf sequence could have been displaced by large right-lateral offsets along the Dalton - Shawak - Denali Fault System (Campbell and Eisbacher, 1974). Richter and Jones (1973) described an Upper Jurassic - Lower Cretaceous marine sequence in eastern Alaska which displays a progradation from shallow-water facies in the southwest to deeper-water facies in the northeast where it is truncated by the Denali Fault. This sequence is 300 km to the northwest of the Dezadeash flysch and could represent a nearshore shallow-water equivalent of the Dezadeash Group, displaced by about 300 km of right-lateral offset along the Dalton - Shakwak - Denali Fault System.

Amphitheater Formation

Tertiary nonmarine sediments ranging in age from possibly Paleocene to Miocene occur as erosional remnants in many parts of the eastern Saint Elias Mountains. The best exposures are near Amphitheater Mountain where a section of 400 m (1,200 feet) of conglomerate, sandstone, mudstone, and coal is exposed. The bulk of the Amphitheater Formation in its type area was derived from the east including as source terrain the crystalline rocks of the Yukon Plateau (Muller, 1967). The clastic material was transported westward by braided and meandering streams over a deeply eroded bedrock pediment. Layers of coal are common but laterally discontinuous in outcrop and distributed erratically throughout the section. This distribution is due to the shifting of high-gradient river channels that carried sand and gravel over swampy terrane during the filling of aggradational Tertiary river basins. The highest units of the Amphitheater Formation range from coarse boulder breccias to lacustrine siltstones indicating a highly differentiated and tectonically active landscape. North of Sheep Creek (west of Kluane Lake), the Amphitheater Formation includes a Tertiary rock slide that can be laterally traced into coarse deposits made up of slide fragments reworked by running water.

Tertiary nonmarine clastics near Bates Lake include scree breccias and alluvial fan deposits derived from elevated Paleozoic terrane to the west. These deposits seem to be older than the Amphitheater Formation in Kluane Lake map-area.

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16. OPERATION SAINT ELIAS, YUKON TERRITORY: TERTIARY VOLCANIC ROCKS

Project 700026

J.G. Souther[1] and Constantina Stanciu[2]

Scattered remnants of Tertiary sub-aerial lavas and pyroclastic rocks are preserved along the entire eastern fringe of the Saint Elias Mountains. Over large areas extrusive rocks lie in flat undisturbed piles on a Tertiary surface of moderate relief. Elsewhere, strata of the same age have been deformed during a late pulse of Saint Elias tectonism and faulted, contorted into tight symmetrical folds or overridden by Pre-Tertiary basement rocks along southwesterly dipping thrust faults. Profound recent uplift, accompanied by rapid erosion has reduced once vast areas of Tertiary volcanic rocks to small isolated remnants. In places the eruptive rocks have been stripped away completely, leaving only subvolcanic plutons, necks, dyke swarms and zones of hydrothermal alteration.

Tertiary volcanic rocks are extensively developed in eastern Alaska, where they are referred to collectively as the Wrangell Lavas (Mendenhall, 1905). In McCarthy Quadrangle, which lies west of the project area, MacKevett (1970), described the Wragnell Lavas as "sub-aerial lava flows, less commonly pyroclastic rocks, vitrophyre and conglomerate more than 5,000 feet thick". Equivalent rocks in western Yukon have been described by Wheeler (1963) in Kaskawulsh map-area, by Kindle (1953) in Dezadeash map-area, and by Muller (1967), who referred to them as the St. Clare Group in Kluane Lake map-area. In this report the name Wrangell Lava is adopted for all the Tertiary extrusive products and Wragnell Intrusions for the felsic, subvolcanic plutons that cut parts of the Wragnell Lava succession. Within the project area, three sub-provinces of the Wragnell terrain are recognized, each having distinctive stratigraphic and structural characteristics:

(1) The Canyon Mountain Province
(2) The St. Clare Province
(3) The Alsek Province.

The Canyon Mountain Province

A relatively small area of Tertiary volcanic rocks, exposed north of White River in the northwestern corner of Kluane Lake map-area, is co-extensive with a much larger area of Wragnell Lava in adjacent Alaska. The base of the volcanic pile rests with structural conformity on Tertiary sandstone and conglomerate that has been locally bleached and silicified. Approximately 2,000 feet of gently tilted lavas and pyroclastic rocks are exposed. Coarse, pyroclastic breccia comprising blocky to loosely welded clasts of black vesicular basalt, form almost the entire lower third of the section and is cut by a mass of dykes and cupolas of brownish grey, porphyritic basalt overlain by thick irregular flows and vitroclastic tuff-breccia of similar basalt.

A layer of volcanic conglomerate, pumiceous tuff, mud-flows and sedimentary breccia separates the lower basaltic complex from a younger group of lavas that cap the higher ridges. Though highly variable in thickness and composition, this clastic layer forms a persistent, light coloured horizon between the lower and upper basaltic units. The upper basaltic unit comprises a sequence of thin regular flows of olivine-bearing basalt separated by layers of loose, clinkery scoria.

The lower and upper basaltic units of the Canyon Mountain Province issued from nearby sources. The predominance of coarse pyroclastic debris, thick irregular flows, and masses of randomly oriented dykes, suggest the central, near-vent environment of a large composite basaltic dome. In contrast the relatively thin clinkery flows of the upper unit clearly issued from several small separate vents fed by a north-south system of dykes. Locally, the dykes have coalesced into elongate necks that tower as great vertical ribs above the eroded remnants of their enclosing scoria. One of these, on the north slope of Flattop Mountain, forms a small, elliptical ring dyke complex with concentric vertical ribs of basalt standing in perfect symmetry like the walls of a medieval fortress.

The lower basaltic unit is cut by several small plutons and numerous dykes of hornblende felsite. Some of the dykes have glassy selvages whereas the larger masses exhibit no quench textures but are commonly surrounded by a narrow zone of silicification. Felsic rocks were not observed cutting the upper basalt complex, suggesting that the intrusive felsites may be subvolcanic equivalents of the felsic pumice layer between the lower and upper basaltic complexes.

The St. Clare Province

South of the Canyon Mountain Province bedrock is obscured by an alluvial plain that extends for ten miles from White River to the mountain front north of Klutlan Glacier. There, Tertiary lavas are exposed across a broad belt of rugged volcanic terrain that flanks the Icefield Ranges as far south as Steele Glacier. South of Steele Glacier isolated remnants of Tertiary lavas are scattered along the Duke Depression and form caps on the mountains to the southwest. All of these rocks are included in the St. Clare Province.

Despite the large area of the province and evidence of many separate eruptive centres, most of the

[1]Regional and Economic Geology Division, Vancouver, British Columbia.

[2]Geological Institute, Bucharest, Roumania.

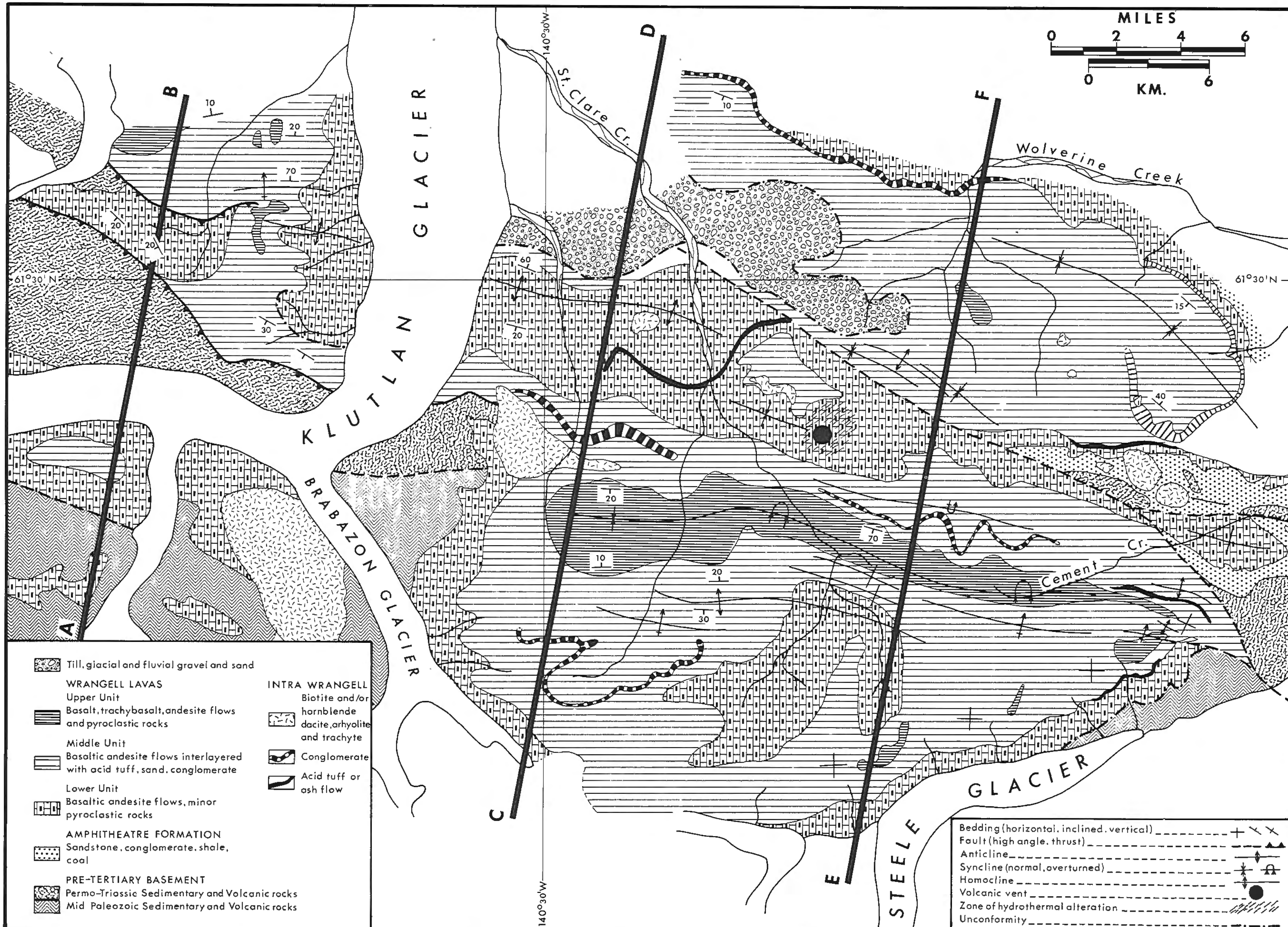

Figure 1. Generalized map of Wrangell Lavas in a part of the St. Clare Province.

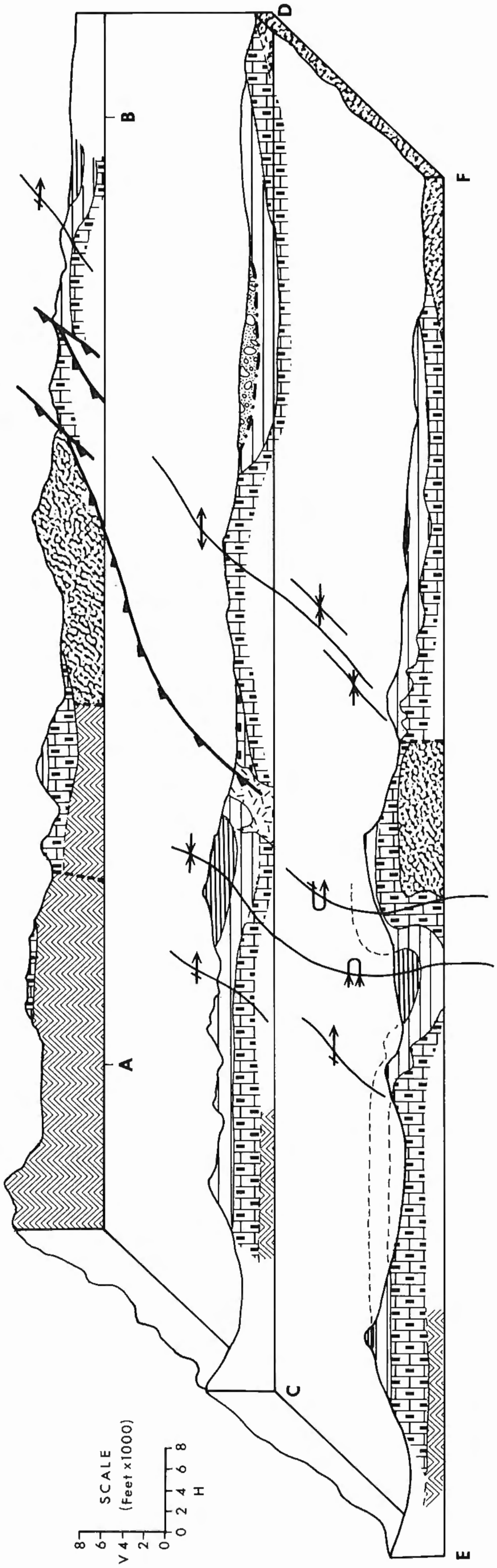

Figure 2. Schematic cross-sections showing the variation in structural style across the St. Clare Province. (For location and legend *see* Fig. 1.)

St. Clare lavas are monotonously uniform. Basalt and/or basaltic andesite either aphanitic or with sparse phenocrysts of plagioclase and rarely pyroxene form at least 90 per cent of all the sections measured. Flows, usually less than 40 feet thick, are several times more abundant than related pyroclastic rocks. Interbedded with them are thin layers of felsic pumice, locally redeposited by water, welded ash flows, pods of coaly siltstone and mudstone and discontinuous sheets of volcanic conglomerate. Though volumetrically small these minor units provide the only reliablè basis for megascopic correlation.

Thicknesses in the St. Clare Province vary from a few feet in some of the small residual caps, through about 1,000 feet along the escarpment facing Wolverine Creek, to more than 6,000 feet along the axis of the St. Clare Creek syncline. The 4,000-foot section facing Steele Glacier is typical (Souther, 1974, p. 40, Sec. 1). On the accompanying map and cross-sections (Figs. 1 and 2) volcanic rocks have been tentatively divided into three units:

(1) A lower unit comprising thick, blocky flows of mainly nonporphyritic basaltic andesite; locally separated by layers of white or light grey clay and coaly siltstone; overlain by a succession of 20 to 40 uniformly thin (2-6 feet) closely stacked basaltic andesite flows with no interflow clastic or pyroclastic material.

(2) A middle unit comprising both porphyritic and nonporphyritic basaltic andesite flows and minor pillow lavas, interlayered with a relatively high proportion of felsic ash flows, air fall, and derived sedimentary deposits including coaly tuff, sandstone and conglomerate.

(3) An upper unit comprising basaltic flows and scoria, volcanic conglomerate, light grey dictytaxitic andesite and olivine basalt.

The volcanic rocks are overlain unconformably by ancient deposits of polymictic fluvial and glacial gravels, tills and lacustrine deposits that contain both Wragnell and pre-Wrangell clasts. These cover a large area north of St. Clare Creek where they are tilted and faulted along with the underlying Wrangell strata.

Discontinuous lenses of conglomerate, some several hundred feet thick, within the Wrangell pile indicate that erosion and redeposition was active during the period of volcanicity. All clasts in these conglomerates are derived from Wrangell Lavas and are believed to have been shed from constructional volcanic edifices rather than from tectonically uplifted terrain. Minor unconformities within the Wrangell pile were observed on the north side of Cement Creek and north of Klutlan Glacier. These exhibit angular discordance between 15 and 30 degrees - too much to explain by simple truncation of beds with a high initial dip. It is more likely that these are areas of volcanogenic uplift and tilting related to volcanic centres or emplacement of subvolcanic intrusions. More significant is the lack of evidence for large scale uplift and erosion during deposition of the Wrangell Lavas and the unavoidable conclusion that this enormously thick volcanic pile accumu-

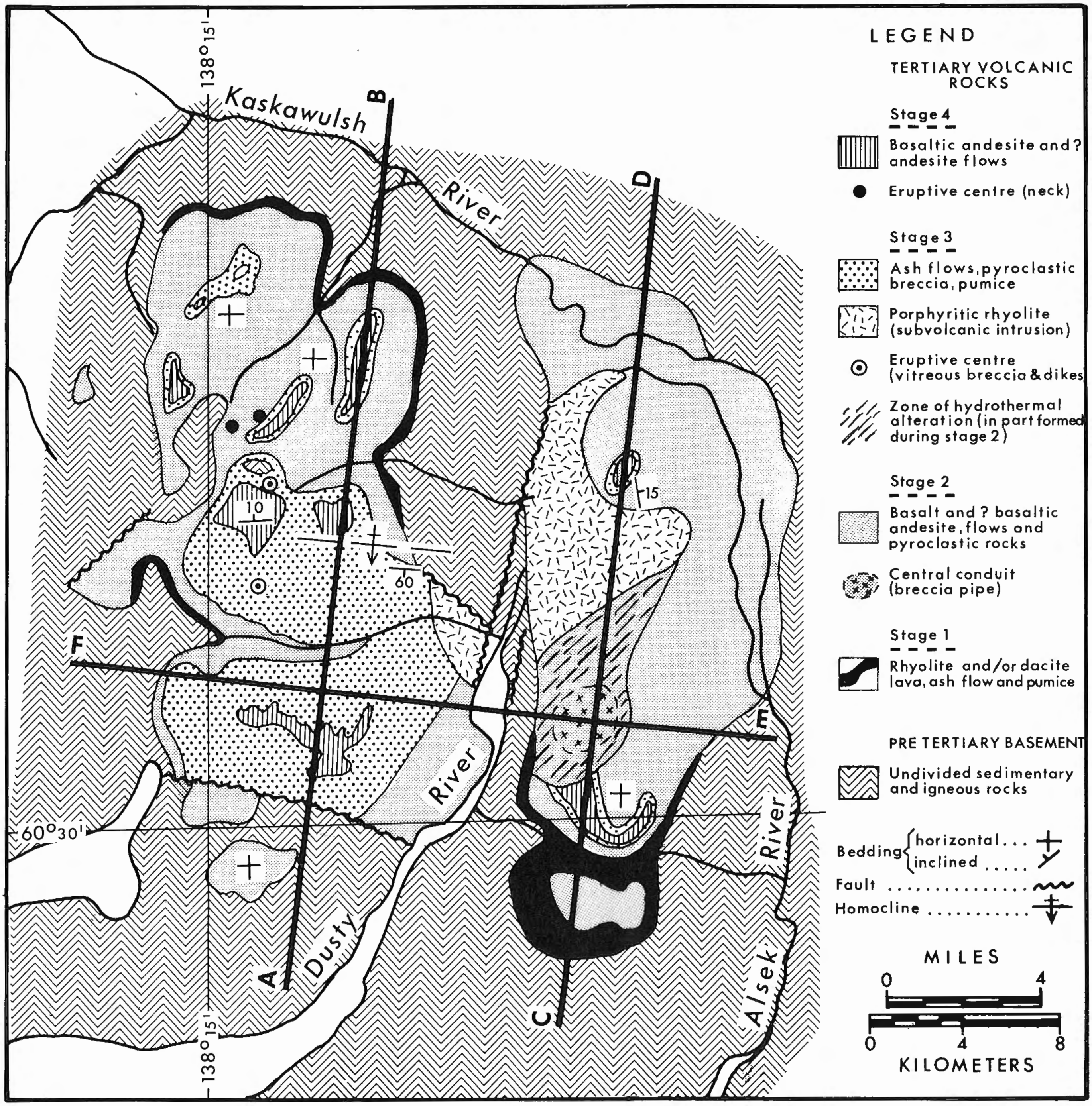

Figure 3. Generalized map of Wrangell Lavas in a part of the Alsek Province.

lated during a relatively short, intense episode of volcanism that was not accompanied by extensive basement deformation.

Intrusive bodies of white hornblende, biotite, and hornblende-biotite felsite (rhyolite, trachyte, dacite) cut the lower and middle Wrangell units. They range from single dykes less than a metre thick to dome-shaped plutons more than 3 km across. Stream-rounded clasts of similar felsite occur in conglomerates associated with air fall pumice interlayered with lavas in the middle unit, suggesting a genetic relationship between the extrusive and intrusive felsic rocks.

Contacts between the felsic intrusions and Wrangell Lavas are commonly sharp. Intrusive breccia usually forms the outer few feet of the felsite bodies and both the breccia and adjacent few feet of enclosing lava are bleached, silicified and locally pyritized. An exception is found in the large felsite mass west of

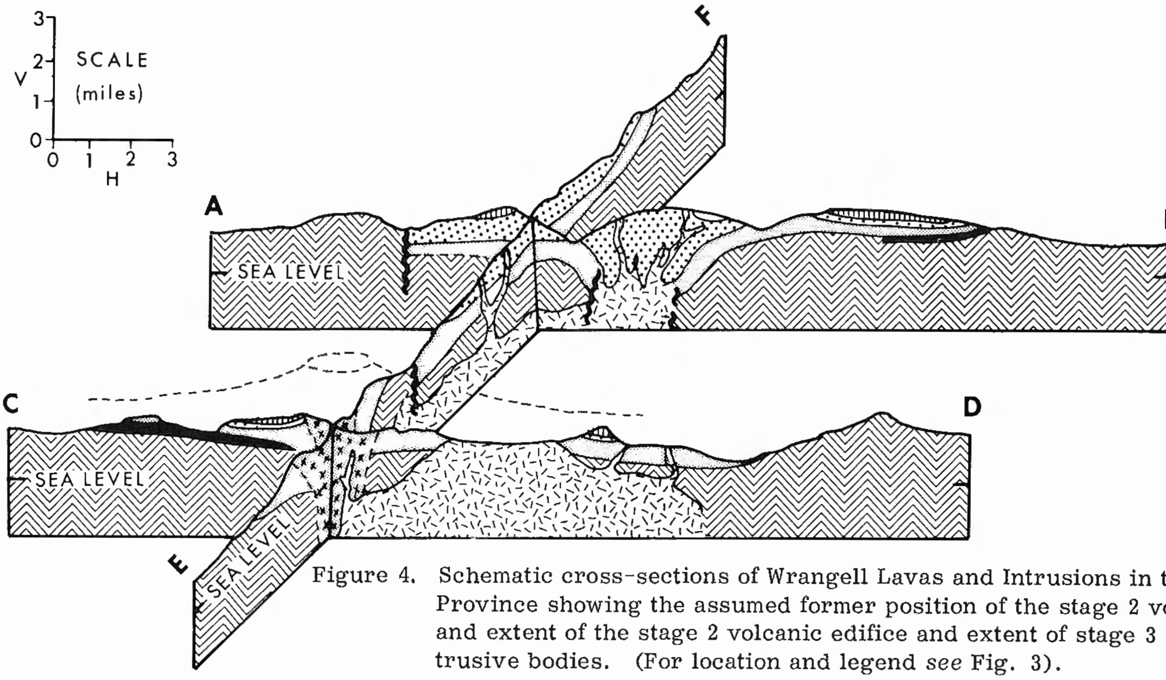

Figure 4. Schematic cross-sections of Wrangell Lavas and Intrusions in the central Alsek Province showing the assumed former position of the stage 2 volcanic edifice and extent of the stage 2 volcanic edifice and extent of stage 3 sub-volcanic intrusive bodies. (For location and legend *see* Fig. 3).

Brabazon Glacier. There, the entire mass appears to have been brecciated, cut by an anastomosing swarm of felsic and basic dykes and intensely hydrothermally altered. Similar hydrothermal alteration has produced a halo in gently dipping Wrangell Lavas. In this alteration halo, which is up to 2 miles across, the lavas and interlayered scoria are bleached and silicified, porous layers of scoria have been attacked preferentially, commonly leaving the cores of thick flows as boudin-like masses, suspended within the highly altered zone. The breccias and surrounding alteration zone are believed to be manifestations of a major felsic volcanic centre that gave rise to a large hydrothermal system circulating through the porous felsic breccias and interflow scoria of the enclosing Wrangell Lavas.

Structures in the northwestern part of the St. Clare Volcanic Province are illustrated schematically in Figures 1 and 2. The structural style changes across the belt from southwest to northeast and along it from southeast to northwest. In the southern part of the area, adjacent to Steele Glacier, the entire section is nearly flat lying (Fig. 5). A few miles farther north, between Steele Glacier and St. Clare Creek, the flat-lying strata turn abruptly down along an en echelon series of north-facing homoclines beyond which the rocks are complexly folded. The intensity of folding increases northward, culminating in a southerly overturned anticline-syncline pair along St. Clare Creek (Fig. 6). The flat northerly limb of this overturned structure is truncated by a nearly vertical fault along which slices of basement are exposed. Strata north of the fault are compressed into a narrow zone of nearly isoclinal folds which terminate northward in a broad, gentle syncline south of Wolverine Creek.

The intense folding developed in upper Cement Creek and St. Clare valleys trends west-northwesterly into more open folds. Near Klutlan Glacier folds pass into reverse faults and north of Klutlan Glacier the principal structure is a south-southwesterly dipping thrust fault along which Permian and older rocks have overridden several thousand feet of Wrangell strata.

Despite the intensity of deformation the lavas and interlayers of clastic and pyroclastic rocks exhibit only minor internal disruption. Thick columnar lavas, thin layers of ash, and poorly consolidated beds of conglomerate maintain their thickness and continuity even around the complex overturned folds of the St. Clare Creek valley. The clastic layers exhibit no internal deformation. Lavas commonly have an imbricate fracture system superimposed on the original jointing. Fracture spacing is seldom less than 10-15 cm and the amount of movement on each fracture is in the order of a millimetre. Slickensides are extremely rare.

The Alsek Province

The Alsek Province includes three principal piles of eruptive rocks and numerous small isolated flow remnants and subvolcanic intrusions. The two largest areas, one on either side of Dusty River, are illustrated schematically in Figures 3 and 4. A third area 3 miles east of Alsek River (Kindle, 1953), has a similar sequence of rocks and is considered to be part of the same volcanic complex.

Although the Tertiary rocks of Alsek Province are locally tilted and faulted, they have not undergone the extensive post-volcanic deformation observed in the St. Clare Province. Conversely, the sequence of eruptive events is extremely complex, involving at least four distinct pulses of volcanicity.

The pre-volcanic surface is mantled by a discontinuous veneer of Tertiary sediments, comprising sandstone, quartz pebble conglomerate, carbonaceous shale and thin coal seams. These are overlain by the products of a rhyolitic eruption (Phase 1) that spread

Figure 5. Escarpment of flat-lying Wrangell Lavas on the north side of Steele Glacier. Approximately 5,000 feet of strata are exposed.

Figure 6. View southeast up the valley of St. Clare Creek showing folded Wrangell strata in the intensely deformed central part of the St. Clare Province. Nearly flat-lying lavas and interlayered clastic rocks on the high peaks at left form the upper limb of an overturned anticline.

pyroclastic debris over the entire region. The activity is believed to have centred east of Alsek River where rhyolite flows form the basal member of the pile. Farther northeast, on the east side of Dusty River, the basal unit is a thick welded ash flow (Souther, 1974, p. 40, Sec. 2) and still farther northeast, on Chalcedony and Hoodoo mountains, thin basal ash flows and pumice beds are probably distal equivalents of the same eruption. The initial burst of rhyolite was followed by construction of a very large composite basalt cone with a vent complex (Figs. 3 and 4) on the east side of Dusty River. There, explosion breccias riddled with dykes and small irregular cupolas occupy an elliptical, pipe-like structure that is considered to be the principal Phase 2 vent.

Phase 3 activity involved the eruption of a high volume of felsic pyroclastic rocks from a series of vents west of Dusty River, near Felsite Creek. Eruption was accompanied by collapse and partial destruction of the portion of the Stage 2 basaltic cone that lay west of Dusty River where the originally flat-lying Stage 2 basalts bend steeply down beneath the pile of felsic breccias. East of Dusty River a large subvolcanic mass was emplaced beneath the Stage 2 pile, tilting the old volcanic edifice eastward and initiating a north-south fault along Dusty River valley. Thin, distal Phase 3 ash flows and air fall pumice are widespread both north and south of the Felsite Creek centre. They are commonly preserved beneath relatively thin caps of Phase 4 basaltic andesite.

During Phase 4, basaltic andesite lava issued from small central vents, several of which are preserved as circular necks north of Felsite Creek. The flows are thin and uniform - indicative of a mobile, highly fluid lava whose remnants defined the upper surface of the Stage 3 felsite mass. On the ridges facing Felsite Creek where the Phase 2 basalt are bent down beneath the thickening felsite pile, the Phase 4 lavas follow the convex upper surface of the felsite pile.

Of particular interest is the central Phase 2 vent which was the locus of intense hydrothermal activity. Preliminary investigation indicates a zonal distribution of rock alteration centred around the vent breccia. An elliptical zone of quartz epidote alteration is surrounded successively by zones of silicification, silicification plus carbonatization, and an outer zone of chloritization. In the most intensely altered parts of the pipe, the matrix of the breccia consists entirely of hydrothermal minerals.

Rocks in the alteration zone contain numerous quartz veins which also show a zonal distribution with respect to the centre. Fifty-three veins varying from a few centimetres to more than one metre thick were counted on one traverse from the periphery to the centre of the breccia pipe. Monozonal veins predominate in the peripheral part, quartz calcite veins in the intermediate part and polyzonal quartz-calcite-epidote veins with sulphides in the central part. Part of the alteration and veining may have been produced during the waning stages of Phase 2 basaltic volcanism, but the Phase 2 breccia pipe has also acted as a porous medium for circulation of hydrothermal fluids related to the underlying Phase 3 subvolcanic intrusion. Localization of some veins along the margins of Phase 3 felsic dykes indicates that some veining took place after or during Phase 3 activity.

Geochemical analyses of samples taken at random from five veins are shown in Table 1. Although some of these contain only traces of valuable metals the presence in two of them of significant silver and copper justifies further study and indicates clearly that Tertiary volcanic rocks in the northern Cordillera may be of economic interest. The writers are preparing a more comprehensive description of this alteration zone.

Table 1. Geochemical analyses of 5 veins from alteration zone east of Dusty River. (All results are in parts per million.)

Sample No.	Au	Ag	Cu	Pb	Zn	Mo
1	.13	.5	19	16	23	12
2	.09	.6	117	18	17	8
3	.01	18.5	5400	640	88	13
4	ND	.6	14	164	63	140
5	ND	134.0	76000	7500	2800	450

Determination by Acme Analytical Laboratories Ltd.

A.A.P.E. 305
with background correction for Au and Ag

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17. BEDROCK GEOCHEMISTRY IN THE IMMEDIATE VICINITY OF ORE DEPOSITS: ELDORADO; PINE POINT; FARO

Project 740077

R.J. Allan
Resource Geophysics and Geochemistry Division

During 1974, a project was initiated to study the geochemical characteristics of bedrock in the immediate vicinity of different ore deposit types. Trace and major element variations found in host rocks and related to classical primary dispersion processes, are likely to be found near only a few deposit types. However, this project will not be limited only to such deposits. The basic objectives are: (1) to characterize geochemical patterns, which could exist due to a variety of genetic pathways, in the bedrock around deposits; and (2) to use this information to develop criteria to: (a) assist in the detection of deeply buried ore deposits; and (b) reduce costs of underground exploration.

The ability of geochemical sampling of surface materials, i.e., rocks, soils, tills, etc. to locate "blind" ore zones has always been of importance. In the future this will be even more significant. Firstly, this will be due to the escalating use of routine, surficial, geochemical surveys. At present, such surveys normally expect to locate only outcropping or sub-outcropping ore zones. Secondly, discovery of ore zones in known mining camp areas will become more difficult as the more easily located deposits are mined out. Analyses of apparently barren drill core from operating mines and proven mining camp areas could result in an estimate of direction and distance to previously undetected mineralization. This could lead to new discoveries and significantly reduce drilling costs of proving reserves.

Examples of previous studies of primary dispersion phenomena are seldom comprehensive. In the Soviet Union, the scale of investigation thought to be necessary is seen in the four year study of the Lovely Gold deposit in Transbaikalia. Here, 57,000 samples of drill core were analyzed for 23 elements. New gold deposits at depths of up to 1,000 feet were located by soil and surface outcrop sampling which intersected the primary dispersion patterns (pers. comm. V.N. Chumakin). A second Soviet example is the primary dispersion study around the Kanimansur deposit in Middle Asia. This work, which was carried out by I.M.G.R.E., is described by Ovchinikov and Gregoryan (1970). Anomalies for Ba, Ag, As and Sb form halos around the near surface levels of this steeply dipping polymetallic orebody. The lower levels of the deposit have halos of Co, Cu and Bi. The cobalt anomaly has a width of about 400 feet. These above case histories have been published and are available in the west. However, it is obvious that the 1970 publication on the deposit at Kanimansur meant that the study took place some years before. The inference is that Soviet results which are available in the west, are often years out of date. A recently published symposium volume on the subject is now available in the west (Polikarpochkin, 1971). In the west, it is possible that companies have carried out studies of primary halos at the scale of sampling and analysis used in the U.S.S.R., and have kept the results confidential. Based on the response to enquiries for drill core, this would not seem to be the case. In the western literature, many papers have been published on aspects of primary dispersion. These include papers on mercury or chlorine halos, on major element ratios (Boyle, 1974), on albitization aureoles, or on dispersion of the ore elements (Whitehead and Govett, 1974). Other than these, two papers in the western literature approach the scale of a Soviet primary dispersion characterization. One is from Sweden (Nairis, 1970) and one from Australia (Smith and Walker, 1971). In the former study, 241 samples from seven drill holes were analyzed for 17 elements. Complex aureoles of Cu, Zn, Pb, As, Ag, Mo and Bi were shown to exist around the epigenetic, predominantly copper-sulphide, ore deposit. The main conclusion was that the dispersion existed but was far more complex than the Russian models would lead one to believe. The latter, a larger study, was of the Mount Isa orebodies of Australia. In this case, some 1,100 drill core samples were analyzed for 21 elements. Of the two ore zones investigated, primary dispersion patterns were discovered around the copper ore but not the Pb-Zn-Ag ore. The inference was that the former was epigenetic and the latter syngenetic in origin. Other western studies of a smaller scale but very significant are the dispersion around silver veins (Dass *et al.*, 1972) and the detection of silver deposits at depth by soil sampling (Gott and Botbol, 1972). In the latter case, soils intersect a tellurium halo associated with blind ore in the Coeur d'Alene district. Two further papers will appear in the Proceedings of the 5th International Geochemical Exploration Symposium held in April, 1974, in Vancouver. One example is in Africa (Colvine, 1974) and one in Canada (Goodfellow, 1974).

To initiate systematic comprehensive studies of bedrock geochemistry in the immediate vicinity of various Canadian ore deposit types requires access to drill core for analyses. Such core is already available at nearly all operating mines and several mining companies were asked to donate suitable core. With one exception, the response was excellent and a wide variety of deposits were offered for study. Three mines were selected: (1) The Eldorado uranium mine in northern Saskatchewan; (2) the Pine Point lead-zinc mine in the Northwest Territories; and (3) the Faro lead-zinc mine in the Yukon. Various opinions exist as to the genesis of these ores but they can be broadly referred to as vein type uranium; Mississippi Valley type lead-zinc; and volcanogenic-sedimentary type lead-zinc respectively. The first is the most likely to show effects of classical primary dispersion. However, metal variations in the bedrock adjacent to all three may possibly show geochemical patterns related to: (1) emplacement or origin of the ore; and/or (2) more recent events such as metamorphism.

A total of 2,164 samples was collected from the three locations. These samples represent a total drill core footage of 25,000 feet. Even at the minimum estimate of $10 per foot (cost) for drilling at these northern locations, it is obvious that the cost of obtaining such samples from other than operating mines, would be prohibitive.

The samples will be analyzed for a variety of major and minor elements, by both total content and by partial leach methods. The latter will be used to separate those elements present in the form of sulphides.

This program could continue with further sampling of the deposits described above or by extension to other ore deposits of different types or of the same type but formed at different geological times. The response from industry indicates that the availability of drill core would not be a limiting factor. It is hoped that via co-operation between government and industry on this project, that a data bank could eventually emerge, of the geochemical characteristics of barren bedrock adjacent to ore grade mineralization. This basic information could prove of immediate value in underground exploration at the operating mines concerned, and in the future extend the usefulness of routine geochemical surveys when the search for ore becomes a truly three-dimensional problem.

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18. REGIONAL SURVEYS (LAKE SEDIMENTS)

Project 740079

E.W.H. Hornbrook
Resource Geophysics and Geochemistry Division

The Geological Survey of Canada in collaboration with the Saskatchewan Department of Mineral Resources, Saskatchewan Geological Survey, through liaison with L.S. Beck, Assistant Director, is carrying out a regional lake sediment survey in Saskatchewan under the terms of an agreement between Canada and the Province of Saskatchewan. This project is the Canada-Saskatchewan Mineral Exploration and Development Program, Project 6-1, Reconnaissance Geoscience Surveys (Lake Sediment Survey). The project is planned by, and is under the direction of, the Geological Survey of Canada and the results will be compiled by that organization.

The survey area is approximately 21,000 square miles. It is composed of that portion of the Canadian Shield lying south of lat. 57°00'N and between the Saskatchewan-Manitoba border on the east and the southern end of the Wollaston Belt on the west.

Centre-lake bottom, organic-rich sediment samples were collected by means of a specially designed lake sediment sampler and a Bell Jet Ranger helicopter at a density of one sample per five square miles throughout the survey area. Samples (including duplicate samples) were collected at approximately 4100 sample sites. The firm of Trigg, Woollett & Associates carried out field collection of samples, in only 32 working days, utilizing operational procedures established by the Geological Survey. A total of approximately 286 hours of flying time were used to collect samples at an approximate rate of 15 samples per hour. Approximate collection costs are $30.00 per sample site or $5.00 per square mile.

Samples are being dried, sieved and prepared by project staff at La Ronge, Saskatchewan.

Analysis of the samples for 12 elements (Cu, Pb, Zn, Co, Ni, Ag, Mn, Fe, U, As, Hg and Mo) are being carried out by Barringer Research Limited. Loss on ignition data will be obtained by project staff in Geological Survey laboratories in Ottawa, Ontario.

Field recorded and analytical data on specially designed computer cards are constantly monitored throughout the survey by computer programs, some of which have been specially developed to meet the monitoring requirements and data reduction and plotting.

J.J. Lynch is responsible for the analytical aspects of the project and R.G. Garrett for computer programming.

19. IN SITU METER FOR MEASURING RELATIVE PERMITTIVITY OF SOILS

Project 630049

J.L. Davis[1] and W.J. Chudobiak[2]

Introduction

The Geological Survey of Canada in co-operation with the Communications Research Centre has been doing research on field techniques for measuring, at high frequencies, the electrical properties of geologic materials (Chudobiak, *et al.*, in press). This work is being conducted in support of the development of a UHF non-contacting technique for measuring the moisture content of soils to a depth of one metre. Before proceeding with the development of such a sensor, it is necessary to confirm that there is a strong relationship between soil moisture content and the soil permittivity (Nikodem, 1966; Hoekstra and Delaney, 1974) and further, to obtain detailed knowledge as to the typical vertical distribution of moisture content in the top metre of the soil. This note describes the successful application of a wide-band time-domain reflectometer and a balanced parallel transmission line technique to these problems.

Principal of Operation

A wide-band time-domain reflectometer (WB TDR) consists of a pulse generator which produces a fast rise time step, a sampler which transforms a high frequency signal into a lower frequency output, and an oscilloscope or any other display or recording instrument as shown in Figure 1a.

The pulse from the step generator travels along the coaxial line until it reaches the point A. The sampler detects and the oscilloscope displays the voltage step A as it travels past point A. The coaxial line which transmits the pulse has a characteristic impedance Z_o of 50 ohms. Whenever there is a discontinuity in this line, a fraction of the wave is reflected back towards the source. Therefore, at the interface of the 50 ohm coaxial line with the parallel transmission line of impedance Z_1 (point B) part of the step pulse is reflected and passes point A again, producing an additional signal B which is displayed on the oscilloscope. An example of a WB TDR record is shown in Figure 1b. The remainder of the wave, which is not reflected at B, travels to C. If we terminate the line at C with an open circuit then all of the wave is reflected back in phase (assuming no losses due to radiation). Part of this pulse is reflected again at B and part of it goes through past A giving rise to another step C. The time between step B and C is the transit time from B to C and back to B again. Multiple reflections between B and C continue until all of the pulse energy is absorbed in the transmission line and the generator.

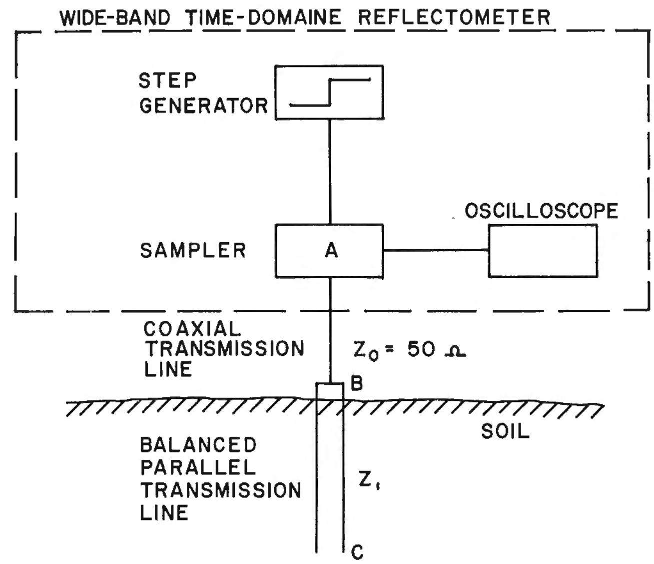


Figure 1a. Schematic diagram of a wide-band time-domain reflectometer, WB TDR, and a balanced parallel transmission line.

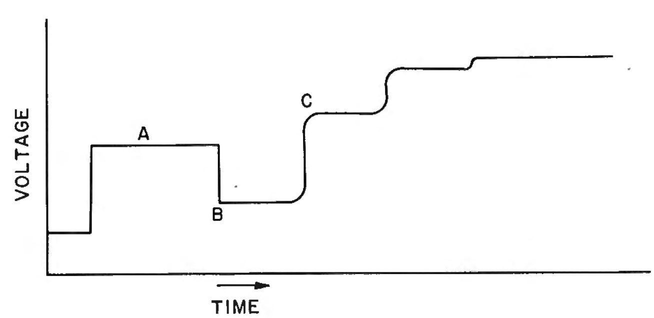
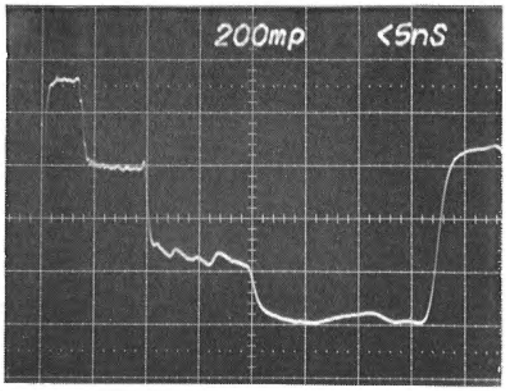


Figure 1b. A WB TDR record from a transmission line filled with soil.

A measure of the transit time between reflecting points such as B and C on a transmission line of known length ℓ may be used to calculate the permittivity of the dielectric in the transmission line. From electro-

[1]Resource Geophysics and Geochemistry Division.

[2]Communications Research Centre, Ottawa.



LENGTH, ℓ (m)	0.33	0.32	0.32
TIME, t (ns)	2.6	6.0	9.9
MOISTURE (percent by weight)	1	8	21
RELATIVE PERMITTIVITY, ϵ_r	2.8	7.9	21.7

Figure 2. A WB TDR record showing the different travel times in three similar lengths of coaxial transmission line each filled with sand having different moisture contents.

magnetic theory the return time, t, of a uniform plane wave in a transmission line is

$$t = \frac{2\ell}{v} = 2\ell(\mu\varepsilon)^{1/2} \quad (1)$$

where

- ℓ is the length of the line
- v is the velocity of propagation
- μ is the magnetic permeability = $\mu_r\mu_o$
- μ_r is the relative permeabitity (= 1 for non-magnetic materials)
- μ_o is the free space permeability = $4\pi \times 10^{-7}$ Hm^{-1}
- ε is the permittivity = $\varepsilon_r\varepsilon_o$
- ε_r is the relative permittivity and
- ε_o is the free space permittivity = 8.854×10^{-12} Fm^{-1}

(Ramo *et al.*, 1965). Simplifying, in non-magnetic materials, the relative permittivity is given by

$$\varepsilon_r = \left[\frac{15\ t}{\ell}\right]^2 \quad (2)$$

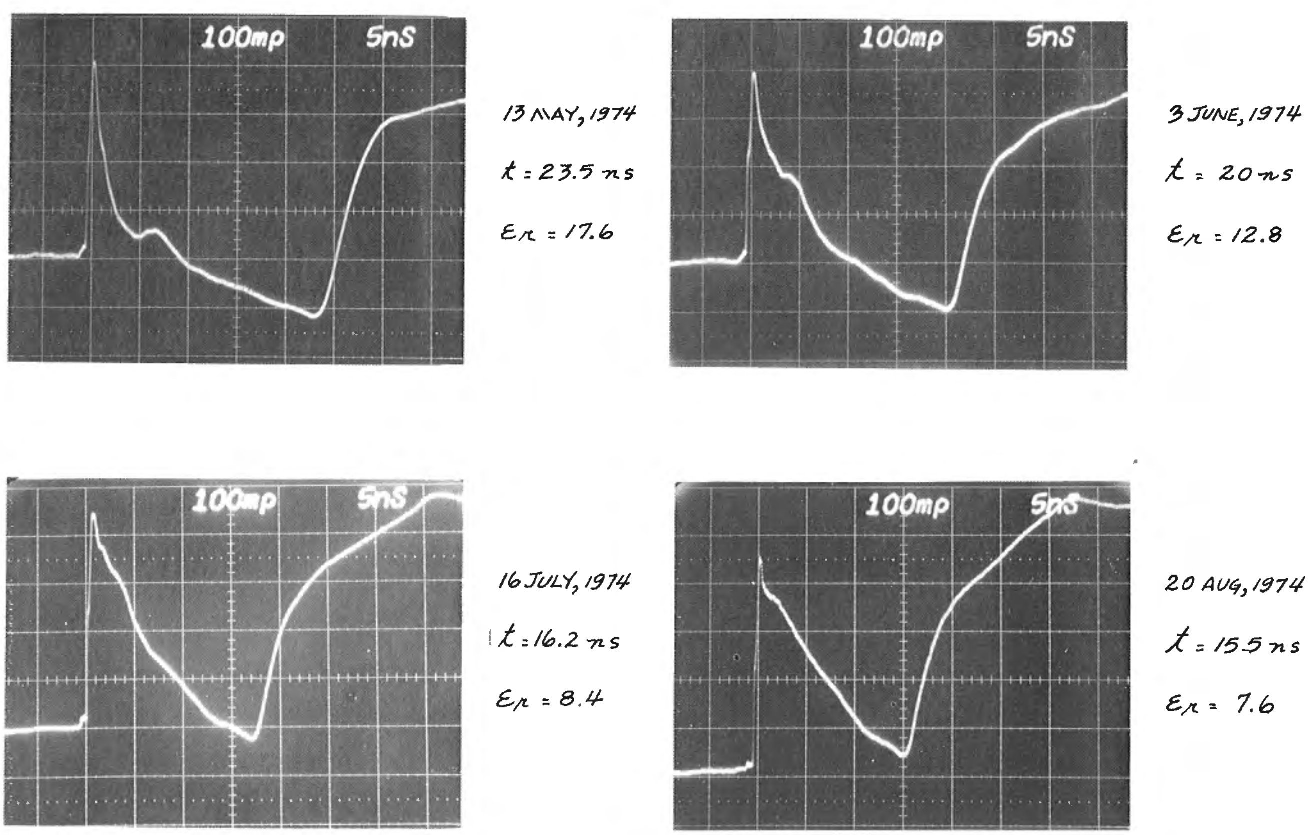


Figure 3. WB TDR records of in situ measurements taken over a period of four months using a balanced parallel transmission line located in soil.

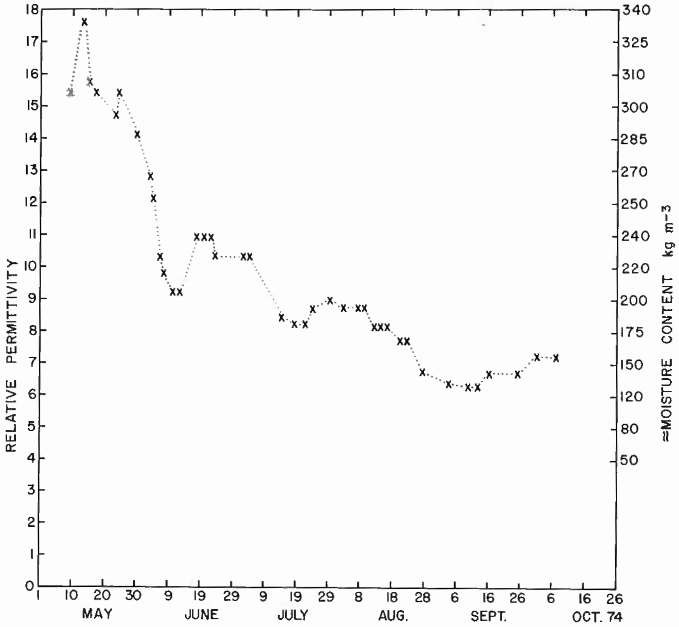


Figure 4. Variation of relative permittivity and soil moisture with time.

where t is in nanoseconds, ℓ in 10^{-2}m, and ε_r is simply determined by measuring t, the two-way travel time, of a wave in a known length of line, ℓ.

Figure 2 is a WB TDR record showing the different travel times in three similar lengths of coaxial transmission line filled with sand having different moisture contents. As the moisture content increases the two-way travel time increases and therefore, the permittivity increases.

The size of the transmission lines should be made as large as possible so that the measurements are representative of the bulk property of soils. The maximum dimensions of the transmission lines is limited by the value at which modes other than TEM occur. In coaxial lines higher order modes are present when the wavelength in the sample, λ_s, is

$$\lambda_s \leq 2\pi (r_o + r_i)$$

where

r_o is the inner radius of the outer conductor and
r_i is the outer radius of the inner conductor.

In parallel transmission lines higher order modes occur when

$$\lambda_s \leq 10D$$

where D is the spacing between the centre of the parallel rods.

For laboratory measurements of relative permittivity, it is convenient to fill coaxial transmission lines with soils that are to be tested, whereas in the field it would be difficult to insert a coaxial line in the ground and thus, a parallel transmission line is better suited.

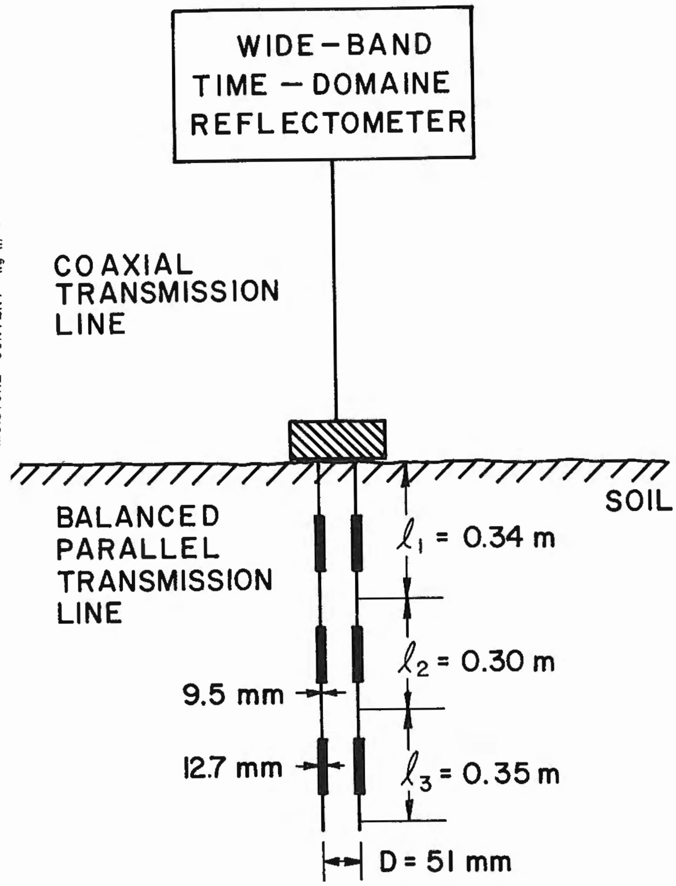


Figure 5a. Parallel transmission line using rods each with two different cross-sectional diameters.

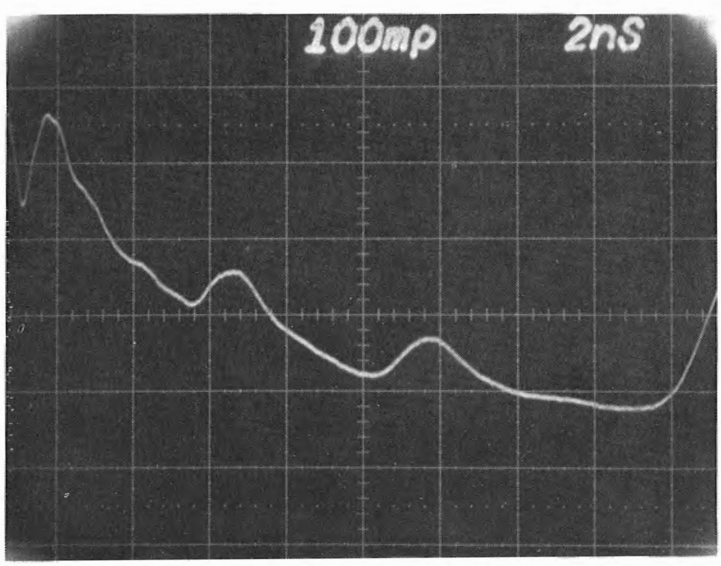
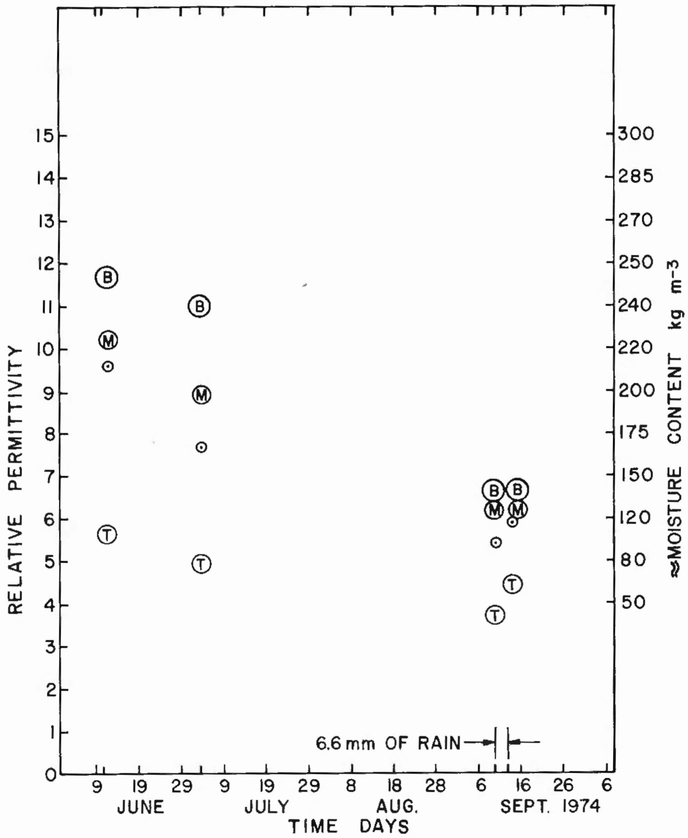


Figure 5b. A WB TDR record of an in situ measurement using a transmission line as shown in Figure 5a. The positive bumps occur where the rod diameters are smaller.



O - surface to 0.99 m depth
T - surface to 0.34 m depth
M - 0.34 m to 0.64 m depth
B - 0.64 m to 0.99 m depth

Note the increase in soil moisture within the top 0.34 m after a rainfall of 6.6 mm.

Figure 6. Variation of relative permittivity and soil moisture with time and depth.

Experimentally, we have determined that the material between the parallel rods affects mainly the impedance of the line and the time of travel of the signal in the line. Material a distance of about 2D from the line has a negligible effect on the electrical characteristics of the line.

Laboratory Measurements

Laboratory measurements of the relative permittivity of a sand and a clay at different moisture contents have been made using a coaxial transmission line, having a characteristic impedance of 50 ohms in air and an outside diameter of 50 mm. The dielectric behaviour as a function of volumetric water content was similar for both soils, above 50 kg H_2O/m^3 of soil. The results agree well with those of Nikodem (1966) and Hoekstra and Delaney (1974).

As the temperature of the soils increases from +1°C to +40°C the permittivity increases by about 10 per cent. The permittivity values determined using the WB TDR technique agreed to within 10 per cent of values measured at specific known UHF frequencies. The results of this work will be reported in detail in a future paper.

Field Measurements

To insert the parallel transmission lines in the ground, holes the same diameter as the rods are drilled into the soil using a slow speed drill, about 600 RPM, and an auger bit on the end of a one metre extension rod. A jig is used to align the spacing between the holes and the direction of the holes. To date no difficulty has been experienced in placing the rods in soils with few or no rocks.

A number of balanced parallel transmission lines have been inserted into the soil outside the laboratory, at the Communications Research Centre (CRC) and left undisturbed for about half a year. It is expected that the only significant variables in this experiment are soil moisture and soil temperature.

The soil temperature probably does not vary by more than 20°C at a depth greater than 0.3 m below the surface and therefore, it should not affect the accuracy of the soil moisture calculations by more than about five per cent. The errors caused by changes in soil temperatures will be neglected for the present.

Figure 3 shows four WB TDR records over a period of about four months using a balanced parallel transmission line, 0.84 m long, located at CRC. The first discontinuity on the record is due to the reflection from the impedance mismatch at the connection of the coaxial line and the balanced transmission line in the soil. The next major discontinuity, approximately 15 to 25 ns later on the record, is due to the reflection from the open circuit at the end of the balanced line. The time necessary for the step to travel from the top of the soil to the open circuit and back to the top of the soil is measured and the average permittivity over the length of the transmission line is calculated using Equation 2.

Figure 4 shows the variation of relative permittivity and soil moisture with time. The soil moisture is estimated from the laboratory experiments mentioned above. Three independent soil moisture measurements were made by determining the weight of water in the soil and the soil density. These results agree to within 10 per cent with the estimates made from the laboratory measurements.

It is desirable to know the moisture content as a function of soil depth within the top metre because it is in this region that vegetation is supported and that large variations occur due to weathering.

Parallel rods each with two different sectional diameters as shown in Figure 5a were used to improve the depth resolution of the soil moisture measurements. The impedance of parallel transmission lines changes when the rod diameters are varied. Figure 5b shows an example of a WB TDR record with such a transmission line. The positive bumps occur where the rod diameters of the parallel line are smaller.

The variation of relative permittivity and volumetric soil moisture with time and soil depth, over lengths of 0.3 m is shown in Figure 6. Note how the permittivity of the top 0.3 m varies between September 10 and 13, 1974 after a rainfall of about 6 mm.

The permittivity variations due to layers in soils may be masked by the impedance variations in the variable diameter transmission line. Therefore, at each site, lines without rod diameter changes and lines with rod diameter changes are placed in the ground.

Conclusions

An in situ measure of the volumetric soil moisture can be obtained by using a wide-band time-domain reflectometer and a balanced parallel transmission line inserted vertically in the soil. The equipment can easily be installed and the soil moisture can be readily calculated in the field to an accuracy of about ten per cent at present. It is expected that this technique will be of use to agronomists and hydrologists. This technique will also be of use for obtaining the ground truth necessary for designing and calibrating remote terrain sensors.

Acknowledgments

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20. BOREHOLE LOGGING (ELECTRICAL)

Project 740091

A.V. Dyck
Resource Geophysics and Geochemistry Division

As fewer near-surface orebodies remain to be discovered it becomes increasingly necessary to direct exploration methods to greater depths. Subsurface borehole exploration with geophysical methods offers one such possibility. At the same time geophysical measurements in boreholes can increase the return per dollar spent on exploration drilling. As a result of revived interest in borehole geophysics the Geological Survey of Canada is co-operating with several members of the Canadian mining industry in a program undertaken to determine the state-of-the-art in borehole surveying for mining purposes and compare in principle the available methods. The co-operating companies are:

Cominco Limited,
International Nickel Company of Canada, Limited
Noranda Exploration Company, Limited,
Canex Placer Limited.

Borehole geophysical methods have, for many years, found extensive use for well logging in the exploration for petroleum, the main goal being subsurface geological mapping by making in situ measurements of the physical properties of the rocks in the immediate vicinity of the hole. In the exploration for mineral deposits the borehole measurement is more often a 'third-dimension' prospecting method in that the aim is to detect directly deposits which are not intersected by the borehole.

The program consists of three phases, the first of which is a survey of the literature. This has been completed by various members of the Resource Geophysics and Geochemistry Division, and the Earth Physics Branch. A preliminary report with bibliography has been compiled and covers the following borehole techniques: seismic, electrical, gravity, magnetic, nuclear, directional and thermal. The second phase consists of a field program to compare currently available instrumentation and interpretation techniques for the electromagnetic (EM), induced polarization (IP), and magnetic methods. The activities of the field program of 1974 form the subject of this report. The final phase of the co-operative program will hopefully result in suggestions for the improvement of borehole survey methods for mining purposes.

A vital part of this program is the establishment of a variety of suitable test sites. The suitability of a particular mineral deposit is determined by several criteria. The ideal test borehole is a 'near miss' of a massive or disseminated sulphide orebody. Enough must be known about the geometry and composition of the mineralization so that the exploration element is reasonably absent from the problem. The long term existence of the orebody as a test site must be assured, and is more likely if the body is sub-economic. The boreholes to be surveyed must be open to the required depth. This is less of a problem in competent rocks of the Precambrian than in younger ones. In addition the holder of the rights to the orebody must be willing to release a certain amount of information. As a result the list of suitable test sites which could be made available was severely restricted. During the months of June to September, 1974, the following sites were visited:

1. Gertrude property (INCO), near Creighton Mine, Sudbury, Ontario; massive sulphide deposit on norite contact of Sudbury basin, two holes;

2. Trillabelle property (INCO), near Worthington, Ontario; massive sulphide deposit on western rim of Sudbury basin, three holes;

3. Stemwinder deposit (COMINCO), near Sullivan Mine, Kimberley, British Columbia; massive sulphide, two holes;

4. J-A zone (BETHLEHEM COPPER), Highland Valley, British Columbia; porphyry copper, two holes. The holes range in length from 300 to 500 m and the mineralized zones are located at depths as great as 425 m.

Induced polarization equipment, three different electromagnetic systems and a three-component borehole magnetometer were available for the field tests. A brief description of each follows:

1. Time-domain induced polarization (GEOTERREX LTD). The main feature of this system is the multi-conductor downhole cable. Lead electrodes are located on the cable so as to allow expanding three-array (pole-dipole) and two-array (pole-pole) IP and resistivity measurements to be made at depth in the borehole. Normal surface time-domain equipment is used to perform the measurements. Information about direction to the orebody may be determined by the directional mode of surveying in which two uniform current fields are established at right angles to each other in the vicinity of the borehole (Wagg and Seigel, 1963).

2. MCPHAR SP-700 EM. This is fixed-separation (30 m) coaxial transmitter-receiver, borehole unit which measures in-phase and out-of-phase at two frequencies, 335 and 1340 Hz.

3. SCINTREX DHP-4. This system employs a large-loop transmitter on surface to establish a fairly uniform subsurface field, sinusoidal in nature. The field at the downhole receiver coil is compared to the field at a surface reference coil and amplitude ratio and phase difference are measured at a single frequency of 2000 Hz.

4. NORANDA DEHEM. Again a large-loop transmitter is employed but instead a square-wave field is radiated. Two samples at two different time delays are taken on the resulting pulse received by the downhole receiver coil. The system operates at 406 and 923 Hz.

5. HETONA HBM IV three-component, fluxgate magnetometer manufactured by ABEM, Sweden.

Only a portion of the field program was completed, due mainly to unexpected difficulties with equipment. In addition one of the test sites, the Stemwinder deposit proved to be unsuitable for making EM or IP measurements, the apparent reason being the existence of a network of interconnected pyrrhotite stringers throughout the host rock. Preliminary examination of the data which was collected indicated promising results. In several cases a known ore zone was detected from a 'near-miss' borehole. However, the summer's field work has not met entirely the objectives of the program. Although disappointing, it has exposed some of the problems associated with borehole geophysics which are faced today by the mining and geophysical industry in Canada.

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21. AUTOMATION IN ELECTRICAL ROCK PROPERTY MEASUREMENTS

Project 630049

C. Gauvreau and T.J. Katsube
Resource Geophysics and Geochemistry Division

Introduction

It has been planned that the Electrical Rock Property (E.R.P.) Laboratory is to make measurements and collect data to create a Handbook on Electrical Properties of Canadian Rocks. The frequency range for measurement is 10^{-2} to 2×10^{8} Hz. This is a wide frequency range, and the measurements require much work and time. This causes a problem when handling a large quantity of specimens, and in the maintaining of constant conditions for measurement. For this reason, the use of a minicomputer has been introduced to automate the measuring system for the frequency range from 1.0 to 10^{6} Hz for moist rocks. This is the frequency range of particular importance to exploration geophysics.

This paper gives an outline of the minicomputer system and the way in which it is applied to ERP measurements. It also discusses the measurement efficiency obtained by automation.

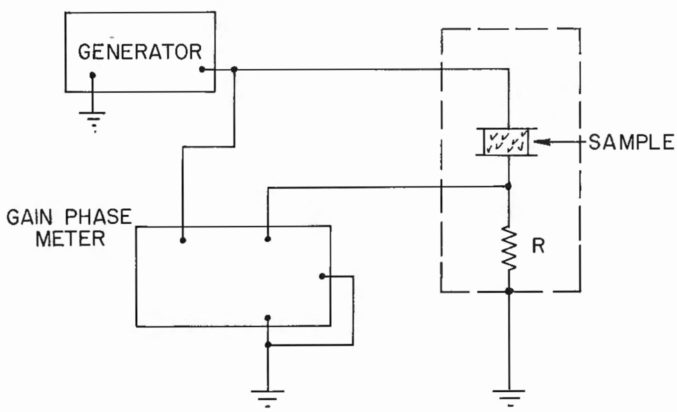


Figure 1. Basic circuit for electrical rock property measurements.

General Description of the System

Principle of Measurement

The basic circuit for electrical measurements of moist rocks is shown in Figure 1. The Gain-Phase Meter (HP 3575 A) is the main part of the measuring unit. It measures the output voltage of the generator (V), the voltage drop (v) across the resistor R, and the phase angle (θ) between V and v. Therefore, the resistance (R_s) and reactance (X_s) of the sample are determined from the following equations:

$$R_s = R\left[\frac{V\cos\theta}{v} - 1\right] \qquad \ldots\ldots (1)$$

$$X_s = \frac{R\,V\sin\theta}{v} \qquad \ldots\ldots (2)$$

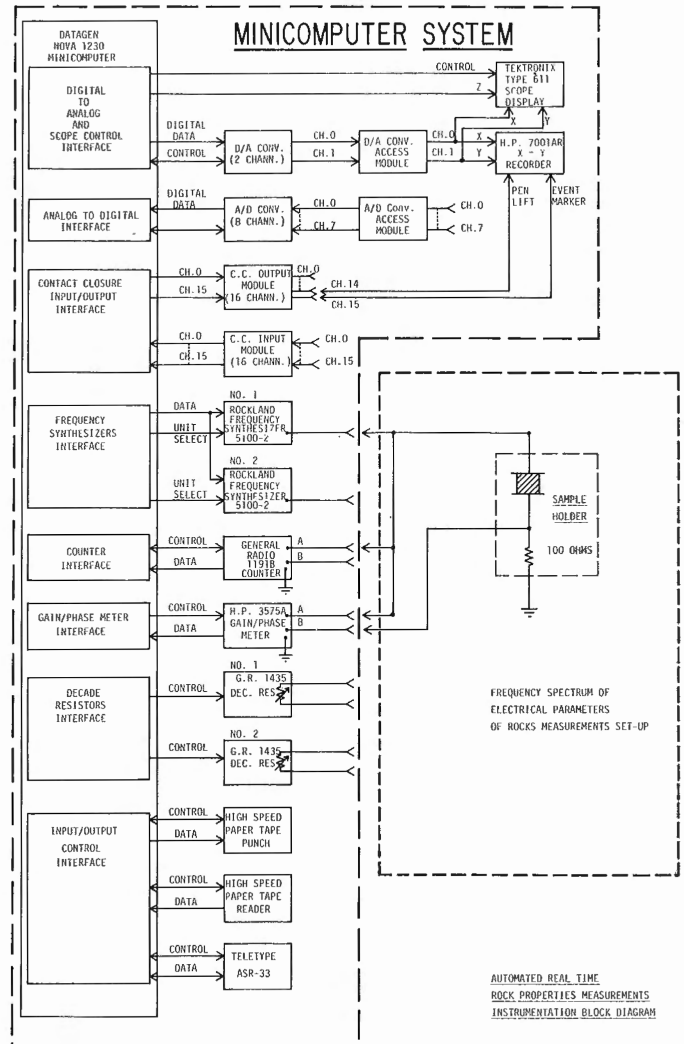


Figure 2. Block diagram of the automatic measuring system.

Since the actual measurements of V and v are in DBV terms, Equations 1 and 2 are replaced by,

$$R_s = R\left[10^{\frac{V-v}{20}}\cos\theta - 1\right] \qquad \ldots\ldots (3)$$

$$X_s = R \times 10^{\frac{V-v}{20}}\sin\theta \qquad \ldots\ldots (4)$$

Automatic System

The automatic system controls the measurement of V, v and θ, makes all necessary calculations, prints out the data in terms of all the parameters required, and plots the curves for some of the parameters (further details will be given later in this paper).

The automated system consists of a minicomputer with high-speed paper tape reader and punch, a teletype, programmable electronic equipment, and a holder for rock samples. Figure 2 shows the configuration for the application to the measurement which is described in Figure 1. The minicomputer system has been designed in such a way that all INPUT/OUTPUT functions and controls are available on the front panel. Due to this arrangement, not only the specific measurement, such as described in Figure 1 or above, but various types of ERP measurements and sample holder configuration can be carried out without modifications to the minicomputer system.

Minicomputer System

General

The automated system is designed and assembled so that the electrical rock property measuring system can be operated either in automatic mode under complete computer control or in manual mode for hand-on tests of different types and for cases of computer failure. The minicomputer controls, through its respective interface, each electronic instrument and function in this system.

Hardware Description

The electronic equipment which constitutes the automated system is listed below (also *see* Fig. 2):

a) Minicomputer: Datagen Canada Ltd. NOVA 1230
b) Contact closure outputs (16 channels)
c) Contact closure inputs (16 channels)
d) Digital to analog converter (2 channels)
e) Analog to digital converter (8 channels)
f) Scope display: Tektronix 611
g) X-Y recorder: HP 7001 AR
h) Frequency synthesizers: Rockland 5100-2
i) Frequency counter: GR 1191 B
j) Gain-phase meter: HP 3575 A
k) Decade resistor: GR 1435
l) Sample holder

Software

The software supplied with the minicomputer consists of assembly language utility programs and mathematical library, a Real-Time Operating System, a Stand-Alone Operating System, conversational extended BASIC, FORTRAN IV, and ALGOL. An assembly language diagnostic test program has been created for each instrument for fast trouble location in case of systems failure. All operational programs that have been created are written in Extended BASIC language.

Figure 3a

Example of the minicomputer printout of the 13 electrical parameters, and the plots of the frequency spectrum of complex resistivity (ρ*) and dissipation factor (D).

```
9 SEPT 74
SAMPLE NAME: SERPENTINITE
SAMPLE NUMBER: 2                    DATA NUMBER :1
C OUT:  3.15E-12                    K:  .045225
STARTING TIME: 14:09
```

FREQ.	SIGMAT	SIGMAR	SIGMAI
1	3.35171E-4	3.31124E-4	5.19317E-5
3	3.50994E-4	3.47982E-4	4.58848E-5
10	3.76142E-4	3.74341E-4	3.67633E-5
30	3.93902E-4	3.9284E-4	2.88884E-5
100	4.12501E-4	4.11896E-4	2.23109E-5
300	4.27026E-4	4.2655E-4	2.00399E-5
1000	4.42062E-4	4.41413E-4	2.35719E-5
3000	4.52378E-4	4.50509E-4	3.99377E-5
10000	4.96112E-4	4.90378E-4	7.13886E-5
30000	5.83067E-4	5.60644E-4	1.48681E-4
100000	7.69073E-4	6.88338E-4	3.04821E-4
300000	1.13854E-3	8.82488E-4	6.04771E-4
1E+6	2.44228E-3	1.61603E-3	1.44916E-3

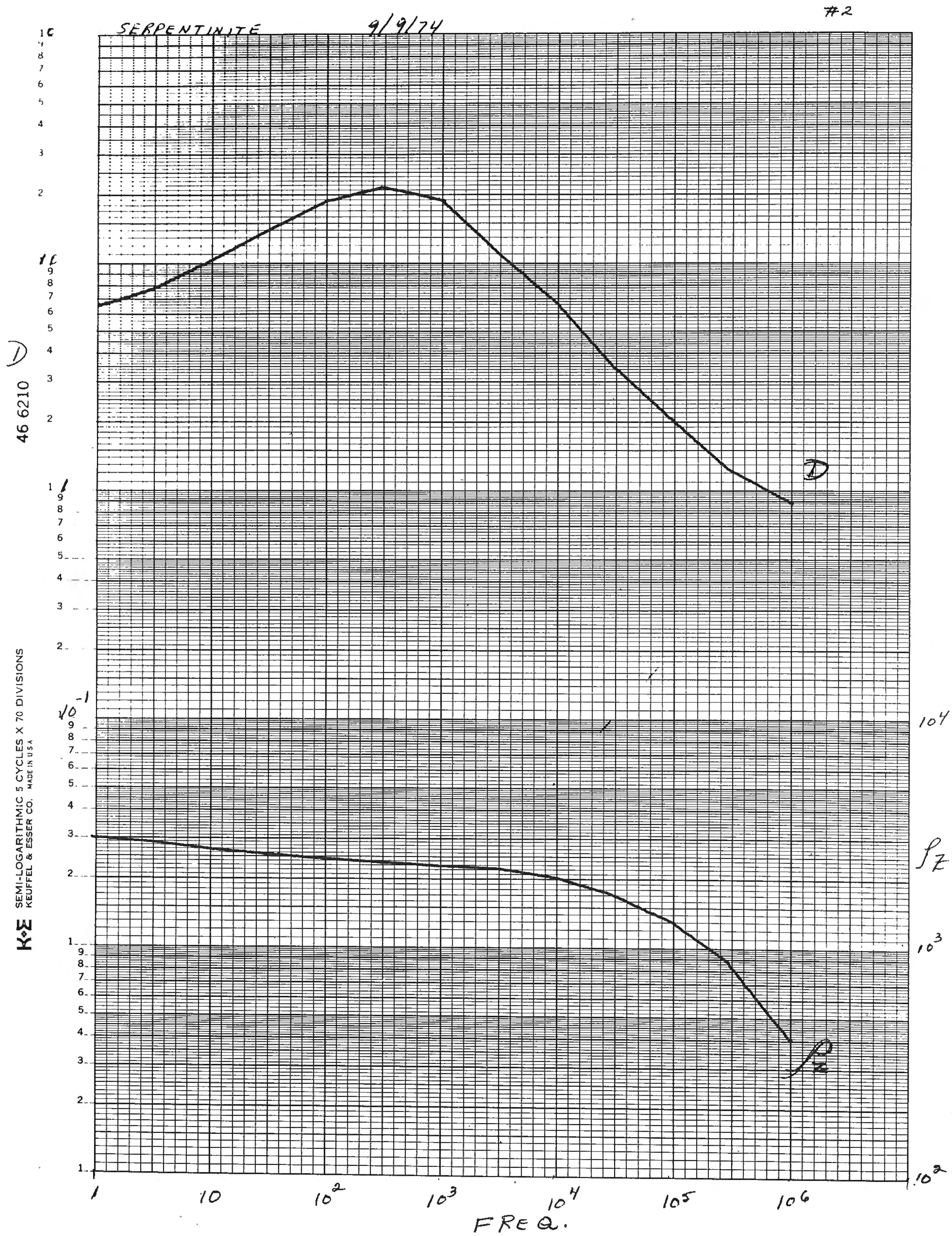
FREQ.	KT	KR	KI
1	6.02482E+6	933498	5.95207E+6
3	2.10304E+6	274934	2.085E+6
10	676064	66083.9	672827
30	235926	17309.5	235290
100	74022.5	4010.5	73913.7
300	25441.2	1200.76	25412.8
1000	7819.57	423.717	7808.08
3000	2634.96	239.3	2624.08
10000	846.49	128.325	836.707
30000	324.363	89.0875	311.889
100000	122.849	54.7932	109.953
300000	57.3518	36.2369	44.4535
1E+6	34.7429	26.0494	22.989

```
END OF RUN

XY-PLOT PARAMETERS
------------------

LOW PLOT= RHO Z
BOTTOM OF GRAPH EXPONENT OF 10= 2
HIGH PLOT= DISSIPATION
TOP OF GRAPH EXPONENT OF 10= 2
```

The electronic equipment is controlled by programs written in BASIC language which call up assembly language subroutines by a BASIC "CALL" statement. An assembly language subroutine has been written for each electronic test unit and external function which is controlled by the minicomputer. This CALL statement can also be used directly on the teletype for testing purposes.

Twenty-six assembly language subroutines, which are accessible to BASIC programs by the CALL statement, have been written to control and obtain data from all electronic test equipment and all functions of the system. Sixteen diagnostic test programs have been written in BASIC for each test equipment and function of the system. These programs test an instrument or function for all possible modes of operation

Figure 3b.



SERPENTINITE
9/9/74
#2
D
46 6210
SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
D
ρz
ρz
10^4
10^3
10^2
10^-1
1
10
10^2
10^3
10^4
10^5
10^6
FREQ.

and settings. All programs are kept on paper tape and are read in by the high speed paper tape reader as required. Results of experiments can be kept for future use by punching the data on paper tape. This tape can be read into the system again by the appropriate BASIC command.

Operation

After the BASIC operating programs are loaded into the minicomputer, it is possible to operate the automatic measuring system from the teletype. The command statements and necessary information enters the minicomputer via the teletype, and from there on the program in the minicomputer sends out the series of necessary command signals and information addressed to the appropriate equipment. The interface of the equipment picks up the commands and information which is addressed to it, and the equipment operates according to them. The types of commands and information which is sent out of the minicomputer is, for example, the voltage and frequency that the generator is to be adjusted to, type of measurements the gain-phase meter is to make, etc. After the requested data has been obtained and accumulated from the measuring equipment into the minocomputer, decisions for further operations are made according to the program.

Application of the System

The current program that controls the measuring system and makes the measurements which are described above operates according to the following procedure:

1. The minicomputer requests information from the operator on name and number of sample, date of measurement, geometric factor etc., through the teletype.

2. After the necessary information is obtained, the frequency synthesizer is adjusted to 10^3 Hz and maximum output voltage.

3. The gain-phase meter measures V and v.

4. The sample impedance at this frequency is calculated and printed out on the teletype. Then the output voltage of the frequency synthesizer is adjusted to transmit a current of 10^{-4} amperes across the sample.

5. The frequency synthesizer and gain-phase meter are adjusted and controlled to make measurements of V, v and θ at 13 different frequencies from 1.0 Hz to 10^6 Hz. The results of each measurement are stored in the memory.

6. From the data stored in the memory, 13 parameters are calculated for each frequency and printed out on the teletype.

7. The minicomputer plots the frequency spectrum of the absolute value of complex resistivity and dissipation factor on the X-Y recorder.

An example of the results is shown in Figure 3. The time required for going through the procedure is 20 minutes. Without the minicomputer this measurement (1.0 - 10^6 Hz) required about 4 hours. Use of the automated system not only reduces the time required for measurement by a factor of 12, but also enables the operator to carry out other work while the sample is being measured, besides increasing the measurement accuracy.

Conclusion

The automatic ERP measuring system consists of a minicomputer with high-speed paper tape reader and punch, teletype, a set of programmable electronic equipment and a sample holder unit. Impedance and phase are measured, 13 other electrical parameters are calculated from these two parameters and the results are printed out on the teletype and plotted on a X-Y recorder. This operation is all called out automatically by the minicomputer. This measurment procedure by the automated system requires 20 minutes, which is a reduction of about 12 times compared to the case when the minicomputer was not used. The automated system also enables the operator to carry out other work during measurement, which was not possible in the past. The automated system also increases the measurement accuracy.

Acknowledgments

Without the kind help and understanding of Mr. L. S. Collett, the minicomputer system could not have been installed. We thank Mr. J. Frechette for his work in the construction of this system.

22. URANIUM STRIPPING DETERMINATION AU NATUREL FOR AIRBORNE GAMMA-RAY SPECTROMETRY

Project 720084

R.L. Grasty
Resource Geophysics and Geochemistry Division

One of the problems in airborne gamma-ray spectrometry is in establishing the correction factor that has to be applied to the count rate observed in the uranium window for Compton scattered high energy radiation from thallium-208 in the thorium decay series. This high energy radiation may be scattered in the detectors, in the ground or in the air. The uranium Compton scattering correction factor or stripping ratio is the ratio of the number of counts observed in the uranium window from the thorium decay series to the number of counts detected in the thorium window.

Instrument manufacturers and survey operators have generally used prepared samples of thorium oxide to determine the uranium stripping ratio. However, the thorium spectrum from a small source is quite different from that obtained from a large source due to Compton scattering occurring in the source (Gregory and Horwood, 1961). For this reason large calibration slabs were constructed at Uplands airport, Ottawa, (Grasty and Darnley, 1971; Grasty and Charbonneau, 1974) which can be considered infinite in size for a detector close to their surface. The uranium stripping ratio calculated using these calibration slabs is the value which applies at ground level and will be larger at aircraft altitude due to Compton scattering in the air (Grasty, 1974). At the present time it has only been possible to calculate theoretically the increase in the ground-level value with aircraft altitude.

The count rate in the uranium window U (corrected only for background radiation) is related to the uranium count rate, U_c (corrected for background and Compton scattering) and the thorium count rate, T, (corrected for background) by the relation

$$U_c = U - \alpha T$$

where α is the uranium stripping ratio at the survey altitude.

i.e. $$\frac{U}{T} = \frac{U_c}{T} + \alpha$$

Provided a suitable area is chosen, a histogram of the ratio of the uncorrected uranium-to-thorium count rates will indicate a minimum value given by the stripping ratio α. This will occur when the uranium-to-thorium concentration in the ground is zero.

This technique was carried out on data from the Fort Smith area of the Northwest Territories (Darnley and Grasty, 1972) which is particularly suitable for this purpose due to its high thorium content. The ratios were calculated using a technique described by Grasty (1972) and a histogram of these ratios is plotted in Figure 1. It is apparent that there is a sharp cut-off in the uncorrected uranium-to-thorium ratio, at

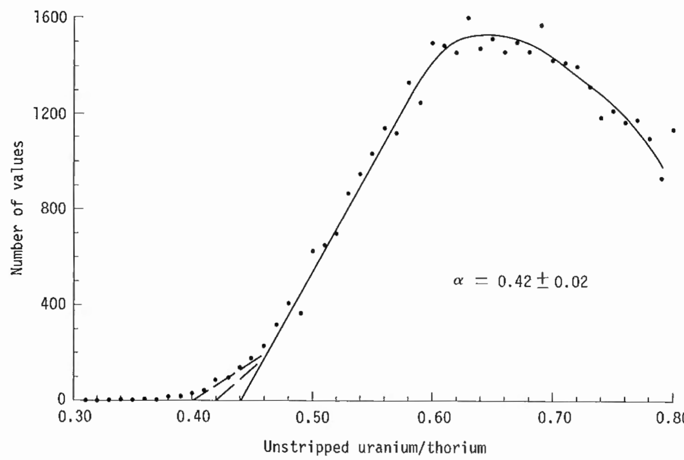


Figure 1. A histogram of the unstripped uranium-to-thorium ratios for the Fort Smith survey.

a value estimated to be 0.42 ± 0.02. The average of seven measurements of the uranium stripping ratio using the calibration pads, gave a value of 0.348 ± 0.015 (Grasty and Darnley, 1971). This increase between ground level and aircraft altitude of 0.07 ± 0.03 agrees with that calculated by Grasty (1974), substantiating the theoretical approach.

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Project 720005

G.D. Hobson and A. Overton
Resource Geophysics and Geochemistry Division

This project was continued in April-May 1974; the earlier work of 1972 and 1973 has been reported (Hobson, 1973, 1974; Hobson *et al.*, 1972).

Seismic refraction data were obtained over 20 profiles covering a distance of 146 miles (230 km) with gravity readings every 4,800 feet over the same profile. Crustal seismic data were not obtained in 1974 as in previous years. The seismic and gravity profile ties into the Sun Oil Lincoln Island borehole at the southwestern extremity of Amund Ringnes Island.

Analysis of the data is proceeding towards a definition of the architecture of the Sverdrup Basin this N-S direction.

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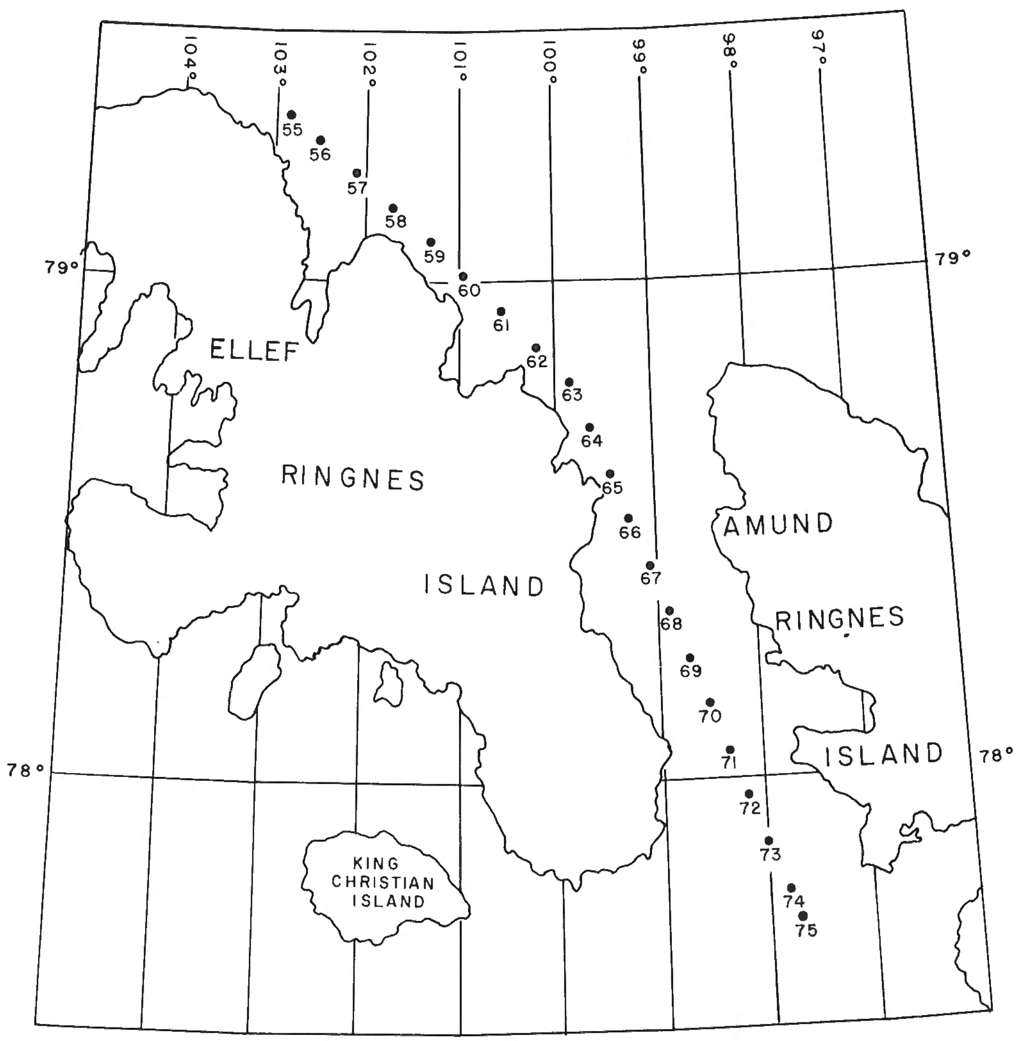

SVERDRUP BASIN 1974 PROJECT
• SHOT POINT LOCATIONS

NORTHERN BAFFIN BAY: LOW-LEVEL AEROMAGNETIC PROFILES OBTAINED IN 1974

Project 650007

Peter J. Hood and Margaret E. Bower
Resource Geophysics and Geochemistry Division

The co-operative aeromagnetic project with the National Aeronautical Establishment was continued during 1974 and survey operations were carried out in northern Baffin Bay during the period April 17 to May 2. The North Star aircraft of the National Aeronautical Establishment which is equipped with an inboard digital-recording cesium magnetometer system was used as the survey platform. The flight elevation was maintained at 300 metres (1,000 feet) above sea level along the survey profiles flown.

There were several objectives for the field operation. The first was to obtain reasonably detailed coverage of two areas of Smith Sound. The first detailed survey was located immediately west of Cape Parry in northwestern Greenland and the second area was in Smith Sound proper. The Cape Parry survey was undertaken to delineate better an interesting sedimentary feature that was apparent on sea magnetometer and seismic reflection records obtained by the Atlantic Geoscience Centre (Keen and Barrett, 1973). It was intended that the survey be carried out and the results be compiled prior to a marine geophysical survey being conducted by the CSS Hudson in northern Baffin Bay in order that the marine survey profiles could be positioned to obtain the most useful information. The aeromagnetic results were compiled by Margaret Bower immediately upon the return of the survey aircraft to Ottawa. The resultant profiles in map form (Fig. 1) were made available to the Atlantic Geoscience Centre in time for the marine operation in Smith Sound.

The second objective was to obtain additional profiles in between some of the lines previously flown in northern Baffin Bay (Hood and Bower, 1974) in order to complete an aeromagnetic reconnaissance at a thirty-mile line spacing in that area. The third objective was to further evaluate a computerized electronic navigation system which utilizes the Global Navigation System 200 VLF receiver and Doppler navigation systems. Comparison was made during the sorties of simultaneous hyperbolic and range-range calculations of position; it appears that the range-range mode gives the most accurate fixes. A new modification this year was a display for the navigator of track, groundspeed and distance and bearing to any one of eight predetermined waypoints, and position update at waypoints. This proved to be useful for flying patterns and parallel tracks for the offshore surveys.

The profiles obtained in the Smith Sound area and shown in Figure 1 have had the regional gradient removed. The profiles west of Cape Parry are spaced about 13 km (7 nautical miles) apart. The most prominent feature on the profiles is the U-shaped anomaly which appears to strike in a northwesterly direction between Northumberland Island and the Carey Islands. Similar anomalies have been observed in Lancaster Sound (Barrett, 1966), Melville Bay (Hood and Bower, 1970; 1973; Keen *et al.*, 1972; Manchester and Clarke, 1973; Ross and Henderson, 1973; Keen and Barrett, 1973), and Cumberland Sound (Hood and Bower, 1974). In all cases the causative body has been interpreted as a graben or half-graben and where subsequent geophysical investigations have been carried out this interpretation has been confirmed. Thus in the case of the present example, it would be logical to conclude that the feature is also a graben. However, from its asymetrical shape and the fact that high-frequency anomalies are evident on its north side, it would appear to be a sediment-filled half graben. Depth determinations carried out on the profiles using the sloping step model as the causative body gives values in excess of 20 km (greater than 60,000 feet) at the east end of the graben and calculated depths of about 10 km (30,000 feet) at longitude 76°W so that the graben becomes shallower to the west. The portion of the lines over Northumberland Island and the Carey Islands including that obtained on the turns which are not shown in Figure 1 show a high frequency component typical of the outcropping Precambrian Shield rocks which are known to occur there.

The magnetic data along the profiles west of Cape Parry have been contoured and the resultant total intensity map is shown in Figure 2. Included on the map are the 200- and 500-metre bathymetric contours which were obtained from Canadian Hydrographic Chart 800.

It is readily apparent from Figure 2 that a bathymetric low curves around Cape Parry and strikes into Inglefield Bay. The same bathymetric feature is readily apparent on the tectonic/geologic map of Greenland published by the Geological Survey of Greenland in 1970. However, the location of the graben, which would coincide approximately with the 57,000 gamma contour, does not correspond very well with the bathymetric low. Although an onshore graben-like feature is apparent on the tectonic/geological map of Greenland in the vicinity of Thule Air Base along strike from the inferred graben. The magnetic geophysical results obtained by the CSS. Hudson are described in a complementary field report by Ross and Falconer (this publication, report), so that the reader should refer to that report for additional geophysical information pertaining to the Smith Sound area.

In Smith Sound proper, some continuity is evident in the magnetic profiles (*see* Fig. 1) in a direction parallel to the main axis of Nares Strait. In general though, the profiles are typical of those over continental crust with the wavelength of the anomalies being mostly quite short.

Figure 3 shows the resultant profiles obtained along the three lines flown in northern Baffin Bay. A fourth profile was actually flown farther south but when plotted it transpired that the line had been flown very close to a previous line. The typical U-shaped anomaly is very apparent on Profile 74-1 across Melville Bay but on Profile 74-2, it would appear that the graben is much shallower and narrower. A U-shaped anomaly also appears on the east end of Profile 74-3 and there is some indication from the magnetic profiles that there may be an extension of the Melville Bay graben in a westerly direction around the coast of Greenland striking towards Smith Sound.

Not much correlation is evident in the magnetic profiles in the central part of the bay. Indeed there are portions of profiles which are relatively flat. Actually a number of earthquakes have occurred in Baffin Bay in recent times (*see* for instance Qamar, 1974) and so there is reason to believe that a major active fault or system of faults is present. In addition,

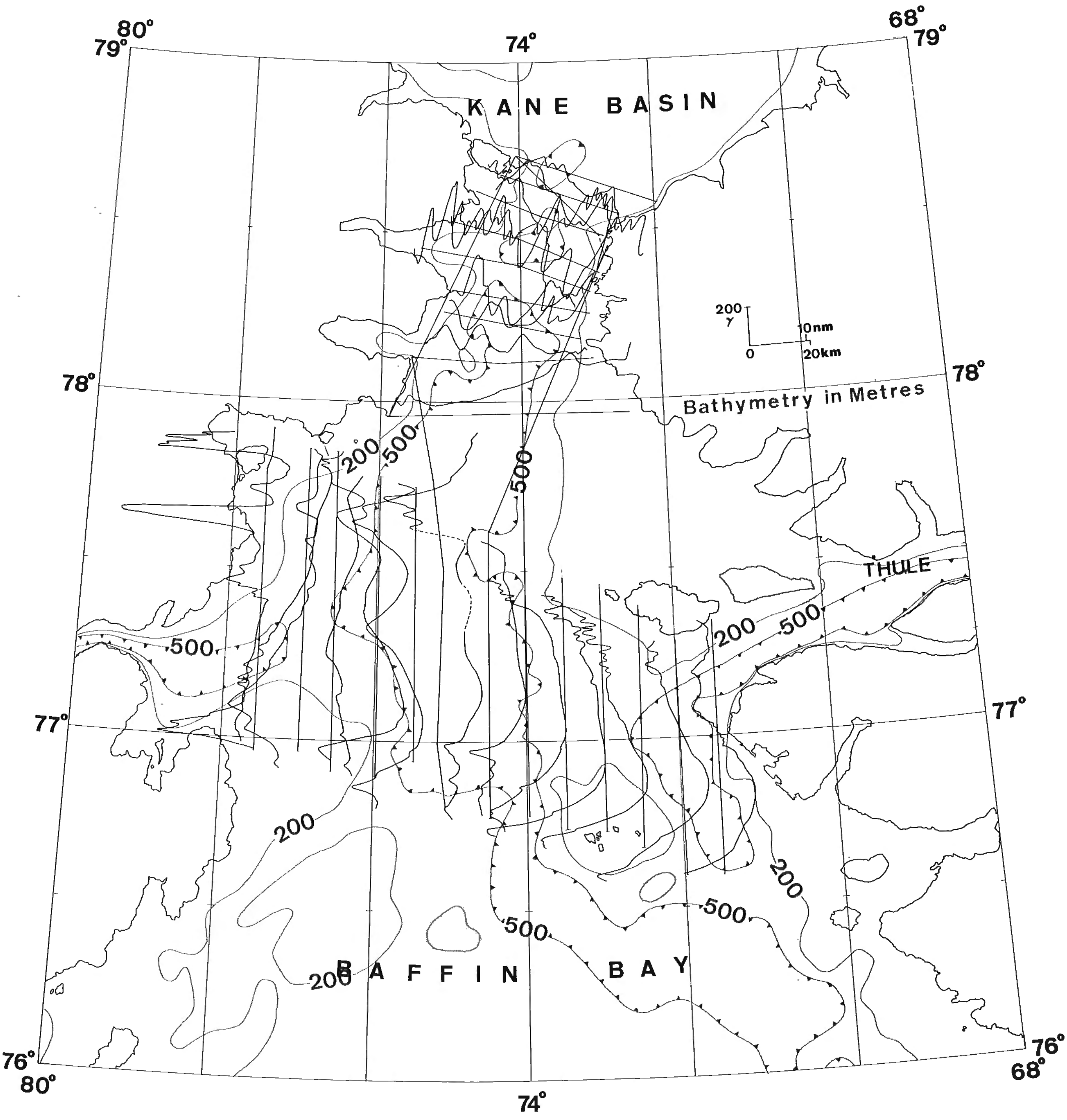

Figure 1. Aeromagnetic profiles obtained in the Smith Sound area during 1974.

Lancaster Sound is a graben and is therefore fault-bounded. The flatter areas on the profiles and indeed some individual anomalies appear to be correlatable in a westerly direction towards Lancaster Sound. It is well known from magnetic studies on land and on the transform faults which offset the mid-Atlantic Ridge that faults usually produce magnetically low areas presumably because the magnetic properties of the rocks close to the fault tend to be destroyed by tectonic movement. From the foregoing considerations, it is inferred that one or several major faults strike in a westerly direction from Lancaster Sound across Baffin Bay.

We wish to commend the performance of the Canadian Armed Forces crew in carrying out the low-level flying operation in this remote area of the high Arctic. Such airborne operations are quite hazardous and therefore require a well-trained aircrew and a maximum of navigational aids. For instance, the weather conditions were quite changeable during the survey and the aircraft had to divert to Sondrestrom on April 25 because of adverse weather conditions at Thule Air Base and remained there for 5 days waiting for the weather to change. The aircrew consisted of pilots Captain J.L. Kite and Captain W.T. Chevrier and navigators, Captain T.R. Brownley and Captain M. Lightstone. Acknowledgments are also made to C.D. Hardwick, B.W. Leach and N. McPhee of the National Aeronautical Establishment for their contributions to the aeromagnetic survey component of the project.

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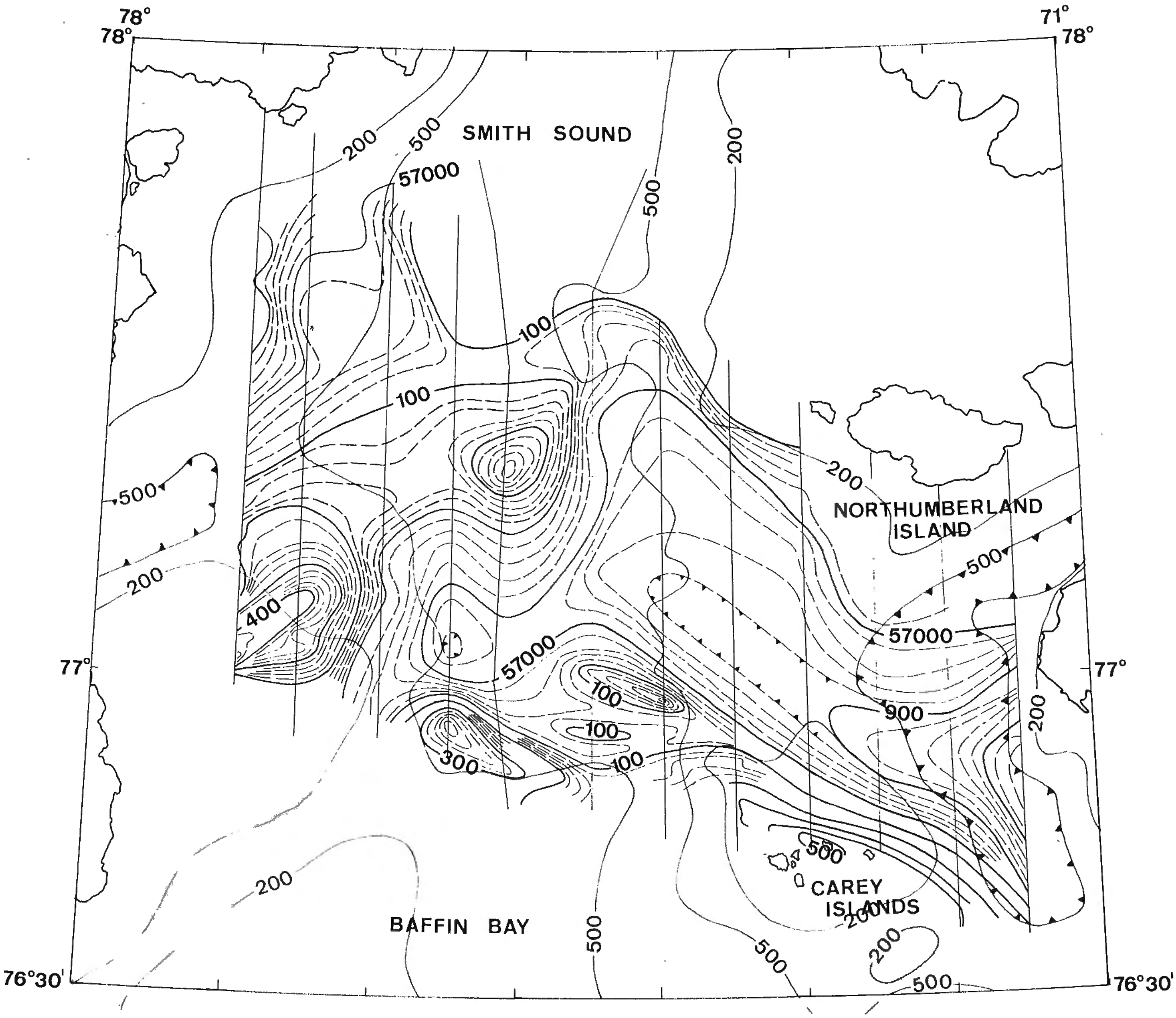

Figure 2. Total intensity aeromagnetic map of the Smith Sound area.

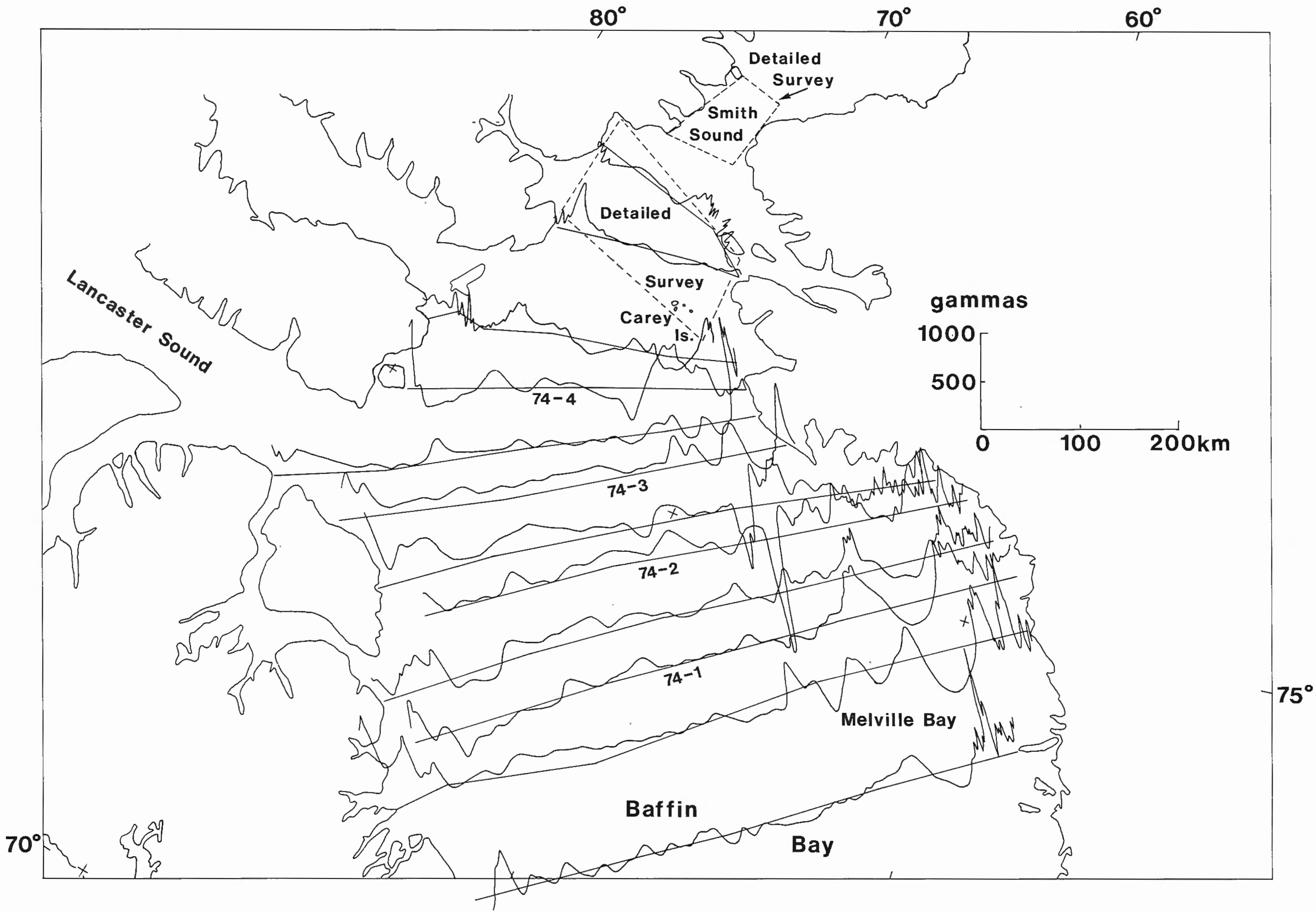

Figure 3. Aeromagnetic profiles obtained in northern Baffin Bay during 1974. The areas covered in more detail and shown in Figure 1 are outlined by dashed lines.

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FREQUENCY RANGE FOR MINERAL DIFFERENTIATION BY IP METHODS

Project 630049

T. J. Katsube
Resource Geophysics and Geochemistry Division

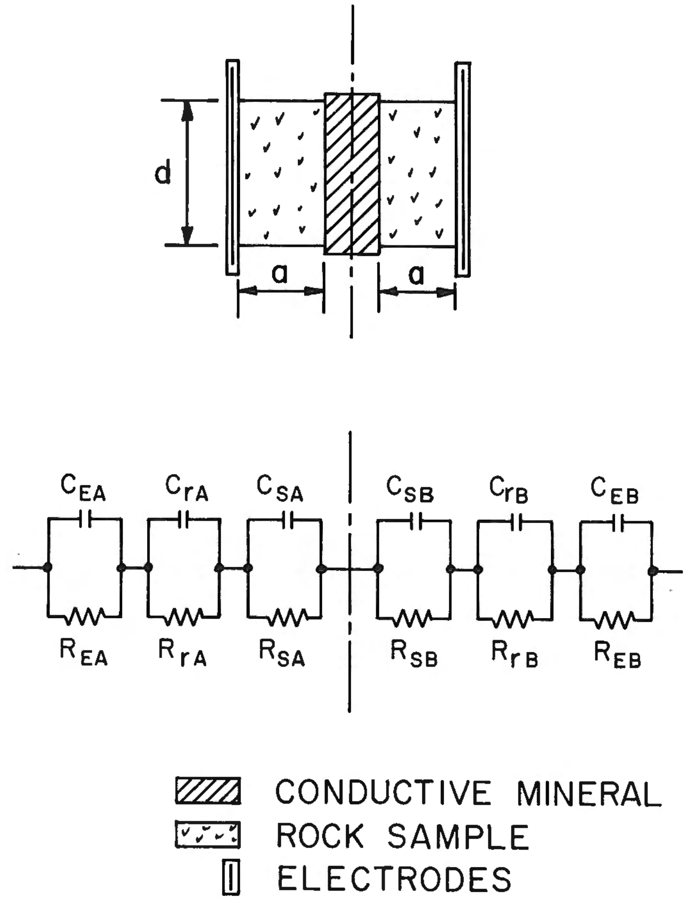
Introduction

The upper frequency limit for existing IP field systems are usually 5 to 10 Hz. Marshall and Madden (1959) and Collett (1959) have indicated that different types of minerals may have different IP characteristics Based on laboratory work, Katsube (1967) indicated that mineral differentiation may be possible by IP methods. Later, based on field and laboratory work, (Zonge 1972; Zonge *et al.*, 1972) indicated that the mineral differentiation is possible only if the frequency range of the IP system extends above 10 Hz. Laboratory work by Katsube (Collett and Katsube, 1973) has also indicated similar results.

At this point it is of interest to know the frequency range that the IP effect appears. Laboratory work by Katsube and Collett (1972) has indicated that both the maximum and minimum frequency limits of the IP effects depend upon the resistivity of the host rock. In this paper results of laboratory IP measurements with further explanation of the phenomena is presented, besides discussing part of the electrical mechanism which is involved.

Experiment

Three types of experiments were carried out. The first type was the electrical measurements on a rock and conductive mineral sample combinations (*see* Fig. 1). This combination consists of two disc-shaped rock samples (diameter: 2.5-2.6 cm, thickness: 0.5-0.8 cm) with a solid sulphide mineral sample (galena or chalcopyrite, same shape as the rocks) inserted between them. This combination was saturated with water, placed between a two-electrode system and the electrical parameters were measured over the frequency range from 10^{-2} to 10^{5} Hz. Part of this measuring system is shown in the paper by Gauvreau and Katsube (this publication, report). The purpose of setting up this combination was to simulate a vein in a sample, or a portion of a vein in the ground where the electrical current flows in the direction normal to the vein. The types of rocks that were used are diorite, basalt, serpentinite and olivine. The olivine sample is a mineral, but it is referred to as a rock for convenience in this paper. In the case of olivine, two samples were not available. Therefore, the combination consisted only of one rock sample, so that when the combination was inserted between the two electrodes, a direct ohmic contact was made between one of the surfaces of the sulphide mineral sample and one of the electrodes. This is a modified combination. Since the resistivity of the solid galena or chalcopyrite sample is very low, this modified combination produces similar results to that of the unmodified combination, if certain mathematical corrections are applied. Further details and measured results on this subject will be given in a later paper.



C_{EA}, C_{EB}, R_{EA}, R_{EB}: Capacitance and resistance of both electrode interfaces.

C_{SA}, C_{SB}, R_{SA}, R_{SB}: Capacitance and resistance of the interfaces on both sides of the conductive mineral sample.

C_{rA}, C_{rB}, R_{rA}, R_{rB}: Capacitance and resistance of of the two rock samples.

Figure 1. Description of the rock and conductive mineral combination placed between the electrodes, and the equivalent circuit.

The second type of experiment was the electrical measurements over the same frequency range (10^{-2} - 10^{5} Hz), on single rock samples in moist state. The third type of experiment was the electrical measurements on the solid sulphide minerals. In this case moist filter paper was inserted between both sample interfaces and the electrodes, to avoid direct ohmic contact and permit the measurement of the electrode

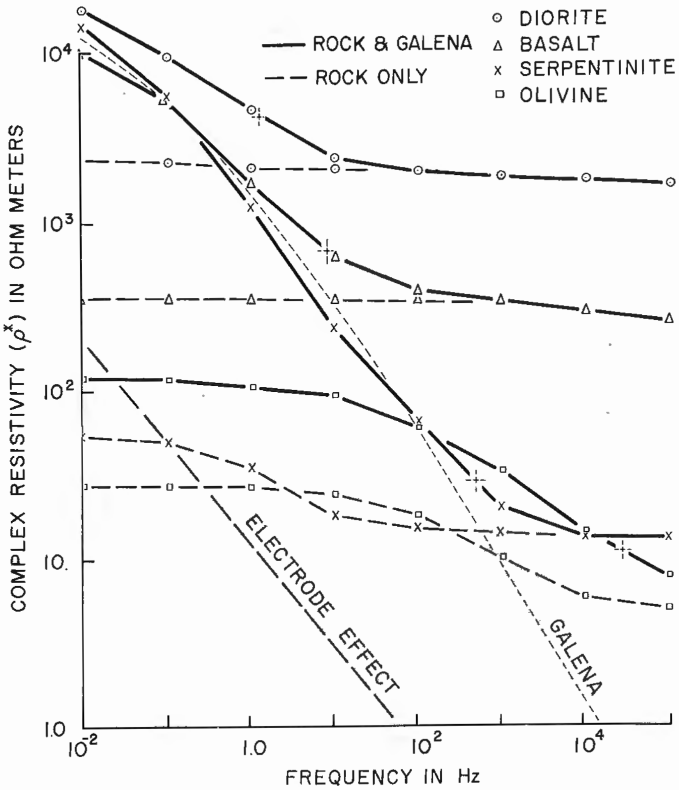


Figure 2. Frequency spectrum of complex resistivity for rock-galena sample combinations, rock samples and the galena sample.

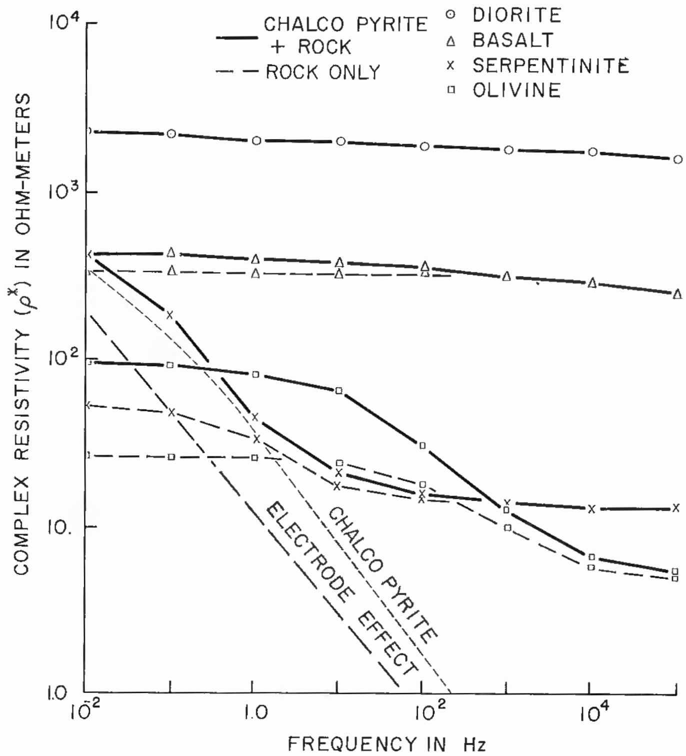


Figure 3. Frequency spectrum of complex resistivity for rock-chalcopyrite sample combinations, rock samples and the chalcopyrite sample.

polarization of both samples and electrodes. This measurement also includes the effect of the filter paper, though it is usually small and negligible.

The effect of the electrodes exist in all three types of experiments. In order to eliminate the electrode effects, the two electrodes were put close together only being separated by one or two layers of moist filter paper, and the resistance (R_E) and reactance (X_E) were measured. This was carried out prior to the measurements of the sample inserted between the electrodes, and R_E and X_E was subtracted from the resistance (R_T) and reactance (X_T) measured with the sample in. The accuracy and further details of this type of measurement procedure will be discussed in a later paper.

If the impedance of the sample or sample combinations in and out of the sample holder are Z_T and Z_E, respectively, the following relationship is seen:

$$Z_T = R_T - jX_T$$

$$Z_E = R_E - jX_E$$

where

$$R_T = R_E + R_S$$

$$X_T = X_E + X_S$$

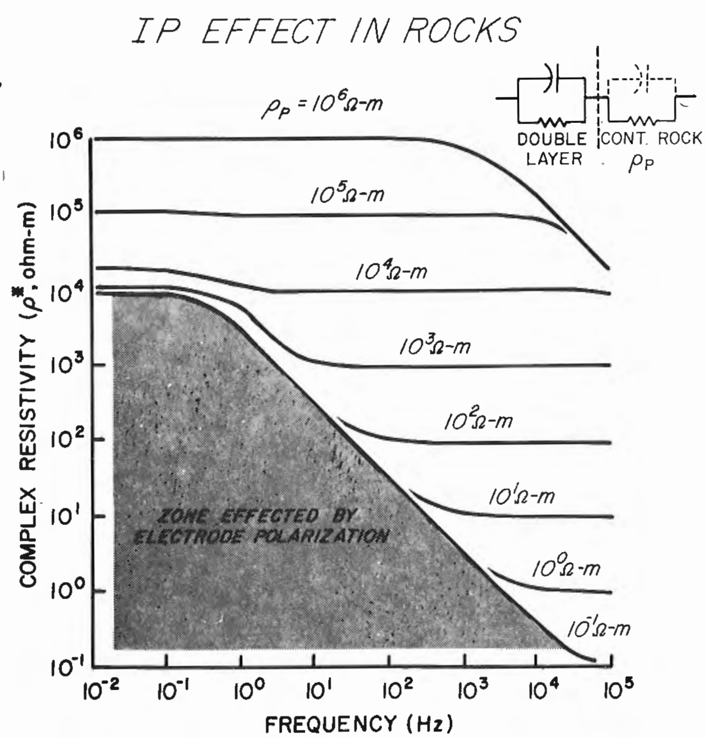


Figure 4. Simplified electrical model of rock and conductive mineral sample combination, and frequency spectrum of complex resistivity with the resistivity of the rock (ρ_p) being a variable (10^{-1} - 10^6 ohm-metres).

R_S and X_S are the resistance and reactance of the rock and conductive mineral sample combination. The relationship between R_S, X_S and the components of the equivalent circuit in Figure 1 for the case of the sample combination, are:

$$R_S = \frac{R_{SA}}{1 + Q_{SA}^2} + \frac{R_{SB}}{1 + Q_{SB}^2} + \frac{R_{rA}}{1 + Q_{rA}^2} + \frac{R_{rB}}{1 + Q_{rB}^2}$$

$$X_S = \frac{Q_{SA}R_{SA}}{1 + Q_{SA}^2} + \frac{Q_{SB}R_{SB}}{1 + Q_{SB}^2} + \frac{Q_{rA}R_{rA}}{1 + Q_{rA}^2} + \frac{Q_{rB}R_{rB}}{1 + Q_{rB}^2}$$

where

$$Q_{ij} = \omega R_{ij} C_{ij} \qquad (i = S \text{ or } r,\ j = A \text{ or } B)$$

ω = angular frequency

Results

Two sulphide mineral samples (galena, chalcopyrite) and four sets of rock samples (diorite, basalt, serpentinite and olivine) were prepared. First, the electrical parameters of the rock samples were measured over the frequency from 10^{-2} to 10^5 Hz (Figs. 2 and 3, thick broken lines). These rocks show different resistivities. Then the rock and conductive mineral combination was measured (Figs. 2 and 3, solid lines).

Figure 2 depicts complex resistivity curves for the case which galena was used as the conductive mineral in the sample combination. Note how the complex resistivity curves of the rock and conductive mineral combination rises with decrease in frequency in comparison to the relatively small frequency dependance of the curves of the rock sample without the conductive minerals. This dispersion of resistivity is the IP effect. It is also interesting to note how the frequency range that the IP effect can be seen increases with decrease in the resistivity of the rocks. The maximum frequency that the IP effect can be seen is about 10 Hz in the case of diorite, and about 10^4 Hz in the case of serpentinite. It is also interesting to see how the complex resistivity curves of the rock and conductive mineral combination come close to the complex resistivity curves of the galena alone.

Figure 3 depicts the complex resistivity curves for the case which chalcopyrite was used. Generally the trends are similar to those in Figure 2. However, the complex resistivity of the chalcopyrite specimen is smaller than that of galena, and it can be seen that the IP effect of chalcopyrite is generally much smaller than that of galena. Note that no IP effect can be seen for diorite.

Discussion and Mechanism

From the results shown in Figures 2 and 3, it can be seen that the complex resistivity of the galena and chalcopyrite samples increases with decreases in frequency. And there are indications that it levels off at the lower frequency end. This trend can be simulated approximately by a RC parallel circuit, and is due to the electrode polarization phenomena at the sulphide or conductive mineral interfaces. The complex resistivity of rocks generally show little or relatively small variations with frequency, but when combined with the conductive mineral sample, they show a large increase with decrease in frequency. This is seen particularly at frequencies where the complex resistivity of the conductive mineral rises above that of the rock. And when the resistivity of the rock is larger than the maximum value of the complex resistivity of the conductive minerals, the IP effect is masked as seen in Figure 3.

Based on the foregoing observations, the rock and conductive mineral sample combination can be simulated by two parallel RC circuits as shown in Figure 4. One simulates the conductive mineral interface and the other simulates the rock. When the rock samples in the sample combination are changed with the conductive mineral sample being the same, the situation is similar to ρ_P (Fig. 4) being varied. Theoretical curves are shown in Figure 4, for complex resistivity of the equivalent circuit in the same figure where:

$C_E = 5 \times 10^{-5}$ Farad/m

$R_E = 10^4$ ohm-m

$\varepsilon_r = 8 \times \varepsilon_0$ Farad/m

$\rho_p = 10^{-1} - 10^{6}$ (variable) ohm-m

$\varepsilon_0 = 8.854 \times 10^{-12}$ Farad/m

It is interesting to note the resemblance between the complex resistivity curves in Figure 4 with those in Figure 2 and Figure 3. The electrode polarization zone in Figure 4 is equivalent to the zone of the IP effect. It has to be admitted that the details of the complex resistivity curves in Figure 2 and Figure 3 (actual measurements) are not similar to the theoretical curves, but the general trends of these curves are similar. For example, note how the IP effect diminishes and finally disappears as the resistivity rises (Fig. 3 and Fig. 4).

Conclusion

Both experiment and theory show that the resistivity of the rocks adjacent to the sulphide or conductive mineral determine the maximum frequency to which the IP phenomena can be seen. In the case of the galena-serpentinite combination, the maximum frequency to which the IP phenomena appears is about 10^6 Hz, and in the case of the chalcopyrite-serpentinite combination, it is about 10^2 Hz. As the resistivity of the rock rises, the maximum frequency to which the IP effect can be seen decreases, and finally the resistivity reaches a value at which the IP effect is masked. As the resistivity of the rock decreases the maximum frequency of the IP effect increases. It appears that no upper limit of the IP effect can be determined, unless the resistivity of the host rock is specified.

The by-pass effect of the host rock on the IP effect has not been discussed in this paper. From simple estimations it is expected that the by-pass effect would determine a lower limit of frequency to which the IP effect can appear. Carrying out of further work on this subject is thought to be of interest.

Work on the electrical mechanism has not been carried out in depth, up to this point. However, use of equivalent circuits and theoretical calculations has aided in obtaining a general understanding of the IP effect of the sulphide mineral interfaces and the effect of the host rock on the complex resistivity.

Acknowledgments

Many thanks are expressed to Mr. L. S. Collett for the general guidance and deep understanding of this work. Thanks are also expressed to Mr. J. Frechette for carrying out many of the measurements.

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Project 630049

T. J. Katsube
Resource Geophysics and Geochemistry Division

Introduction

A significant relationship exists between the electrical parameters used in field geophysics, microwave studies, laboratory electrical rock property studies, electrical insulation studies and other fields related to electricity. However, the type of parameters that are used vary not only between the fields but also within each field. In order to make efficient use of results produced by each field, or by different investigators within the same field, it is necessary to be able to make rapid conversions between the different types of electrical parameters.

For this reason a number of sets of electrical parameters, which appear to be commonly used, were selected and the formulas for converting them into other electrical parameters have been tabulated in Table 1.

Basic Parameters and Equations

The equation of complex permittivity is introduced from Von Hippel (1954):

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \qquad \ldots\ldots (1)$$

Table 1

Conversion table for electrical parameters

Electrical Parameters \ Measured Parameters	κ', D ($\tan\delta$)	κ', σ'	κ^*, D	σ^*, D	W, σ^*	ρ', ρ^*
D, $\tan\delta$	—	$\frac{\sigma'}{\omega\kappa'\epsilon_o}$	—	—	$\frac{W}{\sqrt{1-W^2}}$	$\frac{\rho'}{\sqrt{(\rho^*)^2-(\rho')^2}}$
σ^*	$\omega\kappa'\epsilon_o\sqrt{1+D^2}$	$\omega\kappa'\epsilon_o\sqrt{1+(\frac{\sigma'}{\omega\kappa'\epsilon_o})^2}$	$\omega\epsilon_o\kappa^*$	—	—	$\frac{1}{\rho^*}$
σ'	$\omega\kappa'\epsilon_o D$	—	$\frac{\omega\kappa^*\epsilon_o D}{\sqrt{1+D^2}}$	$\sigma^*\frac{D}{\sqrt{1+D^2}}$	$\sigma^*\omega$	$\frac{\rho'}{(\rho^*)^2}$
σ''	$\omega\kappa'\epsilon_o$	ω D	$\frac{\omega\kappa^*\epsilon_o D^2}{\sqrt{1+D^2}}$	$\frac{\sigma^*}{\sqrt{1+D^2}}$	$\sigma^*\sqrt{1-W^2}$	$\frac{\sqrt{(\rho^*)^2-(\rho')^2}}{(\rho^*)^2}$
κ^*	$\kappa'\sqrt{1+D^2}$	$\kappa'\sqrt{1+(\frac{\sigma'}{\omega\kappa'\epsilon_o})^2}$	—	$\frac{\sigma^*}{\omega\epsilon_o}$	$\frac{\sigma^*}{\omega\epsilon_o}$	$\frac{1}{\omega\epsilon_o\rho^*}$
κ'	—	—	$\frac{\kappa^*}{\sqrt{1+D^2}}$	$\frac{\sigma^*}{\omega\epsilon_o\sqrt{1+D^2}}$	$\frac{\sigma^*}{\omega\epsilon_o}\sqrt{1-W^2}$	$\frac{1}{\omega\epsilon_o\sqrt{(\rho^*)^2-(\rho')^2}}$
κ''	κ' D	$\frac{\sigma'}{\omega\epsilon_o}$	$\frac{\kappa^* D}{\sqrt{1+D^2}}$	$\frac{\sigma^* D}{\omega\epsilon_o\sqrt{1+D^2}}$	$\frac{\sigma^* W}{\omega\epsilon_o}$	$\frac{\rho'}{\omega\epsilon_o\left[(\rho^*)^2-(\rho')^2\right]}$
ω_{cr}	ω D	$\frac{\sigma'}{\kappa'\epsilon_o}$	ω D	ω D	$\frac{\omega W}{\sqrt{1-W^2}}$	$\frac{\omega\rho'}{\sqrt{(\rho^*)^2-(\rho')^2}}$
ρ^*	$\frac{1}{\omega\kappa'\epsilon_o\sqrt{1+D^2}}$	$\frac{1}{\sqrt{(\sigma')^2+(\omega\kappa'\epsilon_o)^2}}$	$\frac{1}{\omega\epsilon_o\kappa^*}$	$\frac{1}{\sigma^*}$	$\frac{1}{\sigma^*}$	—
ρ'	$\frac{D}{\omega\kappa'\epsilon_o(1+D^2)}$	$\frac{\sigma'}{(\sigma')^2+(\omega\kappa'\epsilon_o)^2}$	$\frac{D}{\omega\epsilon_o\kappa^*\sqrt{1+D^2}}$	$\frac{D}{\sigma^*\sqrt{1+D^2}}$	$\frac{W}{\sigma^*}$	—
ρ''	$\frac{1}{\omega\kappa'\epsilon_o(1+D^2)}$	$\frac{\omega\kappa'\epsilon_o}{(\sigma')^2+(\omega\kappa'\epsilon_o)^2}$	$\frac{1}{\omega\epsilon_o\kappa^*\sqrt{1+D^2}}$	$\frac{1}{\sigma^*\sqrt{1+D^2}}$	$\frac{\sqrt{1-W^2}}{\sigma^*}$	$\sqrt{(\rho^*)^2-(\rho')^2}$
W	$\frac{D}{\sqrt{1+D^2}}$	$\frac{\sigma'}{\sqrt{(\sigma')^2+(\omega\kappa'\epsilon_o)^2}}$	$\frac{D}{\sqrt{1+D^2}}$	$\frac{D}{\sqrt{1+D^2}}$	—	$\frac{\rho^*\rho'}{(\rho^*)^2-(\rho')^2}$
θ	$\frac{\pi}{2}-\tan^{-1}D$	$\frac{\pi}{2}-\tan^{-1}\frac{\sigma'}{\omega\kappa'\epsilon_o}$	$\frac{\pi}{2}-\tan^{-1}D$	$\frac{\pi}{2}-\tan^{-1}D$	$\cos^{-1}W$	$\frac{\pi}{2}-\tan^{-1}\frac{\rho'}{\sqrt{\rho^{*2}-\rho'^2}}$
α	$\omega\sqrt{\frac{\mu'\kappa'\epsilon_o}{2}(\sqrt{1+D^2}-1)}$	$\omega\sqrt{\frac{\mu'\kappa'\epsilon_o}{2}\left[\sqrt{1+(\frac{\sigma'}{\omega\kappa'\epsilon_o})^2}-1\right]}$	$\omega\sqrt{\frac{\mu'\kappa^*\epsilon_o}{2}\left[1-\frac{1}{\sqrt{1+D^2}}\right]}$	$\sqrt{\frac{\mu'\sigma^*\omega}{2}\left[1-\frac{1}{\sqrt{1+D^2}}\right]}$	$\sqrt{\frac{\omega\mu'\sigma^*}{2}\left[1-\sqrt{1-W^2}\right]}$	$\sqrt{\frac{\mu'\sigma^*\omega}{2}\left[1-\frac{1}{\rho^*\sqrt{\rho^{*2}-\rho'^2}}\right]}$

where ε^*, ε' and ε'' are the complex, real and imaginary permittivity. From the relationship between permittivity and relative permittivity which is

$$\varepsilon^* = \kappa^* \varepsilon_0 \qquad \ldots\ldots (2)$$

where ε_0 is the permittivity of air or vacuum (8.854×10^{-12} F/m), the following equation is obtained:

$$\kappa^* = \kappa' - j\kappa'' \qquad \ldots\ldots (3)$$

κ^*, κ' and κ'' are the complex, real and imaginary relative permittivity. The real conductivity (σ') is related to these equations by:

$$\sigma' = \omega\varepsilon'' \qquad \ldots\ldots (4)$$

where ω is the angular frequency. From Fuller and Ward (1970) the complex conductivity equation is introduced:

$$\sigma^* = \sigma' + j\sigma'' \qquad \ldots\ldots (5)$$

The relationship to the permittivity is shown in Equation 4. It is known that the complex resistivity (ρ^*) is related to the complex conductivity by the following equation:

$$\sigma^* = 1/\rho^* \qquad \ldots\ldots (6)$$

from which the complex resistivity equation is derived:

$$\rho^* = \rho' - j\rho'' \qquad \ldots\ldots (7)$$

From Von Hippel (1954) and ASTM (1968) the loss tangent ($\tan\delta$) and dissipation factor is introduced. They are related to Equations 1, 3, 5 and 7 by:

$$D = \tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{\kappa''}{\kappa'} = \frac{\sigma'}{\sigma''} = \frac{\rho'}{\rho''} \qquad \ldots\ldots (8)$$

The phase angle (θ) and power factor (W) are introduced from ASTM (1968) and are related to the other parameters by:

$$\theta = \frac{\pi}{2} - \tan^{-1} D \qquad \ldots\ldots (9)$$

$$W = \cos\theta \qquad \ldots\ldots (10)$$

From Katsube and Collett (1972) or Katsube (this publication, report) the critical frequency (ω_{cr}) is introduced. It is the frequency at which D = 1, and at which the displacement current and ohmic current are equal. The relationship between parameters have been reviewed to a certain extent by Collett and Katsube (1973).

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Project 630049

T.J. Katsube
Resource Geophysics and Geochemistry Division

Introduction

For electrical methods "resistivity" has always been the major parameter, while for microwave (radar and radio) and dielectric engineering "dielectric constant" has been the main parameter used in regard to the ground. It has always been known that rocks and other geological material exhibit an electrical phenomena of both resistive and dielectric nature. But the relationship between the two has never seemed to appear clearly in measurements. The papers by Katsube and Collett (1972 and 1974) present data that clearly indicate the relationship between resistivity and dielectric constant, by introducing the concept of "critical frequency". Keller and Licastro (1959) were, perhaps, the first to present data containing this relationship though it did not appear clearly.

In this paper, a review on data which clearly indicates the relationship between the resistivity and dielectric constant, theoretical background of the critical frequency, and its significance on measurement accuracy and electromagnetic propagation in geological material is presented.

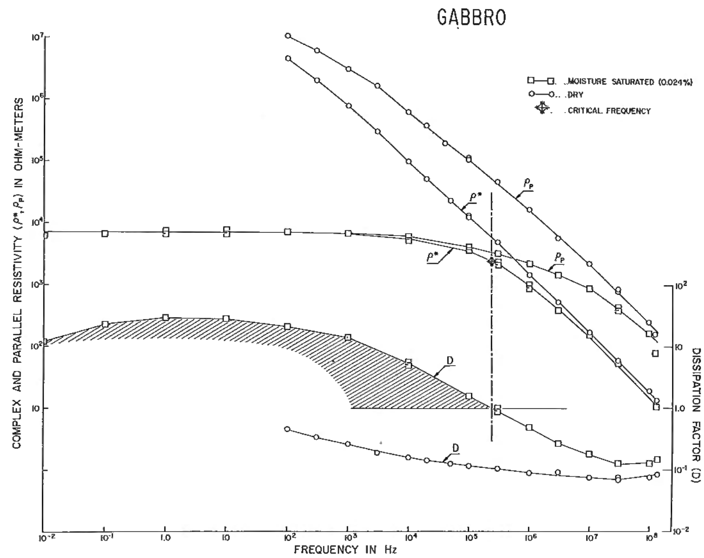

Figure 1. Frequency spectrum of complex resistivity (ρ^*) and dissipation factor (D) for a gabbro sample in both moist and dry state (after Katsube and Collett, 1974). ρ_p is the parallel resistivity.

Review of Data

Data on the frequency spectrum of resistivity for moist rocks over a wide frequency range is shown, perhaps for the first time, in the paper by Keller and Licastro (1959). The data shown in the paper by Keller (1966, Fig. 26-1) depicts the same spectrum more clearly. The term "resistivity" in their work is thought to be equivalent to the term "complex resistivity" used in recent work. Similar results in further detail have appeared in the work by Katsube and Collett (1972, 1973 and 1974). Figure 1 shows an example of these results. It can be seen that the complex resistivity (ρ^*) for the dry gabbro sample decreases at a rate of 45 degrees on the log-log scale. This trend can be explained quite well by theory, as will be shown later in this paper. When the gabbro sample is moist, the complex resistivity varies little with frequency, until the frequency rises above 10^5 Hz. From about 3 x 10^6 Hz the complex resistivity appears to decrease at a rate of 45 degrees on the log-log scale. It is interesting to note that the trend of the ρ^* curves for both moist and dry gabbro are similar at the higher frequency end of the spectrum (Fig. 1), except that the ρ^* curve for the moist gabbro shows lower values than those of the dry gabbro. The same trends and relationships between the two ρ^* curves are seen in all of the other work by Katsube and Collett (1972, 1973, 1974). In the work by Keller (1966) the relationship between the ρ^* curves for moist and dry rock do not necessarily appear to be similar to the recent findings. However,

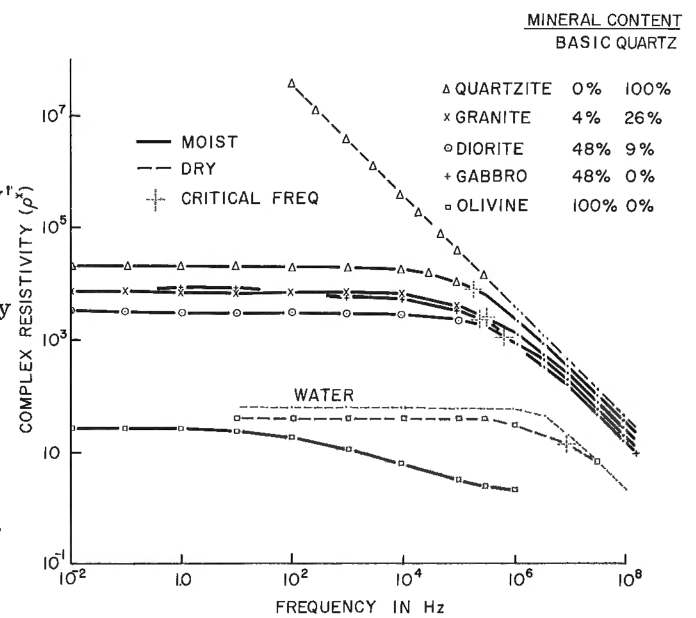

Figure 2. Frequency spectrum of complex resistivity (ρ^*) for 5 rock and mineral samples.

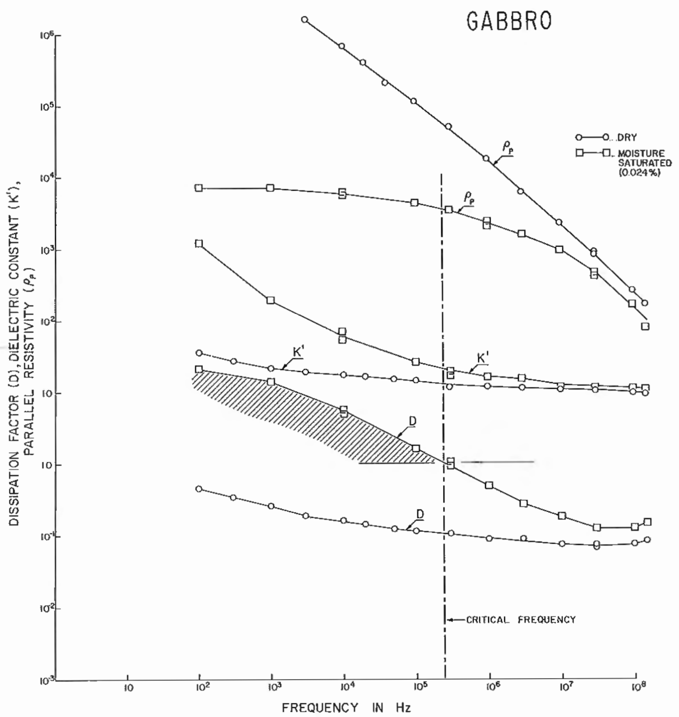

Figure 3. Frequency spectrum of dielectric constant (K') and dissipation factor (D) for a gabbro sample in both dry and moist state (after Katsube and Collett, 1974). ρ_p is the parallel resistivity.

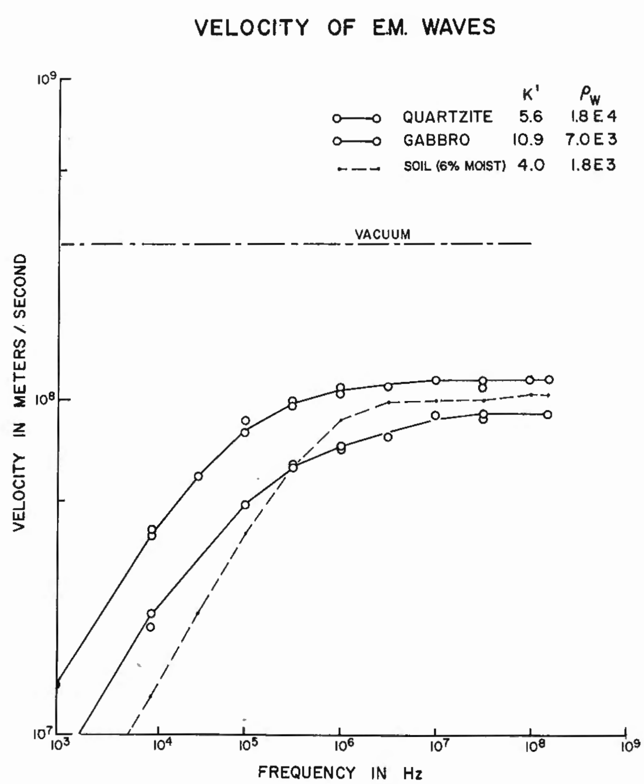

Figure 5. Frequency spectrum of the velocity of EM waves for a quartzite, gabbro and soil sample (Katsube and Collett, 1974). ρ_W: Value of ρ_p determined at frequencies below the critical frequency.

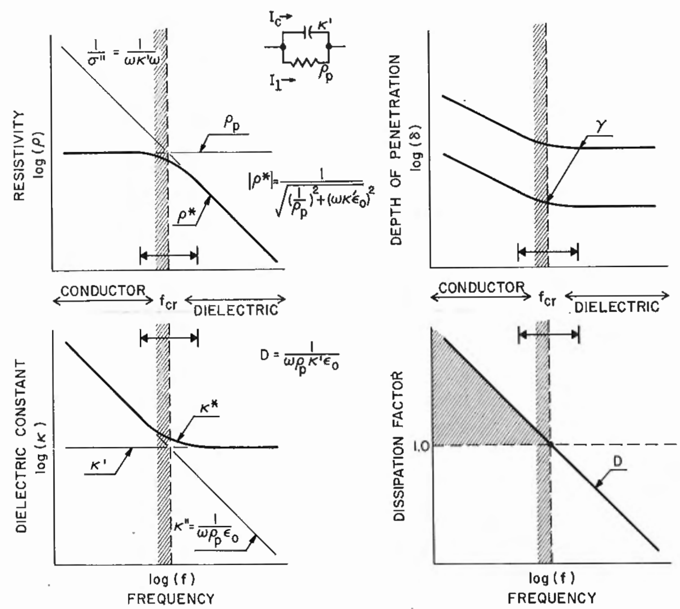

Figure 4. Theoretical curves for complex resistivity (ρ^*), depth of penetration (δ) and dissipation factor (D) of an electrical model of geological materials (RC parallel equivalent circuit). K* is the complex relative permittivity (after Katsube and Collett, 1974).

the results seen in the recent work seem to show a better agreement with theory. Further discussions on this subject will take place in a later paper. More examples of the frequency spectrum of resistivity are shown in Figure 2.

The various trends of parallel resistivity (ρ_p), dissipation factor (D) and dielectric constant (K') are shown in Figure 1 and Figure 3 for both dry and moist rocks.

Theoretical Background

Electrical Simulation

From electrical measurements of rocks it is evident that both an ohmic current (I_ℓ) and a displacement current (I_c) traverse a rock sample when a voltage (V) is applied. Therefore, it is customary to simulate the rock sample by a RC parallel circuit (Von Hippel, 1954) as a first approximation (*see* Fig. 4).

Basic Equations

Based on the equivalent circuit shown in Figure 4, the two currents (I_ℓ, I_c) can be expressed by

$$\begin{cases} I_\ell = V/\rho_p \\ I_c = V\omega K'\varepsilon_o \end{cases} \qquad (1)$$

where ω is the angular frequency and ρ_p is the parallel resistivity. The ratio of the two currents is the dissipation factor (D) and varies with frequency.

From Eq. 1

$$D = \frac{I_l}{I_c} = \frac{1}{\omega\rho_p K'\varepsilon_o} \quad \text{------------ (2)}$$

The complex resistivity equation is

$$\rho^* = \rho' - j\,\rho'' \quad \text{---------------- (3)}$$

where ρ^*, ρ' and ρ'' are the complex, real and imaginary resistivities of the sample. Based on the equivalent circuit in Figure 4, ρ^* can be expressed by

$$\rho^* = \frac{1}{1/\rho_p + j\omega K'\varepsilon_o} \quad \text{--------- (4)}$$

From Eq. 2, 3 and 4

$$\begin{cases} \rho' = \dfrac{\rho p}{1 + (1/D)^2} \\ \rho'' = \dfrac{\rho'}{D} \end{cases} \quad \text{------------- (5)}$$

Therefore, the absolute value of complex resistivity is

$$|\rho^*| = \frac{\rho p}{\sqrt{1 + (1/D)^2}} \quad \text{----------- (6)}$$

Critical Frequency

From Eq. 2 it can be seen that D decreases with frequency, and when D = 1, I_c is equal to I_ℓ. From Eq. 6, when $D \geqq 10$ ρ^* is frequency independent:

$$|\rho^*| = \rho_p \quad \text{----------------- (7)}$$

and when $D \leqq 0.1$ ρ^* is in inverse proportion to frequency:

$$|\rho^*| = \frac{1}{\omega K'\varepsilon_o} \quad \text{----------- (8)}$$

The frequency range where $10 > D > 0.1$ is a transition zone from the situation expressed by Eq. 7 to that expressed by Eq. 8, and includes the frequency where D = 1 (*see* Fig. 4, upper left part).

If the frequency characterization similar to Jordan and Balmain (1968) is adopted, the ρ^* curve in Figure 4 indicates that the frequency range where D > 1 and $I_\ell > I_c$ is the region where the rock reacts similar to a conductor, and that the frequency range where D < 1 and $I_\ell < I_c$ is the region where the rock reacts as a dielectric material. The frequency where D = 1 is an important frequency which divides the two regions. This frequency is designated as the "critical frequency (ω_{cr})". Graphically, it is the frequency where the two lines expressed by Eq. 7 and Eq. 8 intercept. Since all geological material, known to date, can be simulated by the RC equivalent circuit, this concept of critical frequency can be extended to all geological materials.

Comparison

A comparison of the theoretical curves for ρ^* (Fig. 4) and the ρ^* curves for actual measurements show a very good correlation. This indicates the validity of the RC simulation for these rocks, and of the concept for the critical frequency of geological materials.

When the comparison is carried out into further detail, a number of discrepancies can be seen. The difference in the gradient between the curves for D in Figure 4 (lower right part) and those for Figure 1 and Figure 3 is one example. The Cole-Cole diagram for a diorite sample in the paper by Katsube and Collett (1974) shows the centre of the arc below the abscissa, which is not expected from theory. These discrepancies suggest that a distributed type of equivalent circuit should be used for simulation of geological material. Work by Olhoeft *et al.* (1972) and Katsube (1974) are of interest from this aspect.

Effect on Measurement Accuracy

At frequencies where D > 10, I_ℓ is the major current and I_c is the minor current which is 1/10 times the major current. At frequencies where D < 0.1, I_c is the major current and I_ℓ is the minor current which is less than 1/10 times the major current. It is important to note that measurement of parameters related to the minor current of this order is difficult, and can cause problems in measurement accuracy. Therefore, D can be considered a parameter for measurement accuracy, besides having a physical significance.

Effect on Propagation

The critical frequency (ω_{cr}) has a strong effect on some of the electromagnetic wave propagation characteristics of geological materials. Wave velocity (Fig. 5), intrinsic impedance (Fig. 6), and reflection coefficient are examples of the propagation parameters that are affected by the critical frequency (*see* Katsube and Collett, 1974). In these figures, it can be seen that both wave velocity and intrinsic impedance increase with frequency until a certain frequency is reached, and from above that frequency the parameters are little dependent on frequency. This "certain frequency" is the critical frequency.

From Jordan and Balmain (1968) the wave velocity (v) is expressed by (also see Katsube this publication report),

$$v = \frac{\omega}{B} = \left\{\sqrt{\frac{\mu K'\varepsilon_o}{2}\left(\sqrt{1 + D^2} + 1\right)}\right\}^{-1} \quad \text{--- (9)}$$

From this equation it is evident that at frequencies below the critical frequency where D > 10, it can be considered that,

$$v = \left\{\sqrt{\frac{\mu K'\varepsilon_o}{2}\,(D + 1)}\right\}^{-1} \quad \text{-------------- (10)}$$

Since D generally decreases with frequency in the frequency range under discussion (*see* Fig. 1 and Fig. 3) v will increase with frequency, as seen in Fig. 5. At frequencies above the critical frequency, where D < 0.1 it can be considered that,

$$v = \frac{1}{\sqrt{\mu K'\varepsilon_o}} \quad \text{----------------- (11)}$$

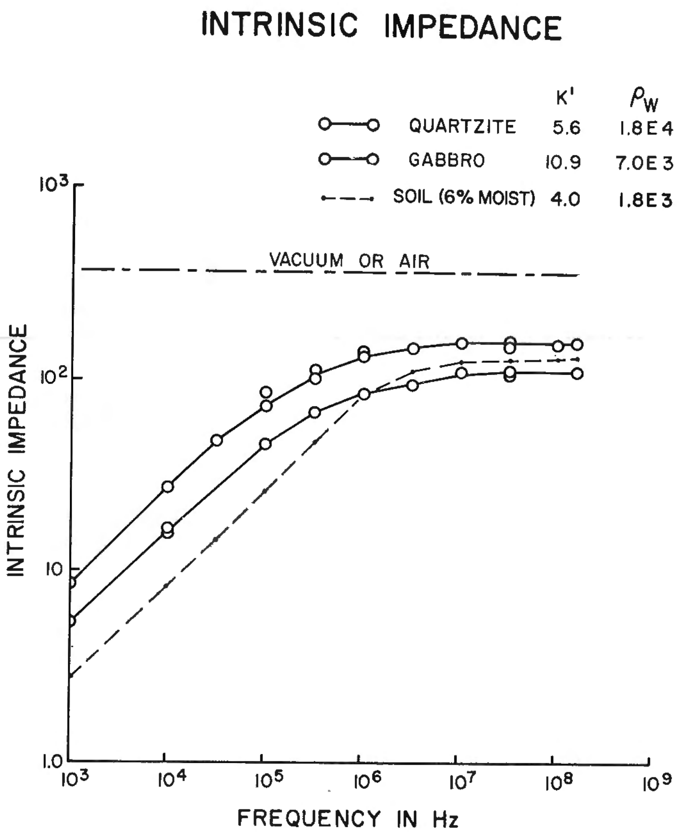

Figure 6. Frequency spectrum of the intrinsic impedance for three rock and soil samples (Katsube and Collett, 1974). ρ_W: Value of ρ_p determined at frequencies below the critical frequency.

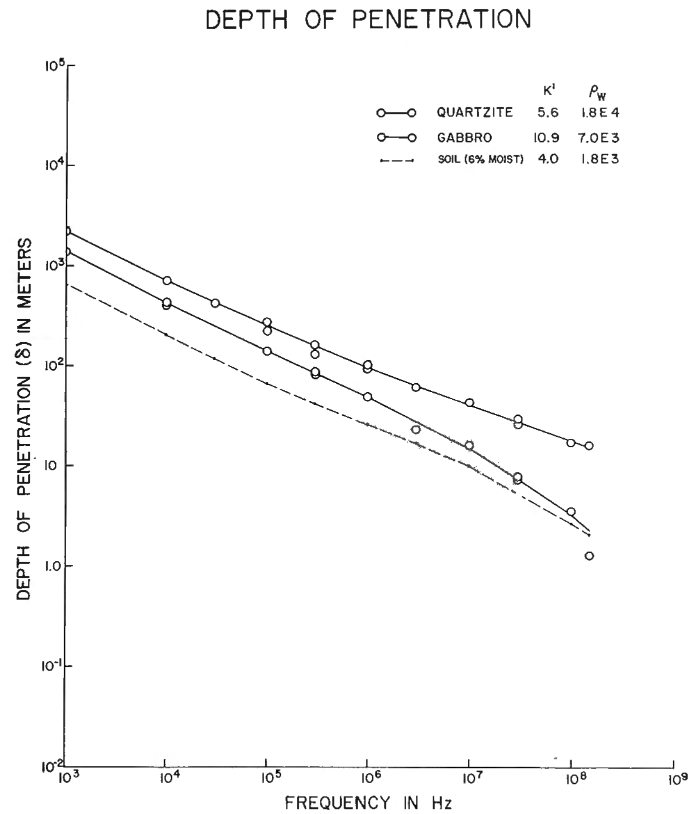

Figure 7. Frequency spectrum of depth of penetration for three rock and soil samples (Katsube and Collett, 1974). ρ_W: Value of ρ_p determined at frequencies below the critical frequency.

which indicates that v is constant with frequency. Similar calculations can be applied to explain the effect of the critical frequency on the intrinsic impedance and on the reflection coefficient.

According to theory, the depth of penetration (δ) of electromagnetic waves is also affected to a great extent by the critical frequency. δ decreases with frequency below ω_{cr}, and is frequency independent at frequencies above ω_{cr}. This trend is shown in Figure 4 (upper right part), which is based on the calculations in Jordan and Balmain (1968). However, in actual measurements the frequency independent part is not apparent (*see* Fig. 7), due to the distributed characteristics of geological materials. There is a discrepancy between theoretical curves and actual measurements, and further details are given in the paper by Katsube (1974).

Conclusions

Data clearly showing electrical characteristics such as critical frequency, conductive region and dielectric regions of rock samples have been reviewed and collected in this paper. There is a good general agreement between theory and laboratory measurements. Comparison in further details between theory and laboratory measurements are a subject to be studied in the future. The critical frequency has an important effect on the electrical characteristics, measurement accuracy and propagation characteristics of rocks.

Acknowledgments

The author wishes to express his thanks to Mr. L. S. Collett, for his general guidance which led to this work. Many of the measurements shown in this paper were carried out by Mr. J. Frechette.

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28. A TWO-DIMENSIONAL FIRST VERTICAL DERIVATIVE OPERATOR

Project 720080

P.H. McGrath
Resource Geophysics and Geochemistry Division

The purpose of this short note is to present the two-dimensional operator used at the Geological Survey of Canada in the production of first vertical derivative maps from high resolution aeromagnetic data. The filter is used to improve the resolution of the small scale local anomalies caused by near surface magnetic sources, and to suppress the longer wavelength anomalies resulting from deeper sources. Being two-dimensional the operator does not discriminate against local anomaly trends which tend to parallel the flight line direction as happens in the application of a one-dimensional first vertical derivative operator to airborne data. Also the filter belongs to a large class of zero phase-shift operators, which simply means that it will produce no spatial translation of any of the frequency components comprising the anomalous magnetic field. Hence using this filter, derived maps are produced which are more useful in support of geological mapping programs than was previously possible using total field magnetic maps or first vertical derivative maps derived using a one-dimensional operator.

The transfer function (theoretical filter response), K (u, v), of the operator is defined as follows,

$$K(u,v) = \begin{cases} 2\pi s & , \ 0 \le s \le s_c \\ 2\pi s_c \ \cos^2\left[\dfrac{\pi(s - s_c)}{2\Delta s}\right] & , \ s_c \le s \le s_c + \Delta s \\ 0 & , \ s_c + \Delta s < s \end{cases} \tag{1}$$

where

s	=	radial spatial frequency, $(u^2 + v^2)^{\frac{1}{2}}$,
u, v	=	spatial frequencies in the x and y axis directions respectively,
s_c	=	cut-off frequency,
Δs	=	roll-off length.

The transfer function, K (u, v), defined by equation (1) is illustrated in Figure 1 for values of $s_c = 0.3$ cycles per sampling interval and $\Delta s = 0.1$ cycles per sampling interval. It can be seen that the transfer function is composed of three parts. For radial frequencies, s, between zero and 0.3 cycles per sampling interval the transfer function corresponds to the theoretical response, 2 σ, of a first vertical derivative operator, whereas between 0.3 and 0.4 cycles per sampling interval it follows a cosine bell roll-off down to a zero response. Studies of amplitude spectra of aeromagnetic data flown at a mean terrain clearance of 300 metres (McGrath, in press) have indicated that the parameters used in the design of this filter, namely $s_c = 0.3$ and $\Delta s = 0.1$ c/si, are suitable to pass the

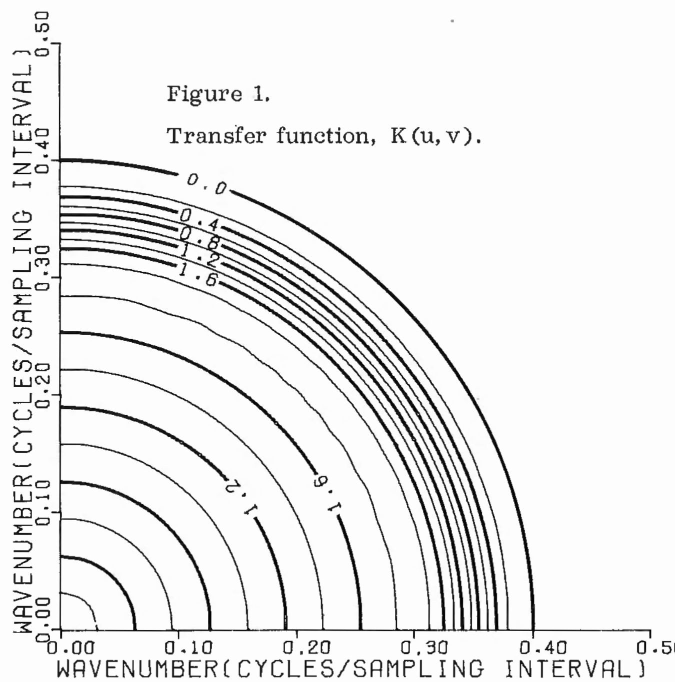

Figure 1.

Transfer function, K (u, v).

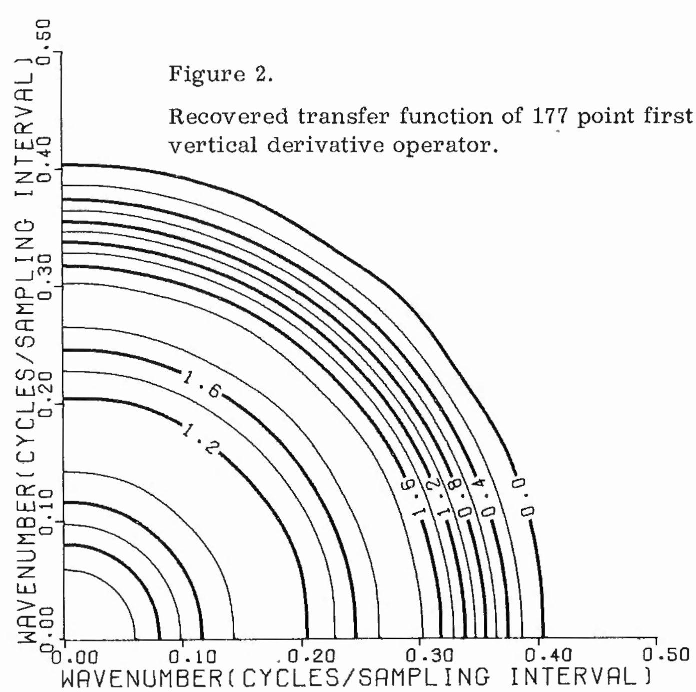

Figure 2.

Recovered transfer function of 177 point first vertical derivative operator.

geological information in the data yet not enhance sampling noise so as to yield good quality derived maps. This presupposes of course that there are no compilation errors in the original gridded high resolution data, e.g. levelling errors, since these errors are enhanced by the derivation process.

The weights for the two-dimensional operator were obtained by calculating the inverse transform of the transfer function, K(u, v), using a multidimensional Fast Fourier Transform computer program (Cooley and Tukey, 1965). This was accomplished by digitizing the transfer function at an interval of 0.02 cycles per sampling interval, the inverse transform of these data yielding a 51 by 51 point spatial operator which is too large for practical applications. A series of amplitude response curves (recovered transfer functions) were calculated using various combinations of these filter weights. By comparing the recovered e.g. Figure 2, and theoretical, Figure1, transfer functions it was arbitrarily decided that the following 177 point operator was small enough to be economical to use yet large enough to yield a recovered transfer function which adequately represented the ideal response defined by Equation (1). It should be noted that had a shaper roll-off been used it would have been necessary to use a larger spatial operator in order to achieve as well-behaved a filter response curve as is shown in Figure 2.

The 177 point spatial operator can be represented by an array, W(x, y), where

	W(-2, 7)		W(2, 7)
	W(-4, 6)		W(4, 6)
	W(-5, 5)		W(5, 5)
	W(-6, 4)		W(6, 4)
	W(-6, 3)		W(6, 3)
W(-7, 2)	W(-6, 2)		W(7, 2)
W(-7, 1),	W(-6, 1)		W(7, 1)
W(-7, 0) ....,		W(0, 0)	W(7, 0)
W(-7, -1)	W(-6, -1)		W(7, -1)
W(-7, -2)	W(-6, -2)		W(7, -2)
	W(-6, -3)		W(6, -3)
	W(-6, -4)		W(6, -4)
	W(-5, -5)		W(5, -5)
	W(-4, -6)		W(4, -6)
	W(-2, -7)		W(2, -7)

The weights are symmetrical about the central weight, W(0, 0), so that there are only 29 unique weights which occur on the lower diagonal side of the upper right-hand quadrant of the array, W(x, y), (*see* Table of Weight Values). All remaining weights can be derived from these unique weights, e.g.

W(1, 0) = W(-1, 0) = W(0, 1) = W(0, -1)

and

W(7, 1) = W(1, 7) = W(-1, 7) = W(-7, 1) = W(-7, -1) = W(-1, 7) = W(1, -7) = W(7, -1)

Table of Weight Values

Weight	Value	Weight	Value
W(0, 0)	0.54850444	W(2, 2)	- 0.05813482
W(1, 0)	0.22661319	W(3, 2)	0.03829643
W(2, 0)	-0.11968571	W(4, 2)	0.00621607
W(3, 0)	-0.02921971	W(5, 2)	- 0.02716782
W(4, 0)	0.03735884	W(6, 2)	0.00626196
W(5, 0)	-0.02444949	W(7, 2)	0.00294804
W(6, 0)	-0.00530630	W(3, 3)	0.02338904
W(7, 0)	0.00892602	W(4, 3)	- 0.02446079
W(1, 1)	0.03216079	W(5, 3)	- 0.01258120
W(2, 1)	-0.12787422	W(6, 3)	0.01158938
W(3, 1)	-0.00418400	W(4, 4)	- 0.01960612
W(4, 1)	0.03106709	W(5, 4)	0.00821481
W(5, 1)	-0.02694710	W(6, 4)	0.00459850
W(6, 1)	-0.00195784	W(5, 5)	0.00754902
W(7, 1)	0.00762026		

The filter weights given above were normalized so that the entire array of weights summed to zero.

A vertical derivative map was produced by convolving these weights with gridded high resolution data (*see* Holroyd, this volume). The high resolution data had previously been gridded at a 62.5 metre interval. For an example of the application of the filter *see* Hood, McGrath and Kornik, this volume.

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29. THE EXTENSION OF THE ADAM (AEROMAGNETIC DATA AUTOMATIC MAPPING) SYSTEM TO INCLUDE THE APPLICATION OF TWO DIMENSION DIGITAL FILTERS TO GRID DATA

Project 680140

M.T. Holroyd
Resource Geophysics and Geochemistry Division

Introduction

Digital filters, both 1 and 2 dimensional versions, have been applied to geophysical data for many years. The 1 dimensional version has seen extensive use on a production basis, especially in seismic data processing but the 2 dimensional type has largely been restricted to experimental or "one off" applications.

The reasons for this are not difficult to uncover. McGrath *et al.* (Geol. Surv. Can., Paper 74-1, Part B) described the use of a 41 weight 1 dimensional filter operator. To produce the possible 960 filtered values from a data array of 1000 values would require 41 x 960 retrieve-multiply-add-store operations. For the 2 dimensional case, to produce one row of 960 filtered values would require 41 times more operations, and either 41 times more memory capacity or additional programming complexities with consequent cost increases to reduce the memory required. For example, to apply a 41 x 41 point filter to the data grid of the Jelicoe high resolution aeromagnetic survey with the straightforward application algorithm would require approximately 3×10^9 retrieve-multiply-add-store operations. This would take 4 hours central processor time on the C.S.C. CYBER 70 computer and cost approximately $4000.

Thus an indication of the reason for the restricted use of 2 dimensional digital filters.

The picture is however constantly improving. The Unit Costs of digital processing are decreasing by about 50% every 10 years. This combined with the design of increasingly more efficient filter operators and application algorithms is bringing the cost of application of 2 dimensional filters well within the realm of the production environment.

The Application Process for 2 Dimensional Filters

Given a grid of data values, to calculate a filtered value at some grid point P the filter grid is overlaid on the data grid with the central point of the filter coincident with P. Each filter weight is multiplied by the subjacent data value and the sum of all such products gives the filtered value. i.e. —

For a single application of an N x N weight filter, the filtered value F_V is given by

$$F_V = \sum_{J=-\bar{N}}^{+\bar{N}} \sum_{I=-\bar{N}}^{+\bar{N}} F_W(I,J) \times D(I,J) \quad \text{----- Eqn 1}$$

where F_W are the filter weights, D the data values and I & J the co-ordinates of a filter weight (or data value) with respect to the central weight I=J=O, thus N = (N - 1)/2.

P.H. McGrath (*see* McGrath, this volume) designed a 15 x 15 weight first vertical derivative filter which has a frequency response satisfactorily close to the theoretically optimum. This filter is of the radially symmetrical type i.e., the value of a weight depends only on its radial distance from the central weight. Thus one octant of the filter contains the unique set of weights, the other 7 octants being merely successive reflections of first. Thus the filter contains only 36 unique weights. This fact enables significant savings to be gained in the application algorithm. Due to the octal symmetry the filter weight at position (I,J) is replicated at positions (J,I), (-J,I), (-I,J), (-I,-J), (-J,-I), (-J,I), (-I,J). In the expansion of Equation 1 the data values at the above co-ordinates would all be multiplied by the same filter weight and added into the total. In fact, these data values can all be summed and then multiplied by the filter weight to produce the same result.

Allowing for the fact that the central weight is not replicated and that the diagonal and axial weights replicate only 4 times, Equation 1, for a radially symmetric filter becomes: -

$$\begin{aligned} Fv = {} & Fw(0,0) \times D(0,0) \\ & + Fw(1,0) \times \sum_{RS_1} D(I,J) \\ & + FW(1,1) \times \sum_{RS_2} D(I,J) \\ & + \sum_{J=3}^{\bar{N}} \sum_{I=2}^{J-1} Fw(I,J) \times \sum_{RS_3} D(I,J) \quad \text{------ Eqn 2} \end{aligned}$$

where RS_1 is the axial replication sequence: — [(1,0), (0,1), (-1,0), (0,-1)]

where RS_2 is the diagonal replication sequence: — [(1,1), (-1,1), (-1,-1), (1,-1)]

and RS_3 is the previously stated octant replication sequence.

Although Equation 2 is a more complex expression than Equation 1 it requires significantly less operations to evaluate. Equation 1, for a 15 x 15 weight filter, requires 225 multiplications and additions whereas Equation 2 requires only 36 multiplications and 225 additions. Further savings are afforded as McGrath's filter contains 7 zero value weights and the addition of a clause of the Equation to skip multiplications involving zero weights reduces the number of operations to 29 multiplications and 181 additions.

Bench Mark Tests of the Application Algorithms

Just as Equation 2 is a more complicated expression than Equation 1, the source coding of the evaluation algorithm in a FORTRAN program is also more complicated. When a program is compiled using an optimization level greater than zero, more complicated source coding may frustrate the objective of reduced processing time as the optimizer may substantially improve the efficiency of simple coding but may leave virtually unchanged code whose complexities are beyond its scope. Accordingly Bench Mark runs were made to determine the actual processing advantage of Equation 2, if any. The programs were stripped down to the equation evaluation routine and each run for 2500 successive evaluations at various levels of optimization producing the following results.

Optimization level =	0	1	2
Equation 1	34.26 Cp Secs	14.74 Cp Secs	11.83 Cp Secs
Equation 2	10.11 "	8.07 "	8.09 "
% Saving	70%	36%	36%

As hoped for, Equation 2 showed a healthy 70% decrease in Cp time when run without optimization and as expected the use of the optimizer reduced the gap to a smaller but still definitely advantageous saving of 36%.

Further tests showed that the addition of the clause to avoid multiplication by zero weights decreased the saving to 21% when all weights were non zero but produced a savings of 90% for the extreme case where all weights were zero. Hence the clause is advantageous if at least 10% of the weights are zero.

The worst-best improvement is 76% which emphasizes the importance of good code and appropriate optimization.

Inclusion of 2 Dimensional Filter Routines within the Adam System

Two program modules were written to extend the ADAM System to allow 2 dimension filter application, GRDX1D and GFIL1A. GRDX1A, the standard module, takes the packed-word total suvey grid, extracts the area of interest, unpacks the data words, and if required extracts a super grid from the original. GRDX1D performs these functions but has the further option of breaking up the final grid into blocks with each block having a specified overlap on the adjacent blocks. A data grid so sub-divided allows a 2 dimensional filter to be applied without requiring prohibitively large storage capacity. GFIL1A applies the filter and produces a magnetic tape file containing the results in a form ready for input to a contouring program. The results of the application of a filter to the Timmins High Resolution Aeromagnetic Survey by the extended ADAM System are shown by Hood, McGrath and Kornik, this publication, report.

Conclusion

The cost of applying a 15 x 15 point filter to the standard grid (10.16 grid cells/inch) covering a 1:25,000 scale high resolution aeromagnetic map is estimated on the basis of the above bench mark runs to be less than $20.00. The cost of contouring the results will be in the range of $50 - $100 depending on the complexity of the data. (It is considered that an electrostatic plotter would be adequate, and probably more appropriate for plotting derivative maps, in which case the cost of contouring would also be less than $20.) This is considered to be cheap enough to allow systematic application of 2 dimensional digital filters to high resolution aeromagnetic data if the results of such filtering are thought to produce a useful variant from the standard total field contour map. An interesting statistic was derived from examination of the bench mark figures which emphasizes the advantage of digital data acquisition and processing.

If a person whose job consisted totally of pencil and paper calculations, worked official Public Service hours and was paid at the same rate per calculation as the computer is paid, their year's salary would be very close to one cent! So who does pencil and paper calculations any more? — buy them a pocket calculator and with training they might work 100 times faster, and raise their yearly salary to $1.00.

Acknowledgments

To the personnel of the E.M.R. Computer Science Centre for their patience and invaluable assistance.

30. EVALUATION OF DERIVED VERTICAL GRADIENT RESULTS IN THE TIMMINS AREA, ONTARIO

Project 720080

Peter J. Hood, P.H. McGrath and L.J. Kornik
Resource Geophysics and Geochemistry Division

Since the aeromagnetic survey technique was first introduced shortly after World War II, it has been apparent that much geologically-meaningful information that is present on the recorded analog profiles and correlatable from line to line is lost in the subsequent compilation of the data into total intensity maps. For this reason, most experienced interpreters utilize the original analog charts rather than reconstituting a given profile from the published map. Thus the charts have been retained as an end product of the aeromagnetic surveys and are available on what is essentially a permanent open file by the Geological Survey of Canada or in some cases by the responsible provincial government agencies.

With the advent of optical absorption magnetometers in the early 1960's, it became apparent that the resultant high sensitivity data should be recorded in a digital format. A prime reason was to overcome the dynamic range problem which was created in utilizing the higher resolution of the optical absorption magnetometers in order to permit the accurate delineation of the more subtle features, such as inflections on the side of an anomaly in the magnetic signature along a given flight line. In addition digital recording permitted the data to be compiled by computer, enabled various kinds of data processing techniques to be applied subsequently to the data, and permitted the modern techniques of data storage and transmittal to be utilized.

This progress report deals with a description of recent experiments at the Geological Survey of Canada in one type of data processing technique which is intended to make the magnetic survey data better reflect the underlying near-surface geology. Thus it is now generally accepted that other types of end product (usually referred to as derived maps) in addition to total intensity maps should be standard end products of high sensitivity aeromagnetic surveys.

One of the useful techniques which may be applied in the data treatment stage prior to interpretation is the calculation of the first vertical derivative of the total field. Vertical derivative calculations have actually been carried out for some time and Baranov (1953) appears to be the first to have constructed a template for calculating the first vertical derivative from a total intensity map. However, because the aeromagnetic data are degraded in the map compilation process, a significant proportion of the higher frequency signal is consequently lost in this procedure.

One of the main advantages of vertical gradient maps is that at high magnetic latitudes, the zero gradient contour outlines steeply dipping contacts between rock formations having a measurable magnetization contrast (Hood, 1965). Moreover the resolution of vertical gradient data is significantly better than total field data enabling nearby features to be better differentiated.

The first high sensitivity aeromagnetic maps that were compiled by computer at the Geological Survey of Canada resulted from a survey in the Timmins area of Ontario flown under contract by Canadian Aero Service Ltd. during the 1968/69 winter. Part of the resultant 10-gamma maps, which include Geol. Surv. Can. Aeromagnetic Maps 20,002G, 20,003G, 20,005G and 20,006G, are shown in Figure 1. The north-south flight lines were spaced 0.25 mile apart and were flown at 1,000 feet elevation. For clarity the boundaries of Macdiarmid and Jamieson townships have been shown on Figure 1.

Because of the availability of the digitally-recorded high sensitivity data, it was logical that the Timmins aeromagnetic survey data be the first to be used in evaluating digital filtering techniques. In addition the area had been the object of detailed ground geophysical investigations by the Ontario Division of Mines (Middleton, 1973, 1974).

It was hoped at the outset of the study that a one-dimensional vertical gradient filter would prove efficacious, because it is relatively simple to apply such a filter sequentially along the lines and then contour the resultant values. The result of applying a low pass one-dimensional vertical gradient filter which utilized a 41-point operator is shown in Figure 2. It is clear that the north-northwest striking linear anomalies, which are due to a diabase dyke swarm, are suppressed and that many other features with considerable areal continuity tend to be broken up into smaller circular anomalies which are difficult to relate to one another. Thus it is clear that the one-dimensional vertical gradient filter tends to emphasize those features which strike at high angles across the flight lines and discriminates against those features which are subparallel to the flight lines.

In order to avoid the foregoing directional filtering problem, it was decided to experiment with two-dimensional vertical gradient filters, and P.H. McGrath undertook the task of devising one. The resultant filter is described in a preceding report so that the interested reader may experiment with it. The use of a two-dimensional array of filter weights with which to convolve the aeromagnetic data requires much more computer time than a one-dimensional filter and the techniques for minimizing this are described in the preceding paper by M.T. Holroyd. We would however warn the potential user that his data must be of good quality, preferably high sensitivity and noise free, and also, be without significant levelling errors.

Figure 3 shows the resultant vertical gradient map which resulted from the convolution process using the two-dimensional vertical gradient operator. All positive gradient values have been shaded and Macdiarmid and Jamieson townships have been outlined

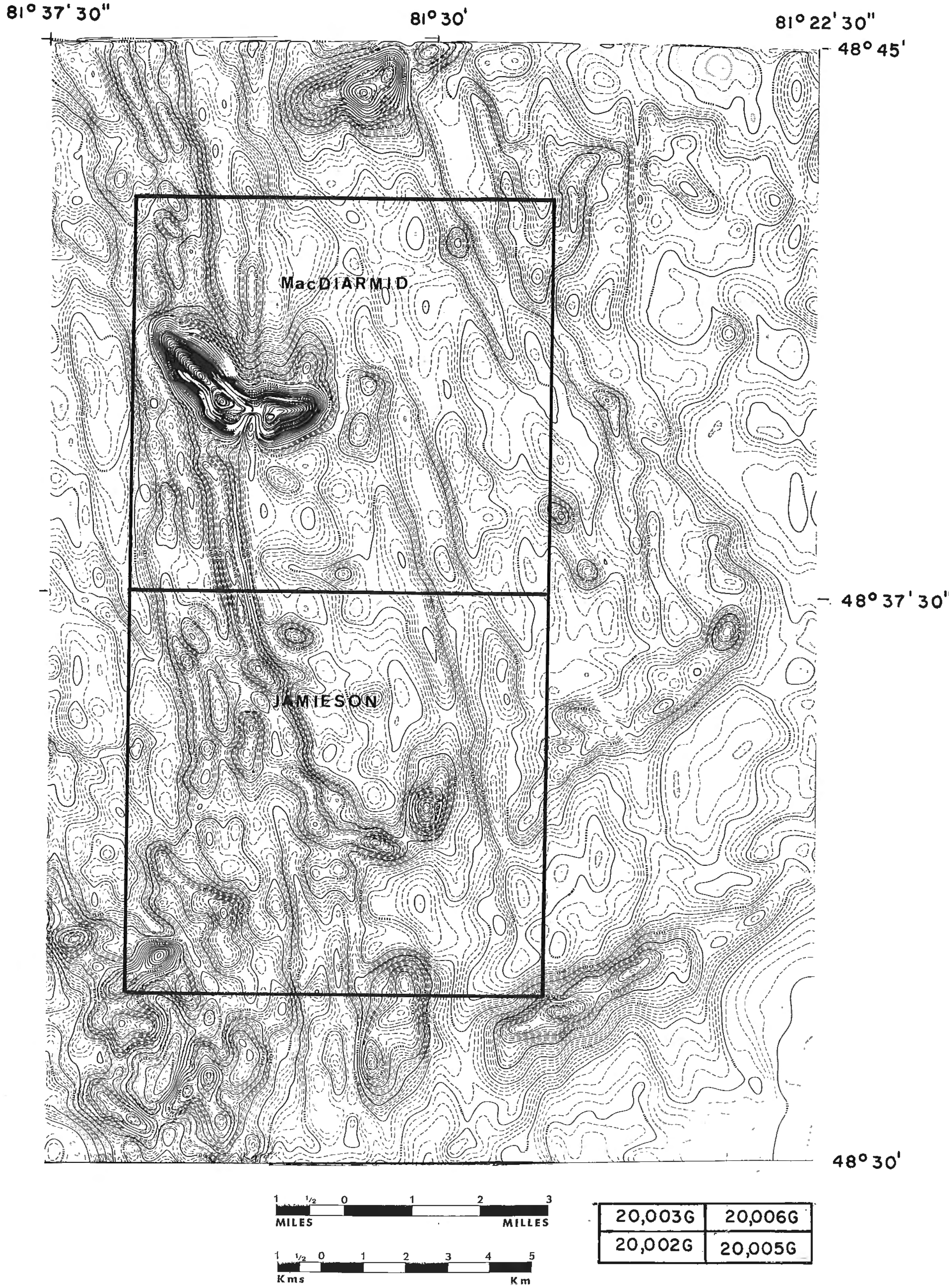
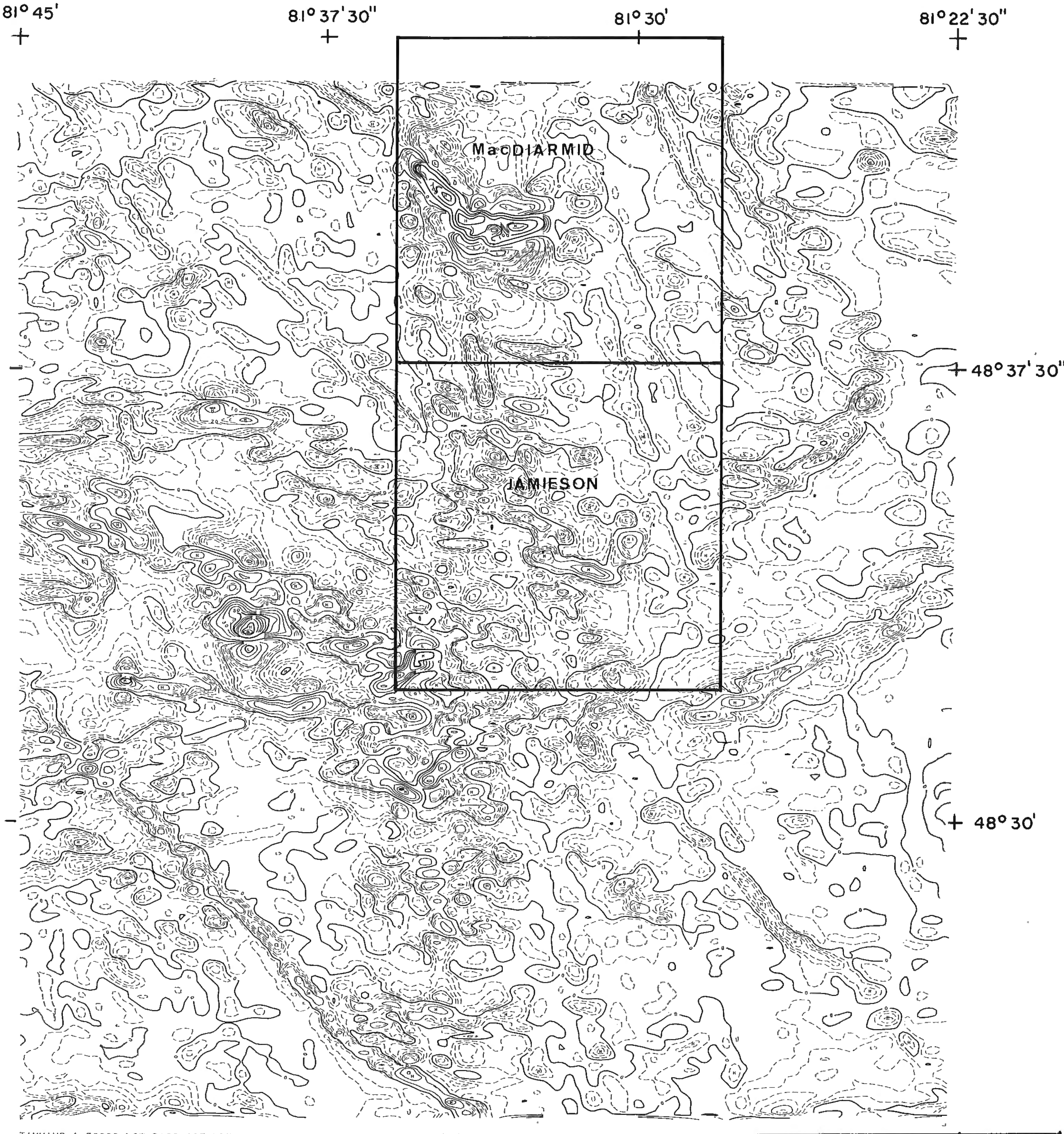
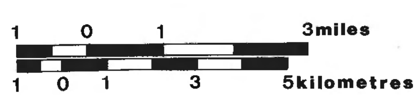


Figure 1. Total intensity map of part of the Timmins area, District of Cochrane. The contour interval is 10 gammas. Macdiarmid and Jamieson townships have been outlined by the solid lines.





20,003G	20,006G	20,009G
20,002G	20,005G	20,008G
20,001G	20,004G	20,007G

Figure 2

Vertical gradient map of the Timmins area obtained using a 41-point operator on the total intensity values which were spaced approximately 46 metres (152 feet) along the flight lines.

Figure 3.

Vertical gradient map of the Timmins area obtained using a two-dimensional 177 point operator on gridded data (sampling interval 125 metres (410 feet)).

by solid lines. It is instructive to compare the Precambrian geology of these townships published by Middleton (1973, 1974) at a scale of 1:31,680 with the features appearing on the total intensity and vertical gradient maps. Middleton also presents vertical force ground magnetic maps for the townships, and these have been used in the preparation of the geological map. The area lies at the western end of the Abitibi greenstone belt and the bedrock consists of Precambrian metavolcanics, metasediments and mafic and felsic intrusive rocks which are cut by a swarm of diabase dykes.

When the vertical gradient and total intensity maps are overlain in turn directly on the geological map enlarged to the same scale, the better resolution of the former is immediately apparent. Individual features on the vertical gradient map are much better defined and are generally narrower in width. For instance, in Macdiarmid Township the feature labelled Y on Figure 3 is only apparent on Figure 2 after close scrutiny. It is due to bifurcating diabase dykes. The dyke swarm that strikes south-southeast of the prominent anomaly (due to a composite intrusion of gabbro, peridotite, dunite and serpentinite containing asbestos veins) in the west-central part of Macdiarmid Township is not readily apparent (except for one prominent dyke) on the total intensity map (Fig. 2). Actually most of the individual dyke anomalies observable on the ground magnetometer map are also apparent on the vertical gradient map except in a few cases where two dykes are very close together.

We have also concluded that faults are more easily detectable on vertical gradient maps than on the equivalent total intensity map. The reason for this is that individual anomalies are narrower on the vertical gradient map so that offsets of the contours are more apparent.

Unfortunately in the present area studied there are an excessive number of dykes which tend to dominant the resultant filtered maps and mask the regional geology. It is therefore intended to apply the same filter to other areas which have been surveyed by high resolution magnetometer in order to further assess its capability as a near-surface geological mapping tool.

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31. GROUND MAGNETIC SURVEY, ROBERTS ARM, NEWFOUNDLAND

Project 680121

P.H. McGrath and G.W. Cameron
Resource Geophysics and Geochemistry Division

During the 1974 field season, a vertical field ground magnetic survey was carried out near Roberts Arm in north-central Newfoundland in support of, the geological mapping of the Roberts Arm Group (*see* Bostock, this publication, report). The aim of the project was to map variations in lithology and structure within the Ordovician volcanic and sedimentary Roberts Arm sequence, and to relate these features to associated mineral deposits.

Figure 1 shows the location of the survey lines which were traversed by a two-man team. The lead man ran the line using a compass and air photographs. He towed a 25-metre-long rope which was tied to his backpack, and flagged the stations to be occupied. The second man signalled the lead man when he had proceeded 25 metres, and read the magnetometer at the flagged stations. This procedure worked well, the tow rope seldom becoming fouled even though the trees were often closely spaced. The total length of lines traversed was 162.5 kilometres, representing approximately 6,500 stations.

Two Sharpe MF-1 fluxgate magnetometers were employed for the survey. One magnetometer was used for traversing, while the other was connected to a strip chart recorder at a fixed base station and used to continuously monitor variations in the earth's magnetic field occurring throughout the day. The base station was established in an area of low gradient at Roberts Arm, and the two instruments were arbitrarily set to readings of 500 gammas each morning at this station. The traversing magnetometer was reread at the base station at the end of the day. Due to varying rates of drift, differences between the two magnetometers of a few tens of gammas were often measured. For purposes of correcting the data, the base station magnetometer was assumed to have a zero drift and the traversing magnetometer a linear drift. The base station record was used to supply diurnal corrections to the traversed data.

The corrected magnetic data from Southbrook to Roberts Arm (*see* Fig. 1) is represented in Figure 2 as the unfiltered trace. These measurements were collected holding the magnetometer as close as 3½ feet above the potential causative bodies. In order to adequately sample variations in the magnetic field at such close proximity to the causative sources, a sampling interval of approximately two feet (McGrath, in press) would be required. Such a sampling rate is not feasible if one wishes to survey a large area. We arbitrarily selected a sampling interval of 25 metres, and as a result our data probably contains aliased anomalies. Aliasing occurs when an apparent longer wavelength anomaly is produced from a series of small anomalies whose spatial extent is less than two sampling intervals. In addition, some of the smaller anomalies were undoubtedly missed by our survey. These shortcomings in the data appear to be problems with which we are forced to live.

The magnetic data shown in Figure 2 contains many one station anomalies which are caused by variations in magnetization which are not persistent over more than one station. The filtered trace presented in Figure 2 is a representation of the magnetic trace after it has been passed through a digital filter. A three point recursive filter (Shanks, 1967) was used for this purpose where

$$F_n = aM_n + b_1 F_{n-1} + b_2 F_{n-2}$$

and

F_n = the filtered data,
M_n = the original magnetic data,
a, b = filter weights,
n = 1 to N, and N represents the number of data points.

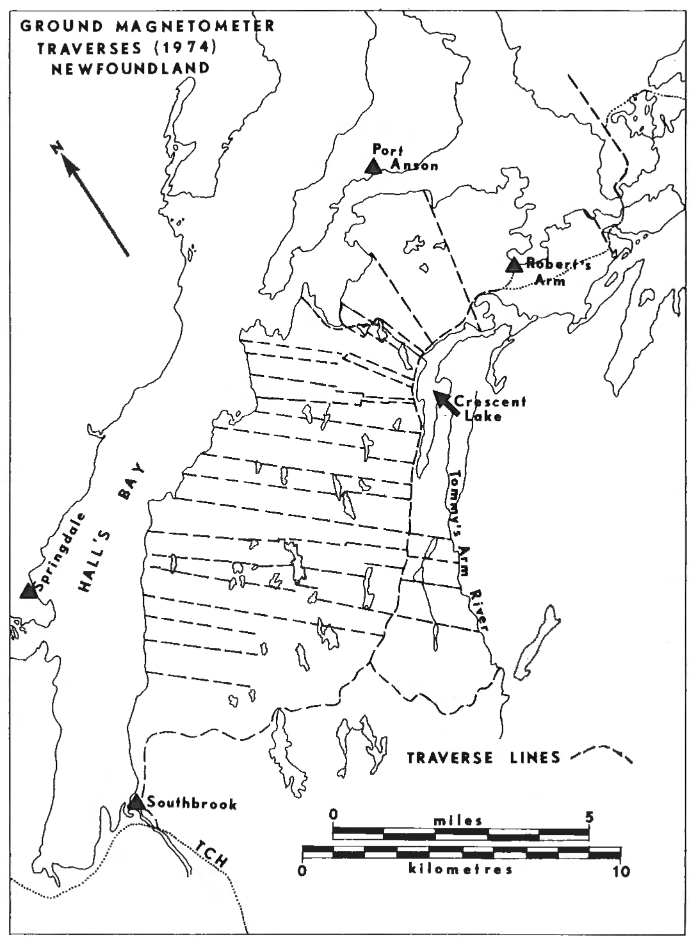

Figure 1. Ground magnetometer traverses in the Roberts Arm Area, Newfoundland.

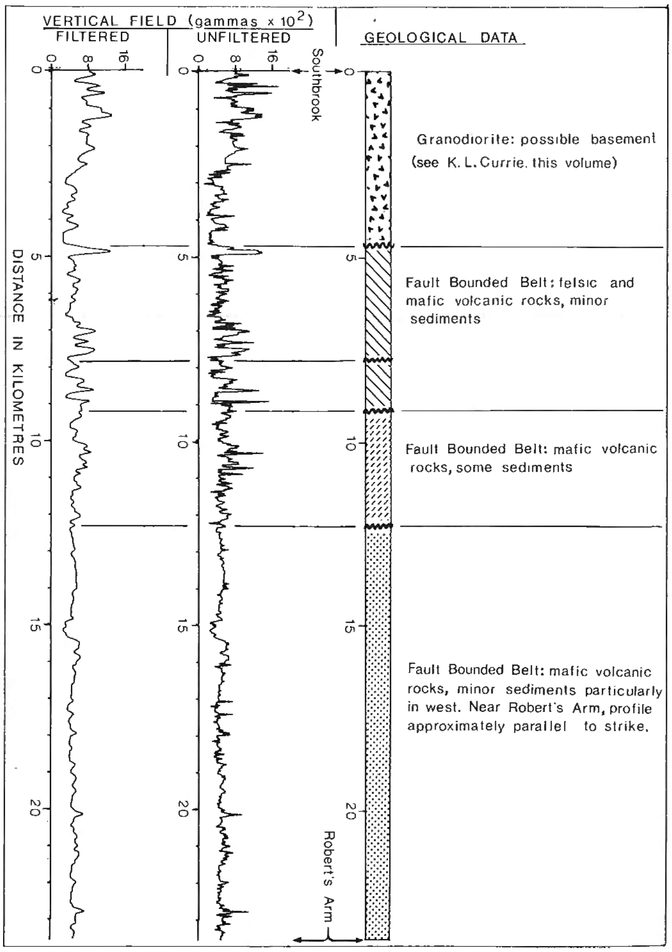

Figure 2. Comparison of filtered and unfiltered ground magnetometer data with geological cross-section along profile from Southbrook to Roberts Arm.

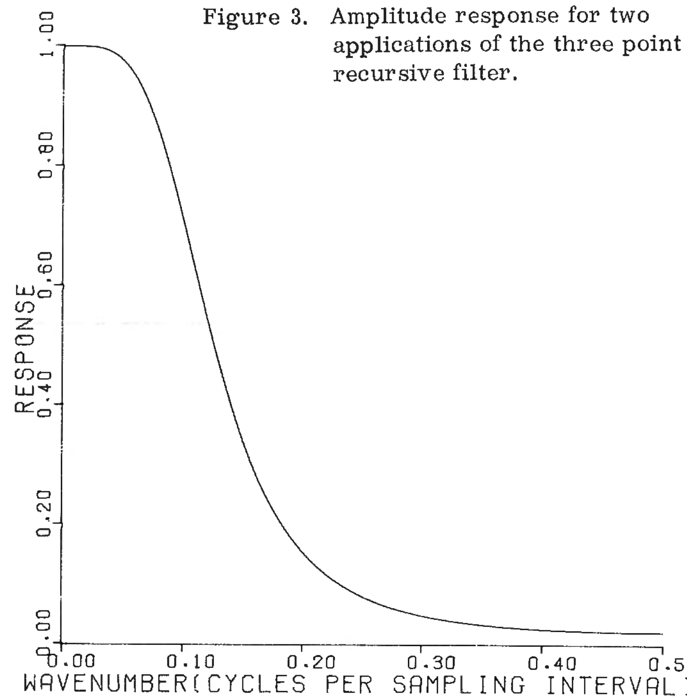

Figure 3. Amplitude response for two applications of the three point recursive filter.

TABLE OF WEIGHTS	
a	0. 33871
b_1	0. 99193
b_2	−0. 33064

The filter is of the feedback type, and produces a phase shift in the frequency components comprising the magnetic data. In order to overcome this problem the filter is applied twice, in one direction on the original data and again in the return direction using the once filtered data as input to the filter. This assures a zero phase shift in the resultant data. Figure 3 is an amplitude response curve for two applications of the filter. It can be seen in Figure 3 and in the filtered trace (Fig. 2) that most of the one station anomalies are eliminated by the filtering procedure, and we are able to see variations in the magnetic data which are persistent over several stations.

In comparing the two magnetic traces with the local geology derived from a traverse along the Roberts Arm highway (*see* Bostock op. cit.), there seems to be little in the way of longer wavelength anomalies in the magnetic data which could be correlated to changes between fault blocks. There is, however, a gradual increase in the level of the magnetic field as one proceeds from the fault contact at about kilometre 4. 7 toward Southbrook which could be a reflection of zonation within the granodiorite.

The most striking feature in both the filtered and unfiltered magnetic data is the variation in amplitude and wavelength of the smaller anomalies along the profile. We can in fact divide the magnetic profile into six patterns or signatures. Signature one occurs between kilometres 0. 0 and 4. 7, and corresponds to the granodiorite. At kilometre 4. 8 a large amplitude local anomaly was recorded which is caused by a thin zone of mafic volcanic rocks. The high intensity of this anomaly as compared to other mafic volcanic anomalies suggests that the intensity of magnetization of this unit may have been enhanced by contact metamorphism caused by the adjacent granodiorite although other geological evidence would refute this interpretation (*see* Currie, this publication, report). Signature three extends from kilometres 5. 0 to 6. 9 and corresponds to a zone dominated by felsic volcanics. Signature four from kilometres 6. 9 to about 9. 0 is related to a zone of mafic volcanics with minor sediments. The fault at kilometre 7. 8 is not apparent in the magnetic data. Signatures five and six occur between kilometres 9. 0 to 12. 3 and from 12. 3 to Roberts Arm respectively. Hence we can observe the seemingly good correlation between variations in magnetic signature and geological map units.

The magnetic signatures obtained in the ground survey are caused by inhomogeneities in the near surface rock magnetizations. It is suggested that the magnetic signatures are related to variations in lithology and/or variations in the structural-metamorphic history of the rocks within each associated belt. Hence it appears that the mapping of the geographical distribution of the various magnetic signatures may be an effective aid in support of the geological mapping of the Roberts Arm Group. Analysis of the additional ground magnetic data plus completion of geological mapping in the surrounding terrain will provide an improved basis for assessment of this correlation.

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A SEISMIC INVESTIGATION NEAR FLIN FLON, MANITOBA

Project 660053

A. Overton
Resource Geophysics and Geochemistry Division

Introduction

In June 1966, a team from the Seismic Section of the Geological Survey of Canada set out to determine whether seismic methods could be used to detect interfaces between Precambrian rock-units near Flin Flon, Manitoba (Hobson, 1967). Two profiles (locations A and B, Fig. 1) were located off Highway 35, 20 km southwest of Flin Flon. Profile A consisted of an eleven station, 0.9 km linear seismometer array which recorded nine dynamite blasts detonated in lakes to the northwest and southeast colinear with the array. Distances of the blasts from the array ranged from 1.4 km to 3.6 km. Profile B consisted of a twelve station linear seismometer array 168 m long which recorded blasts from three shotpoints colinear with, and in the lake to the northwest of the array (Figs. 1 and 2). Distances of these shots from the array ranged from 6 m to 685 m. All seismometers for both arrays were set on outcropping bedrock, thus minimizing complications of delay time variations on the array due to muskeg and drift.

The two profiles were situated about 490 m from JXWS borehole A (Fig. 1). Interval velocities from sonic logs in relationship to borehole lithology were obtained for the 3.03 km hole depth (Geophysical logs, 1966). In particular, seismic data were examined for evidence of refracted and/or reflected energy from velocity and lithological discontinuities in the borehole. In general, seismic events were also examined which may be related to many other interfaces between Precambrian rock-units in the vicinity of the profiles (Fig. 3). Many seismic events were observed, some which are unrelated to the shot complicate interpretations. This report presents an attempt to explain all events which were observed, an interpretation of their significance, and suggestions for improving field techniques for similar experiments.

Geological Setting

The general geology of the area (Fig. 3) is described by Froese (1969).

> "The Precambrian rocks of the Flin Flon region are divided into three units. Predominantly volcanic rocks of the Amisk Group and clastic sedimentary rocks of the Missi

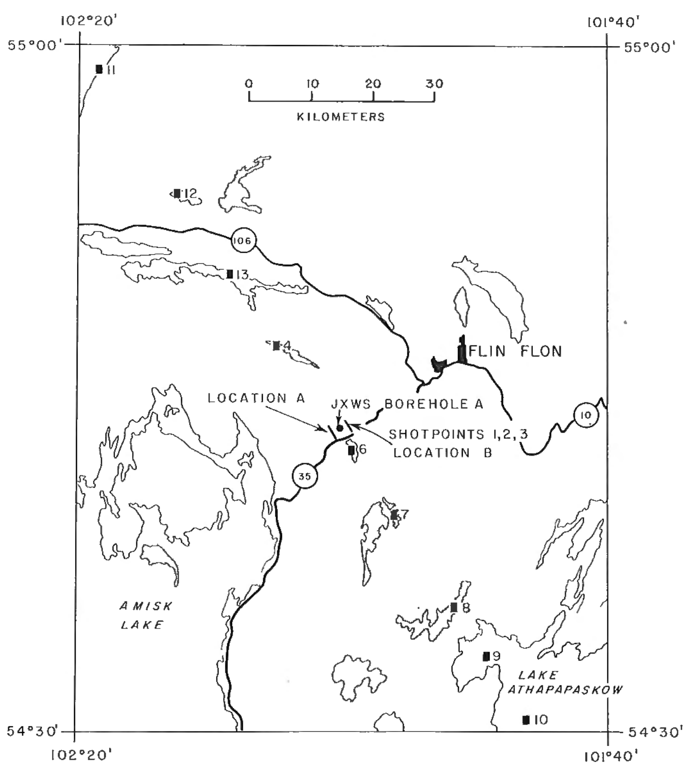

Figure 1. Location map showing shotpoint and seismometer arrays for profiles A and B in relationship to JXWS borehole A.

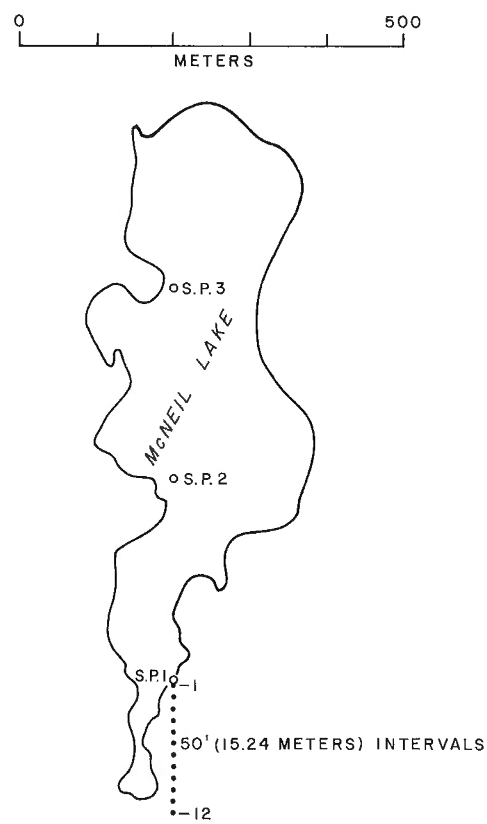

Figure 2. Detailed plan of profile B.

Group form a sequence of rocks, which, in the northern part of the region, have been metamorphosed to gneisses constituting the Kisseynew Complex. Numerous basic intrusions are associated with the Amisk volcanic rocks. During a period of orogeny, all these rocks were subjected to deformation and regional metamorphism accompanied by granodioritic intrusions. The masses of granodiorite, as well as all earlier rocks, are cut by late wrench faults and shear joints. The area is underlain by rocks of the Amisk Group, basic intrusions, and granodioritic masses. The volcanic rocks contain some sulphide mineralization."

Borehole Data

Average interval velocities from sonic logs (Geophysical logs, 1966) for 30.48 m intervals and borehole lithology (Gendzwill, 1968) are shown (Fig. 4) for the 3.03-km depth of the borehole. Interval velocities increase abruptly from 5.46 km/s near the surface to 5.83 km/s from 60 to 400 m. An inversion to 5.75 km/s at 400 m marks the beginning of a gradual increase in velocity to 5.95 km/s at 2 km. Another inversion to 5.86 km/s precedes an abrupt increase at 2.2 km to an average of 6.1 km/s for widely varying velocities in the remainder of the borehole. This abrupt increase does not appear to correlate exactly with indicated interfaces between rock-units, but probably marks the change from less dense leuco quartz diorite to denser mafic quartz diorite having densities of 2.68 and 2.81 g/cc respectively (Gendzwill, 1968). If this abrupt increase in velocity represents a seismically detectable interface which persists over the region covered by the seismic profiles at the indicated depth of 2.2 km, it should be evident as a reflection at about .75 second travel time at close recording ranges, and as a first arriving refracted event having a velocity of about 6.1 km/s and a delay time of about 0.2 second beyond a recording range of 31 km.

Operational Procedures and Problems

An account of procedures and problems is necessary as they affect interpretations of the data.

The fundamental parameters in seismic exploration are distance and time. Depending upon the type of geological problem being investigated, these parameters may be determined with varying degrees of precision. For the present problem which seeks to delineate contacts between Precambrian rock units, variations in seismic velocity within the different units and resulting differences in time through different seismic paths are likely to be small. Time differences of a few milliseconds may be highly significant. The oscillograph paper speed used (33 cm/sec) was adequate to give a timing resolution of ± 1 ms, but a number of problems encountered weaken, and in some cases make entirely impossible, any attempt at interpretation of recorded events. These problems are itemized:

1. Short period blasting caps (1 period) were used. These detonators have an expected firing time of 30 ms and the standard deviation is not expected to be greater than ± 5% providing that the minimum firing current of 1.5 amperes is ensured. Three tests were taken to establish the cap detonation time by recording the firing pulse and the pulse produced on a seismometer by the detonation. All three tests show a detonation delay of 36 ms, which is large compared with the expected value. This discrepancy may have been caused by the exponentially decaying firing current from the capacitive-resistive blaster which was used. This timing discrepancy would be a minor source of error providing it remained constant within a few milliseconds on all records. Seismocaps are specifically designed to meet the rigid requirements of seismic exploration and should be used in such an experiment.

2. The tests using short period blasting caps utilized a direct ohmic connection for recording the application of the firing pulse. When the shot point is displaced from the recording instrument by more than a few hundred metres, wire leads connecting the blaster to the recording instrument become prohibitively long. In these cases, the detonation pulse is more easily transmitted to the recorder by radio. This is effected by transmitting from the shooter's radio a tone which is terminated by the detonation pulse; the tone is recorded on the oscillograph and the cut-off point provides a timing reference. All the records of this experiment indicate a malfunction in this system. On two of the nine records for profile A there were no "time breaks" at all. On the remaining records the tone does not terminate as it should, but decays in an apparently exponential manner after a pulse which is presumed to represent the application of the firing current. No calibration was done on this system to check its reliability, but two records taken at close range indicate that the previously determined cap detonation correction of -36 ms yields travel times which are at least a few milliseconds too small, when applied to the first arrival times referred to the transmitted reference pulse. This discrepancy may also be tolerable if it remains constant on all records, but reliability of timing precision is in doubt on at least three records. The malfunction was most serious when no time break was recorded at all, making these records uninterpretable except in a qualitative sense. These shots should have been repeated until suitable time breaks were recorded.

3. Shotpoints were established in lakes by landing an aircraft in the vicinity of predetermined positions. The position of the ensuing shot was noted on aerial photographs by visual reference to shoreline features or other landmarks. Distances to the seismometers were then measured from 1:50,000 and 1:63,400 scale maps. Uncertainties in distance can be larger than one hundred metres by this method, corresponding to timing errors of 17 ms at a typical velocity of 6 km/sec. These uncertainties could have been reduced by a factor of ten by marking the shotpoint with a buoy and photographing the buoy relative to nearby landmarks

from the air. Shotpoint positions could then be determined by photogrammetry.

4. A glance at the geological map of the area (Fig. 3) shows the great number of possible interfaces between different rock-units and the faults which exist. The seismic method may be effective in detecting any one of them. It would be highly fortuitous if seismic events related to these interfaces should have travel paths confined to a vertical plane containing the shotpoint

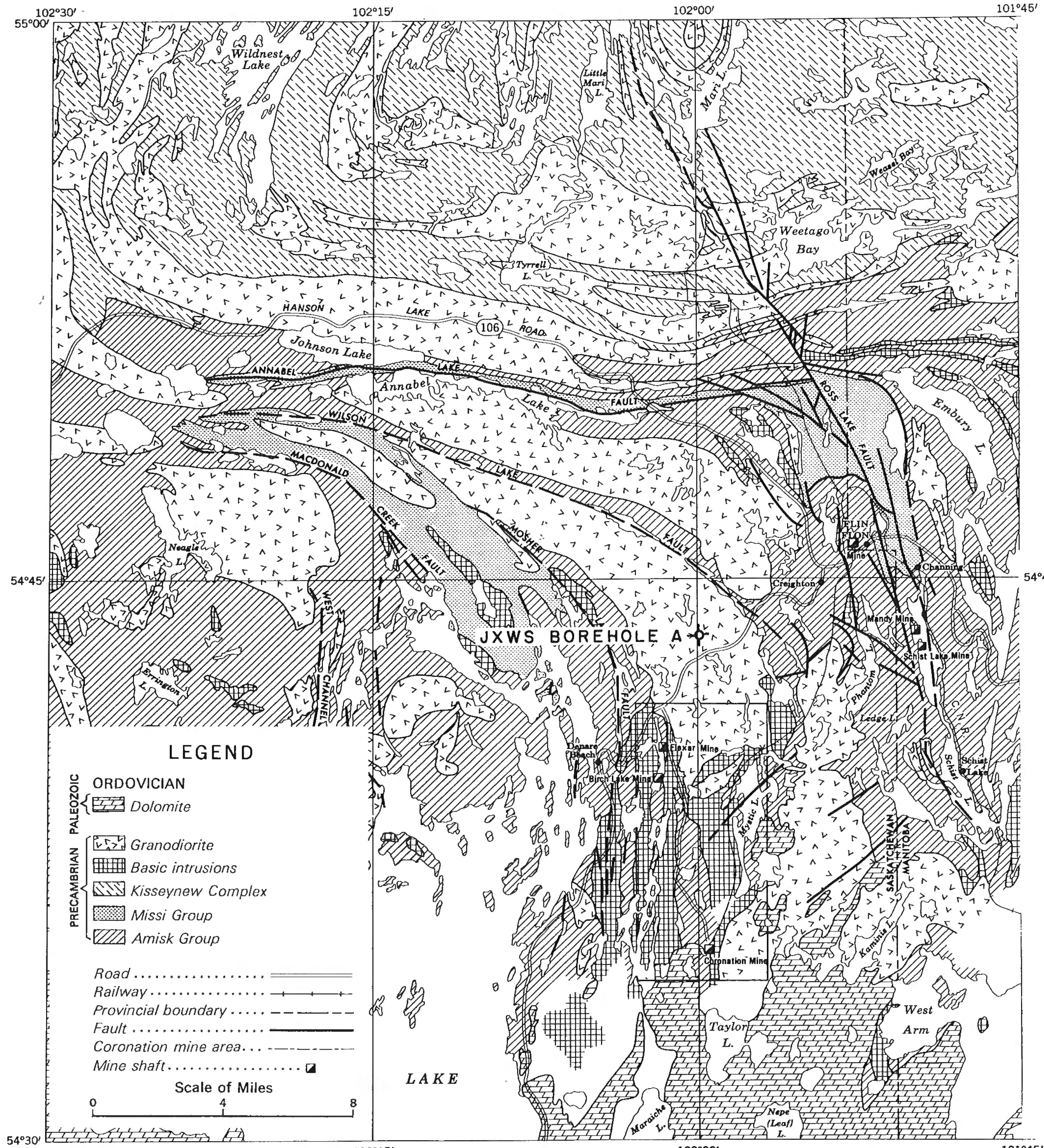

Figure 3. Geology of the region relating to the experiment, after Froese, 1969.

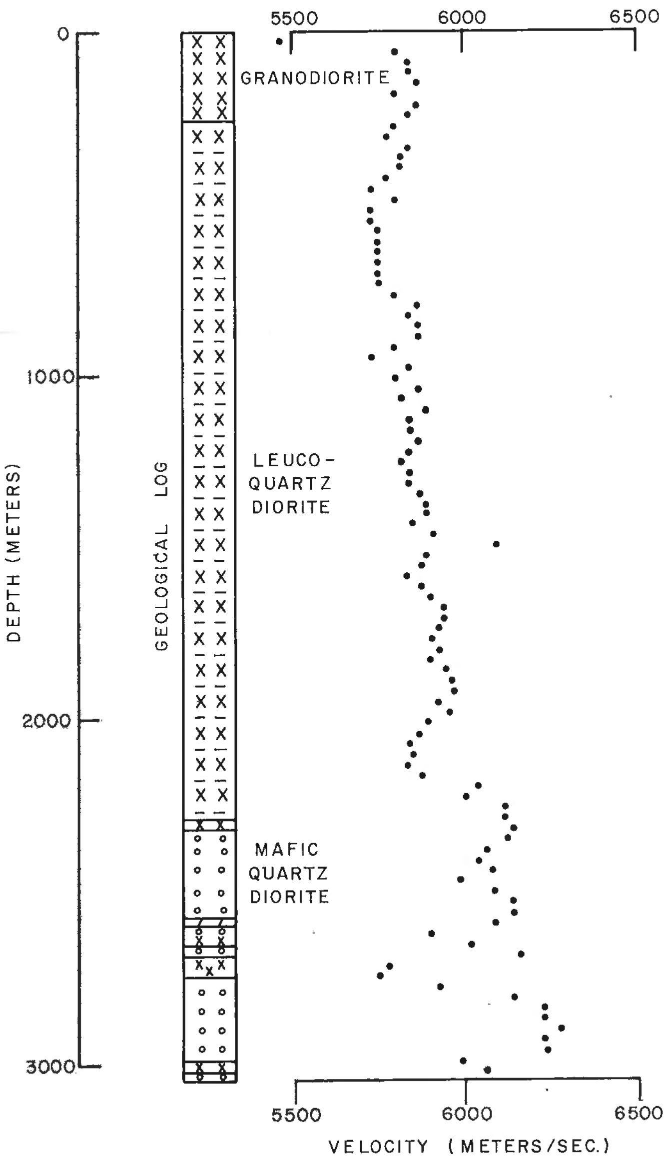

Figure 4. Geological log (Gendzwill, 1968) and interval velocities at 30.48 m intervals for JXWS borehole A.

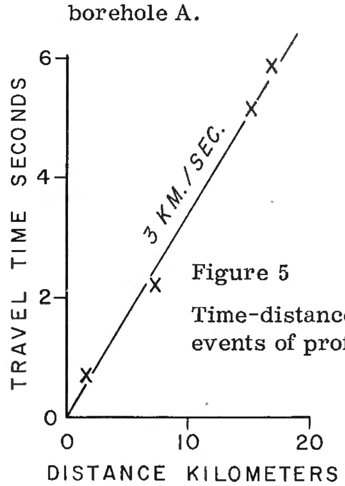

Figure 5

Time-distance plot for secondary events of profile A.

and seismometer spread. Yet this is the type of event which is generally presumed on analyzing data from linear seismic profiles such as those used in this experiment. Structures off-line giving rise to reflections, refractions or diffractions cannot be pinpointed except vaguely as being a certain distance perpendicular to a point on the profile within the half space beneath, or on the ground surface. To facilitate positive interpretations the seismometers should have been laid out with an areal distribution; common arrays used are "cross spreads" which consists of two linear seismometer arrays having different azimuths (ideally at right angles). This simple expedient allows the determination of true velocities and direction of propagation of seismic events which in turn allows an interpretation of a position for the causative interface. It is also preferable, before even conducting the experiment, to select particular interfaces of interest, and design the shotpoint and seismometer patterns to facilitate detection of each interface.

5. Charge sizes were too small to produce interpretable events on two records of profile A. These shots should have been repeated with larger charges.

6. There is evidence that muskeg or drift on the lake floors underlying the shots produce large delay times. Muskeg thicknesses may be 60 m as suggested by the depth of some of the lakes in the area. This thickness can produce delay times of about 30 ms which must be accounted for if events from Precambrian interfaces are to be analyzed. Shotpoint delay times should have been measured either by close range recording or reversed profiling.

7. On at least one seismogram which was recorded for 25 seconds before the shot detonated, there is unmistakable evidence of considerable local seismic activity which is not related to shots of the experiment. On this particular record there are at least a dozen well defined events which precede the shot time. These events must be caused by local natural, cultural or industrial activity. A certain amount of this form of extraneous seismic activity may have been due to the mining and construction activity in the area and trucking operations on nearby highways. These events are interpretational problems on some other records where they cannot be identified positively as being unrelated to the shot. Here again, at least two shots at each location and the minimum requirement of repeatability for a shot-generated event will solve this problem.

8. Seismograms for profile B were recorded with the instrument set for a passband of 30 to 215 Hz, a medium speed automatic sensitivity control, and maximum ultimate sensitivity. These records are characterized by shot-generated events with travel times as much as one second, after which a high level of wideband noise (50-500 Hz) is evident. Most of this noise is unmistakably generated by the instrument itself and is a result of operating at full sensitivity with noisy amplifiers. It is revealed as instrument noise by at least two records having an inoperative seismometer. The oscillograph trace for this seismometer naturally

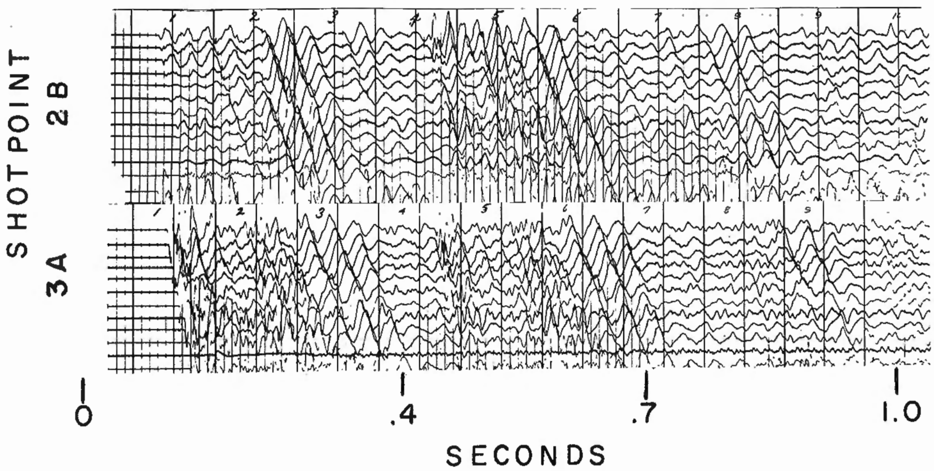

Figure 6

Record section showing events recorded on profile B.

shows no evidence of shot-generated energy, but after the automatic sensitivity control has allowed the instrument to assume its maximum sensitivity, the trace becomes as active as the other eleven traces, showing the same wideband noise with much similar phase relationships. This is due to a faulty recording procedure; the instrument should not be operated at maximum sensitivity with noisy amplifiers. The sensitivity should be reduced so that with no automatic sensitivity control the traces are quiet, and charge sizes should be increased to compensate for the decreased sensitivity.

9. Records of shotpoints 12 and 13 show seven pulses which affect all oscillograph traces simultaneously. These pulses were recorded at an intermediate sensitivity and are unmistakably caused by an instrument malfunction. A more subtle suggestion of this problem is seen on records of profile B which were taken at full sensitivity; however, the problem is not so convincingly due to instrument malfunction on these records because events which occur simultaneously are the rule rather than the exception due to the short seismometer array. Many types of events, especially extraneous seismic activity broadside to this array would appear to affect all traces simultaneously. The malfunction creates further doubts since it produces pseudo events which cannot be identified positively as such. Even duplication of shots does not remove this doubt when the instrument is used at full sensitivity and automatic sensitivity control; in this mode the instrument is highly susceptible to decay characteristics of bias voltages and noise in the automatic sensitivity control network. Time constant characteristics can cause instrument generated pulses to repeat with successive trials and create pseudo events which may be misinterpreted. Again this is a problem of using high sensitivity with noisy amplifiers.

Secondary Surface Events

Five of the nine records (6, 7, 8, 12, 13) of profile A show events with apparent velocities of approximately 3.2 km/sec and frequencies of 6-20 Hz. On these records the events appear to be shot generated, with a time-distance relationship of 3.0 km/sec. (Fig. 5). These events might be representative of transverse or shear waves in the near-surface rocks. On records 8 and 11 similar events are recorded which are definitely unrelated to the shot, with some showing negative time-distance relationships, preceding the first arrivals from the shot and even preceding the shot time. These events are caused by local seismic activity unrelated to the experiment. Their similarity in velocity and character with shot generated events interpreted as transverse waves suggests that this mode of propagation is most efficient in transmitting local noise.

Some of the shot generated events on records 8 and 13 may be due to Rayleigh wave propagation. For the special case where Poisson's ratio for the propagating medium is 0.25, the ratio of velocities for Rayleigh waves to shear waves is about 0.92. This ratio is approximated by the events on records 8 and 13 which indicate both average and apparent velocities of 2.94 km/sec. These events are characterized by the low frequency of 6 Hz.

Local Seismic Activity

Records 8 and 11 show many events with the characteristic hyperbolic time-distance relationship of seismic reflections. They occur randomly over the entire length of the records, with many of them preceding the shot time, thus establishing their source as being unrelated to the shots of the experiment. Many of them are well defined and lend themselves to analysis by least squares fitting of a hyperbolic curve which yields estimates of distance of the source from the array, and velocity of propagation. The source is indicated to be a distance of about 190 m perpendicular to the seismometer-array from a point about 140 m southeast of the northwest end of the array. On the ground surface this position is close to two other boreholes on either side of the array. The noise may be related to activity near the boreholes. The velocity is approximately 3.7 km/sec which is suggestive of transverse wave propagation.

Apparently Correlating Events

Two conspicuous events were recorded with travel times of about 4.7 seconds on record 6 and 5.0 seconds on record 7. They stand out, even against a high level of background seismic activity, by virtue of their negative time-distance relationship; that is, the travel times decrease with increasing distance of the seismometers from the shotpoint. This pronounced character suggests that the events may correlate between the two records, which in turn implies that the events are shot generated rather than due to extraneous seismic activity. A small degree of hyperbolic variation of the travel times across the seismometer array suggests that the events are due to reflected seismic energy. Apparent velocities are about -23 km/sec and -17 km/sec respectively. If these events are caused by reflection of shot-generated energy from a plane interface, the interface must have a component of distance colinear with the profile on the opposite side of the seismometer array from the shotpoints in order to reverse the time-distance relationship. The very high absolute values for apparent velocities require that the interface also be offset perpendicular to the profile. These distance components depend upon the velocity of propagation for the events, which was not measured. Estimates of these components assuming compressional wave propagation (6 km/sec) and transverse wave propagation (3.05 km/sec) are shown in Table I, which indicates that the reflecting interface for the two shotpoints is not coincident. Neither is it coplanar. It is impossible to be more explicit in accounting for these events; it is not improbable that they are in fact, due to extraneous seismic activity. Duplicate shots would have removed the latter doubt, and a dual azimuth seismometer array would have allowed the determination of the direction and velocity of propagation.

First Arrivals

Table II itemizes the average distances, times, apparent velocities, average velocities, and relative delay times for the first arriving compressional wave events of both profiles A and B.

In general, Table II shows that apparent velocities (column 5) increase with distance of the shotpoint from the seismometer array. Velocity differences between the closest and the furthest shots are highly significant. For example, the difference in velocity of 0.43 km/sec between shotpoints 4 and 12 forms a ratio of 5.25 with its standard deviation. The corresponding ratio for the 0.1% probability level is about 4. The difference is therefore highly significant and cannot be attributed to uncertainties in the data; the difference could arise by chance in such an indicated population only once in more than a thousand trials.

Close range recording tends to give velocities similar to near surface velocities from the JXWS borehole "A" sonic log (Fig. 4).

A major and significant increase in velocity is indicated for shotpoints 11 and 12 compared with closer shots. It is indeed unfortunate that no attempt was made to obtain a shot reference time on these records, as they may show the only positive indication of seismic events related to a Precambrian interface resulting from the whole experiment. However, allowing for some possible dip on the interface indicated in the borehole at 2.2 km the range at which this increase occurs is not incompatible with that required for the interface. The higher velocities measured from shotpoints 11 and 12 may then represent the denser mafic quartz diorite layer indicated at 2.2 km in the borehole.

At closer ranges, between shotpoints 4 and 10, velocities appear to be generally higher from shots to the southeast than from those to the northwest; this may represent a shallow seismic interface with a component of dip toward the southeast. There is no clearly defined evidence for such an interface on the borehole velocity log.

Average velocities are shown to be highly dispersed with no consistent trend. Delay times are shown computed with respect to the highest average velocity merely to avoid negative delay times. This does not imply that negative delay times cannot exist, they probably do exist in Precambrian seismology, it just means that they cannot be accounted for with the data of this experiment. The delay times are also highly dispersed. It is impossible with the data of this experiment to interpret these delay times into their components which may consist of timing errors, distance errors, varying thicknesses of drift or muskeg, or varying depths to a shallow seismic interface under the shotpoints.

Details of Profile B

Records of profile B show many characteristics which require description. Figure 6 is a one second section of records from shotpoints 2 and 3 showing the distinct events recorded on this profile. These events may be separated into three groups between 0-0.4 second, 0.4-0.7 second and 0.7-1.0 second. The second and third groups are replicas of the first group and are caused by an oscillating collapse of the gas bubble resulting from shots in water. These oscillations act as new sources of seismic energy and duplicate whatever events are created by the initial explosion. The time interval in seconds between events from the initial explosion and the first oscillation or "bubble pulse" is given by the well known formula:

$$T = 2.03\, M^{1/3}\, (D + D)^{-5/6}$$

where M is the charge weight in kilograms and D is the depth of water in metres overlying the charge.

Events in the first group, from the initial explosion, appear to correlate from record to record. These events are plotted on the time-distance graph (Fig. 7). First arrivals show compressional wave velocities ranging from 5.39 to 5.74 km/sec (also see Table II). Ratios of differences to standard deviations for differences for these three velocity determinations are small, indicating that the differences are likely to be due to uncertainties in the data rather than to physical causes. Velocities for the later events ranging from 2.0 to 2.7

TABLE I

DISTANCE COMPONENTS WITH RESPECT TO SEISMOMETER ARRAY

	COLINEAR NW	PERPENDICULAR	COLINEAR NW	PERPENDICULAR
VELOCITY OF PROPAGATION	COMPRESSIONAL	6 km/sec	TRAVERSE	3. 05 km/sec
Shotpoint 6	3. 6 km	13. 1 km	0. 6 km	6. 8 km
Shotpoint 7	4. 3 km	10. 4 km	0. 7 km	5. 2 km

TABLE II

Direction of shotpoint from array	Profile and shotpoint	Average distance kilometres "X"	Average time seconds "T"	Velocity on array km/sec with std. dev.	Average velocity km/sec "X/T"	Delay times seconds "T-X/6. 051"
	A 11	35. 52	No time break	6. 45 ± . 08		
	A 12	23. 79	"	6. 51 ± . 18		
	A 13	15. 25	Very weak	5. 85 ± . 16		
Northwest	A 4	8. 74	1. 447	6. 08 ± . 14	6. 040	. 003
	B 3	0. 60	0. 133	5. 74 ± . 25	4. 511	. 034
	B 2	0. 35	0. 101	5. 49 ± . 22	3. 465	. 043
	B 1	0. 09	0. 016	5. 39 ± . 20	5. 625	. 001
	A 6	1. 88	0. 363	5. 90 ± . 05	5. 179	. 052
	A 7	7. 43	1. 259	5. 98 ± . 08	5. 902	. 031
Southeast	A 8	16. 97	Very weak	5. 87 ± . 13		
	A 9	23. 69	3. 915	5. 91 ± . 06	6. 051	. 000
	A 10	28. 12	4. 720	5. 99 ± . 04	5. 958	. 073

km/sec are much lower than those indicated for compressional, transverse or Rayleigh waves and therefore cannot be due to reflections, refractions or diffractions propagated in these three modes. The propagation velocity for these events must be lower than any of the indicated apparent velocities. The only mode efficient enough to transmit these strong events and with a velocity lower than 2 km/sec is compressional wave propagation through the water layer at about 1. 5 km/sec. These events are therefore caused by ground coupled water reverberations. Apparent velocities of 2. 0 to 2. 7 km/sec indicate that propagation is not colinear with the seismometer array, but is by refraction of the reverberations off the boundaries of the lake, and coupling to the ground takes place along the shorelines which roughly parallels the seismometer array (Fig. 2).

Identification of these events allows another observation from Figure 7. The time discrepancy between correlating events of shotpoints 2 and 3 appears to be constant for all events. Since the secondary events are transmitted by water rather than through lake floor material to bedrock, the time discrepancy cannot represent an accumulation of muskeg or other low velocity material under the shotpoints. It must be due to a distance or timing error.

Three shots were recorded from shotpoint 1, and two shots were recorded from shotpoint 2. For these records it is possible to isolate shot generated events from those generated by extraneous seismic activity by the criterion of repeatability. Two apparently repeatable events are recorded on records of shotpoint 1: one at a travel time of 0. 587 second which at 6 km/sec may represent a reflecting interface approximately parallel to the seismometer array and 1. 76 km distant. There is no event to be seen at 0. 75 second which might represent the velocity discontinuity in the borehole. The other repeatable events on records of shotpoint 1 is at a travel time of 3. 68 seconds, which at 6 km/sec may doubtfully represent a reflecting interface approximately parallel to the array at a distance of 11 km, or at 3. 05 km/sec a distance of 5. 5 km. This event is most likely caused by a time constant characteristic of the instrument. There is no evidence of events on records of shotpoints 2 and 3 which correlate with the repeatable events of shotpoint 1 to suggest

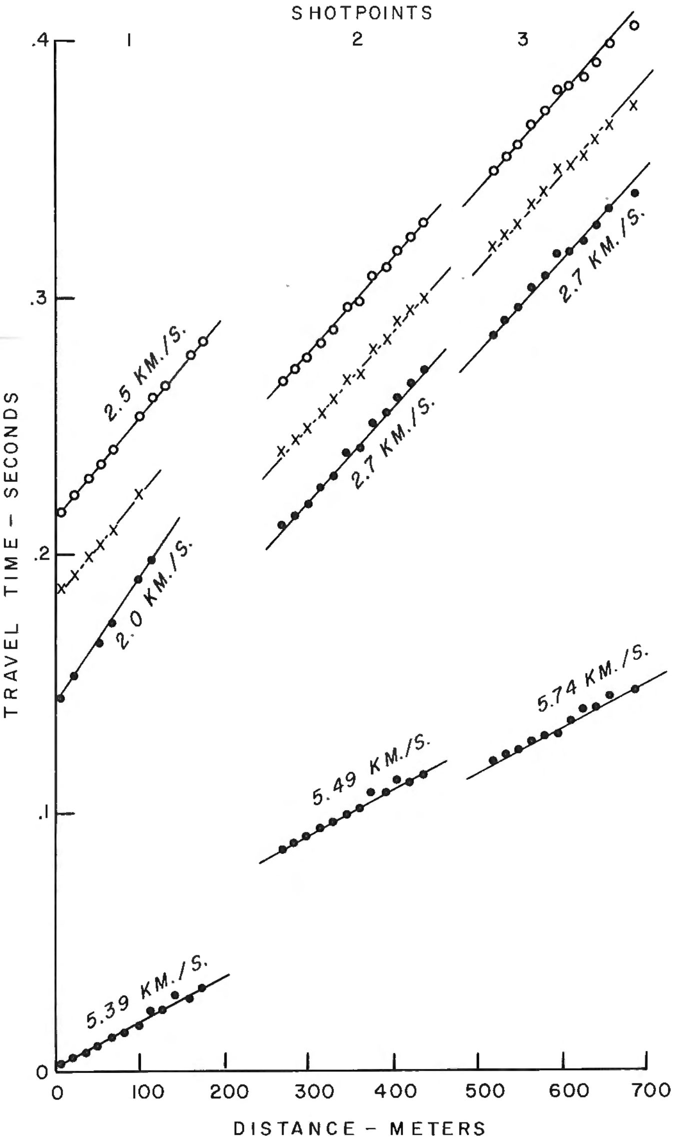

Figure 7. Time-distance plot for events of profile B.

that the source is a continuous reflecting interface. No repeatable events were seen on records of shotpoint 2 other than those discussed under earlier headings.

Much activity on these records is due to instrument noise and extraneous seismic activity as discussed earlier.

Conclusions

1. Compressional wave velocities increase with distance between the seismometer array and shotpoints. If interpreted as a layered structure, the higher velocities appear to correlate with higher density mafic quartz diorite logged at depth in JXWS borehole "A". The seismic refraction method may be effective in mapping this rock-unit when it constitutes a layered structure overlain by less dense leuco quartz diorite. Compressional wave velocities in Precambrian rocks range from 5.4 km/sec to 6.5 km/sec.

2. Transverse wave velocities are indicated at about 3.2 km/sec.

3. Some evidence of Rayleigh wave propagation is indicated.

4. Considerable local seismic activity complicates interpretations.

5. Sophisticated field techniques may prove that seismic methods are effective in detecting Precambrian interfaces.

Acknowledgments

The writer is indebted to G.D. Hobson for encouraging this description of the experiment and critically reading the manuscript. The manuscript was also critically read by H.A. MacAulay. Figures were drafted by R. Gagne.

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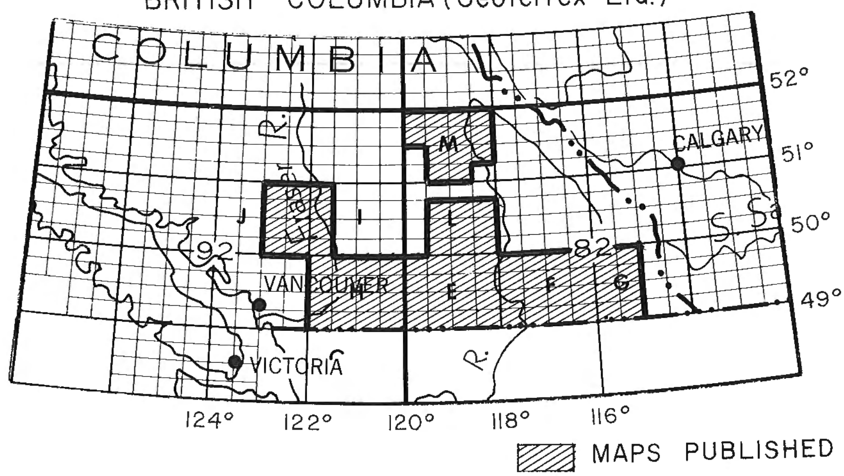
CONTRACT AEROMAGNETIC SURVEYS

E. Ready and Peter J. Hood
Resource Geophysics and Geochemistry Division

BRITISH COLUMBIA (Geoterrex Ltd.)



BRITISH COLUMBIA

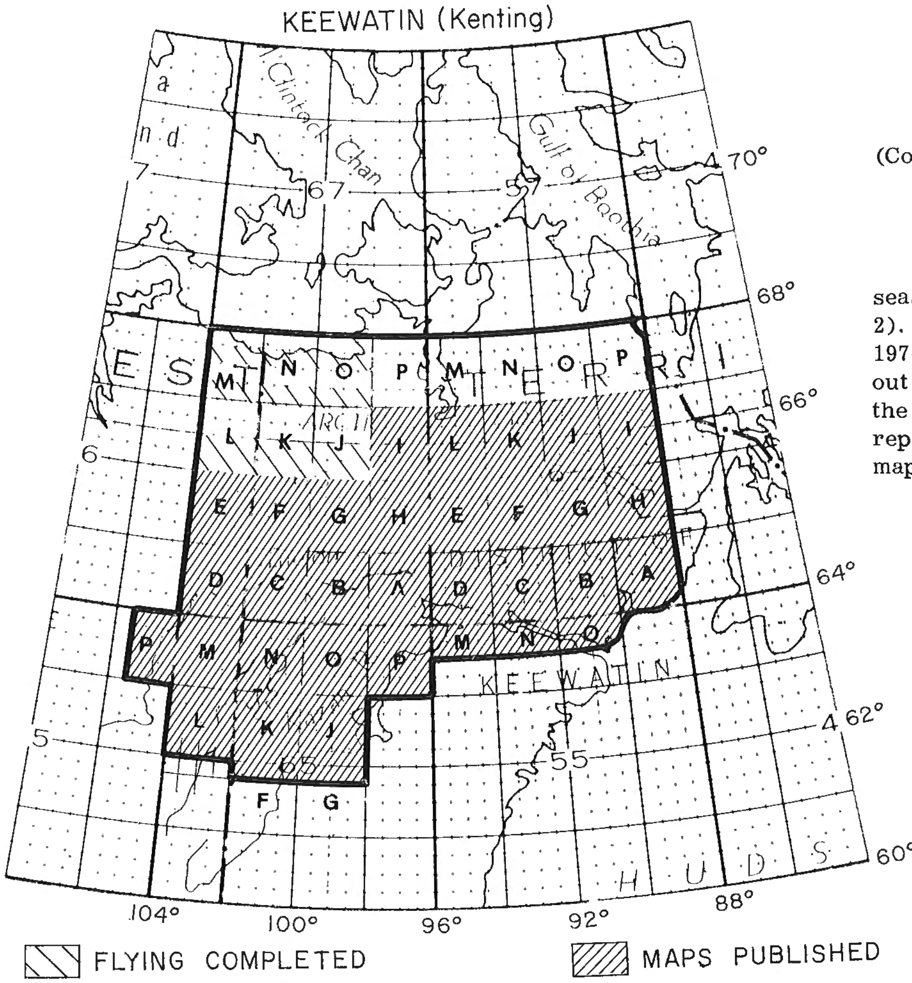
(Contractor, Geoterrey Ltd.)

Project 690066

The flying component of this survey, which amounted to 73,000 line miles, was completed in October, 1972 (*see* Fig. 1). The remaining 60 one-mile maps were released in two stages — 19 on December 20, 1973, and 41 on March 11, 1974, along with 8 four-mile composite maps covering NTS 82 E, 82 F, 82 G (W ½), 92 H, part of 92 J and completing the four-mile map areas of 82 L, 82 M and 92 I. All raw data, final positives and negatives etc., have been delivered and checked by the Geological Survey of Canada inspectors before storage in archives.

This project is now completed.

KEEWATIN (Kenting)



KEEWATIN-MACKENZIE DISTRICTS

(Contractor-Kenting Earth Sciences Ltd.)

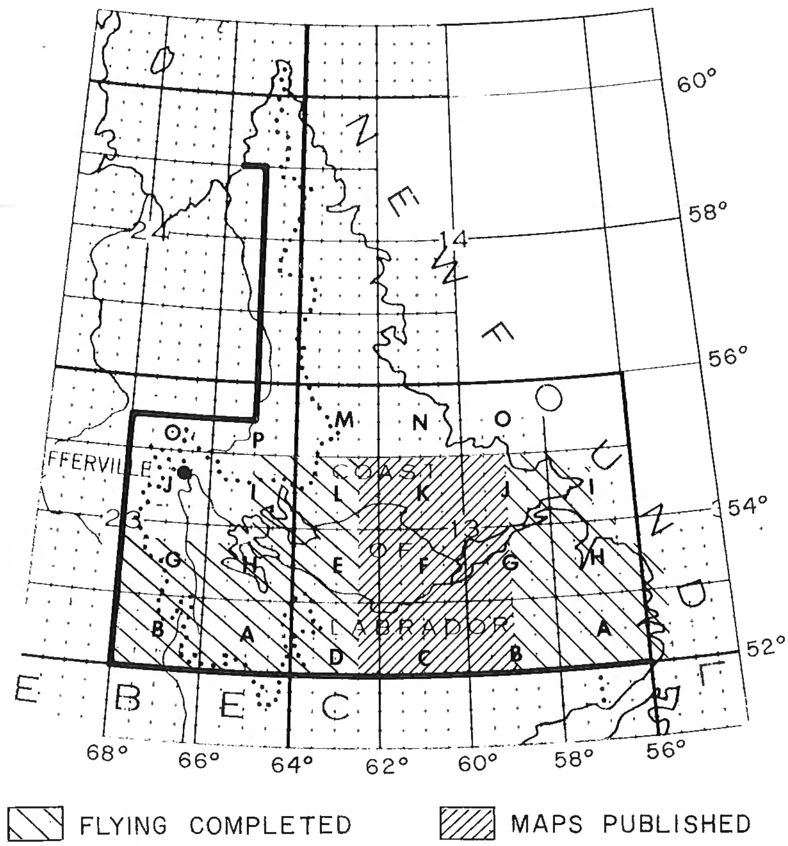
Project 690068

Flying production during the 1974 field season was 38,888 line miles (*see* Fig. 2). Total mileage flown to the end of the 1974 flying season is 322,402 line miles, out of an estimated 359,536 line miles for the complete survey area. Since the last report (Larochelle, 1974), 168 one-mile maps have been released as follows:

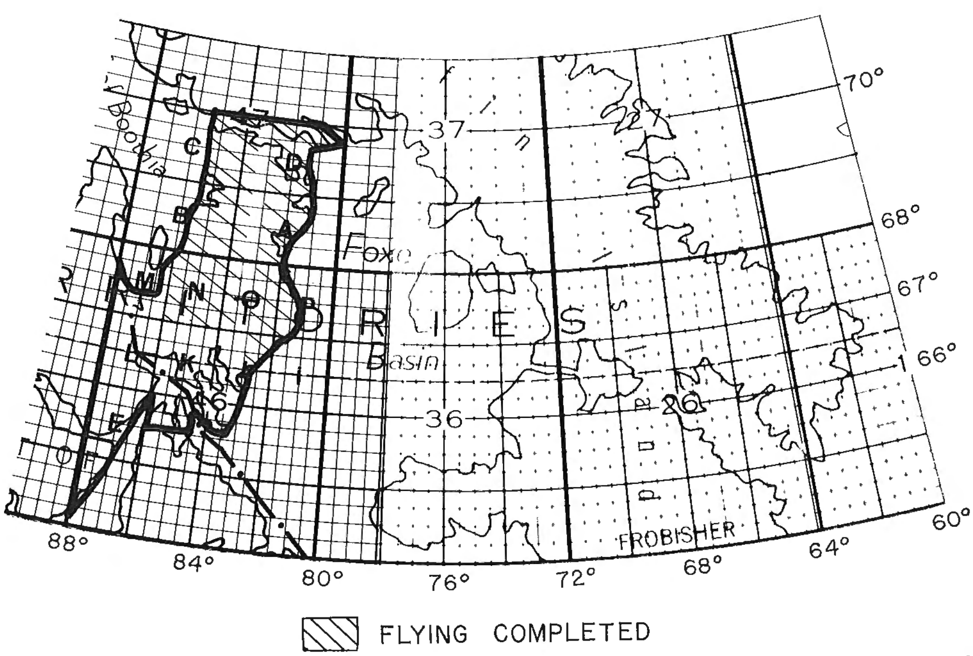
January 8, 1974 – 61 one-mile maps
February 25, 1974–19 one-mile maps
March 28, 1974 – 20 one-mile maps
June 17, 1974 – 52 one-mile maps
July 24, 1974 – 16 one-mile maps

At the present time, 455 one-mile maps have been published out of a total of 543. Between 66°N and 68°N, two one-mile map-areas are printed together on a single map-sheet (15 minutes of latitude by 1 degree of longitude).

LABRADOR (Geoterrex, Lockwood, Survair)



MELVILLE PENINSULA (Geoterrex, Lockwood, Survair)



<u>LABRADOR-MELVILLE PENINSULA-COPPERMINE</u>
(Contractors-Geoterrex Ltd., Northway Survey Corp. Ltd., Survair Ltd.)

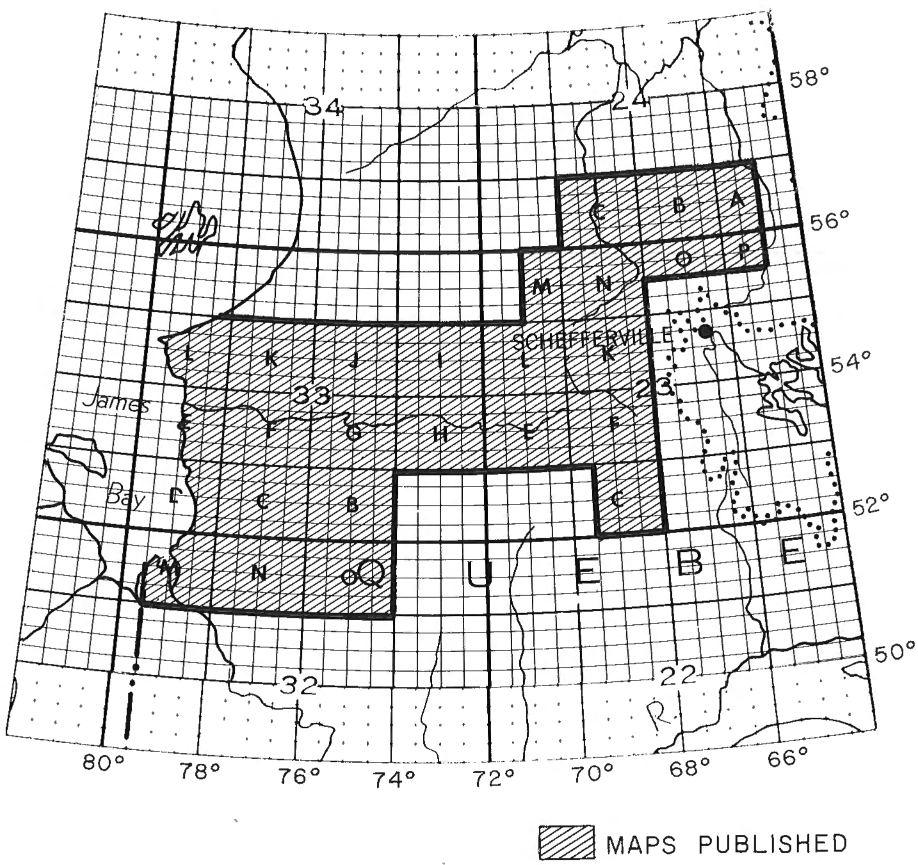
Project 690072

1. <u>Labrador Aeromagnetic Survey</u>

By the end of the 1973 field season, a total of 184,161 line miles had been surveyed out of an estimated 314,000 line miles (*see* Fig. 3). The 1974 season, which began in late August, has resulted in approximately 11,197 line miles of data being obtained. The total mileage to September 30, 1974, is 195,358 line miles. No maps have been published since the last report (Larochelle, 1974), although 66 one-mile maps and 3 composite maps at 1:250,000 will be printed and delivered by November 15, 1974. This portion of project 690072 totals 443 one-mile maps and 34 complete and/or part four-mile maps. As the Contractor has been requested to give first priority to completing the Melville Peninsula portion of this project, not much additional flying in Labrador is anticipated over the next two field seasons. Nevertheless, the Contractor will continue to compile those areas surveyed for publication.

As is mentioned briefly in the Melville Peninsula portion of this report, as far back as the 1972 field season the Contract Survey Section inspectors detected serious sensing and recording problems in a proton magnetometer installation used for the Labrador survey. In some cases, the magnetometer records were completely illegible due to steep magnetic gradient, slow speed of the chart drive and too high a sensitivity. More seriously, the magnetometer seemed to be incapable of functioning properly in steep magnetic gradients and the sensing unit appeared to lose its phase lock between the precession frequency and that generated by the voltage-controlled oscillator. The Contractor was requested to refly the areas of steep magnetic gradient with a fluxgate magnetometer, following the original flight path as closely as possible, with the chart speed increased to six inches per minute. On comparing the fluxgate record with the original proton magnetometer record, it was obvious that the proton record was not valid under certain conditions. Approximately 3,000 line miles of reflights were requested in the Labrador survey area. To date (October, 1974) about 2,200 line miles have been reflown.

QUEBEC (Aero Photo)



Also contributing to the poor production in Melville Peninsula during the 1974 field season was the requirement to make modifications to the sensing equipment in both aircraft and to carry out reflights over previously flown traverses which contained faulty data. These faulty records, totalling approximately 3,000 line miles, were monitored by the Geological Survey inspectors while investigating similar problems with erratic data in the Labrador survey area. A Geological Survey inspector visited the Contractor's field operation in July and was instrumental in determining whether the newly acquired data was valid. Approximately 12 aircraft days were required to carry out the reflights.

Commencing on the east side of the project area, the first published maps will probably not be available until March, 1975. A total of 122 one-mile sheets and 16 four-mile sheets will be published in the Melville Peninsula area.

3. Coppermine Aeromagnetic Survey

No aeromagnetic survey flying has been carried out to date in this survey area.

The above problems resulted in a great number of compiled one-mile maps being withheld from printing until the quality of the aeromagnetic survey data can be verified by the inspectors.

2. Melville Peninsula Aeromagnetic Survey

Survey flying began in the Melville Peninsula early in 1972, with one survey aircraft, which resulted in only 2,437 line miles of production due to poor atmospheric conditions and heavy snow cover. The 1973 season produced 18,182 line miles during June, July and August, utilizing two survey aircraft, with poor weather and diurnal conditions. In the 1974 flying season, 27,022 line miles of production were attained, again utilizing two aircraft, during the period June 17 to September 11, under severe diurnal and weather conditions (*see* Fig. 4). In addition, the Contractor lost 18 possible production days due to repairs being carried out on the runway at Hall Beach, N.W.T. The runway resurfacing took place during the month of August.

To date, total mileage flown in the Melville Peninsula is 47,631 line miles, leaving approximately 40,000 line miles to complete the survey. From a consideration of the production rate in previous years, it is doubtful that the remaining line miles can be flown during the 1975 season.

QUEBEC
(Contractor-Aero Photo Inc.)

Project 690073

The flying portion of this project was completed in May, 1973 (*see* Fig. 5). The remaining 186 one-mile and four-mile maps were released as follows:

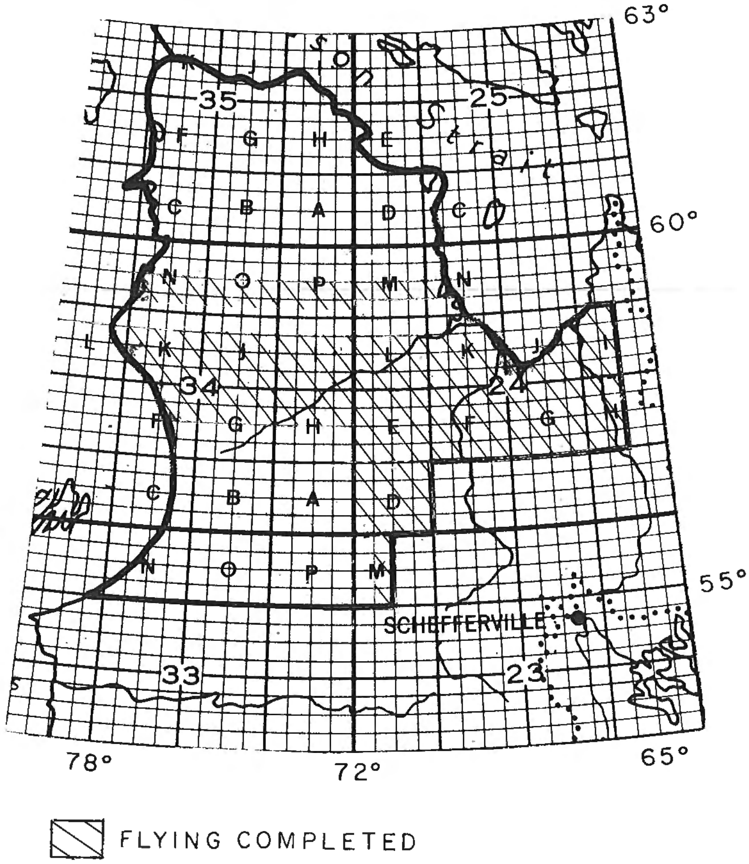
August 22/73 - 8 one-mile maps and 12 four-mile maps; February 18/74 - 80 one-mile maps; June 12/74 - 72 one-mile maps; June 25/74 - 14 four-mile maps.

Delivery of all raw data, final negatives and positives has been made to the Department of Natural Resources, Quebec City as per contract specifications.

QUEBEC
(Contractors-Photographic Surveys Inc. - Geoterrex Ltd.)

Project 730012

At the end of the 1973 survey season, 49,652 line miles had been flown. The 1974 season resulted in an additional 86,758 line miles of production (*see* Fig. 6), NEW QUEBEC (PSI-Geoterrex)



bringing the total to 136,410 out of an estimated 332,912 line miles contracted. No maps have been published to date but it is anticipated that several will be released by March, 1975. A total of 519 one-mile maps will be published for this northern Quebec aeromagnetic survey.

All survey aircraft are equipped to record the survey data in digital form which is the first such contract requiring digital recording under the Federal/ Provincial aeromagnetic survey scheme. In addition, the compilation will be fully automated. This contract was awarded by the Province of Quebec in 1972 with the Geological Survey of Canada acting as Technical Advisor and continuing to monitor the data prior to publication. The Contractor's survey aircraft has been based at Fort Chimo and will probably continue to work from there for the next two field seasons. A Geological Survey inspector visited the project during the period of June 17, to June 21, 1974.

Hudson Bay

In 1965, a Decca-controlled survey was carried out in the central part of Hudson Bay using the North Star aircraft of the National Aeronautical Establishment. Further details have been given by Hood *et al.* (1969). Subsequent publication of the resultant aeromagnetic maps, which were compiled by Margaret Bower, was delayed pending the completion of an agreement between EMR and Aero Service Corporation for the payment of line mileage royalties on the use of the optical absorption magnetometer employed in the survey. On October 16, 1974, the seven 1:125,000 and three 1:250,000 aeromagnetic maps which resulted from the Hudson Bay survey were issued by the Geological Survey of Canada and these covered parts of NTS 44L, 44M and 54I.

Summary

Since the last report one year ago (Larochelle, 1974), a total of 163,865 line miles of aeromagnetic data of previously-unsurveyed areas has been obtained under the Federal-Provincial aeromagnetic survey scheme and in the Northwest Territories by contract surveys. In addition 388 one-mile, seven 1:125,000, three 1:250,000 and 34 four-mile aeromagnetic maps have been issued, which is a total of 432 aeromagnetic maps for the report year.

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RESULTS OF A RECONNAISSANCE TYPE AIRBORNE GAMMA-RAY SPECTROMETER SURVEY OF THE BLIND RIVER - ELLIOT LAKE AREA, ONTARIO, 41 J

Project 720071

K.A. Richardson, P.G. Killeen and B.W. Charbonneau
Resource Geophysics and Geochemistry Division

The question of the source of the uranium in the Elliot Lake deposits, and whether the granitic rocks to the north of the Quirke Lake syncline contain higher than normal concentrations of uranium, has been discussed by Roscoe and Steacy (1958), and Bottrill (1971) among others. The conclusions of the papers by Roscoe and Steacy and Bottrill are in disagreement regarding the uranium content of the pre-Huronian rocks in the Elliot Lake area, and Little (1974) used this example to point to the need for further investigation into the origin of uranium deposits.

In this context, an airborne gamma-ray spectrometer survey was carried out in June, 1974 to determine the regional pattern of radio-element distribution in the pre-Huronian granitic terrain north of the Elliot Lake area. An earlier detailed airborne gamma-ray spectrometer survey was carried out by the Geological Survey of Canada in 1970 which was mainly restricted to the area of Huronian rocks in the vicinity of Elliot Lake (Darnley and Grasty, 1971) resulted in rather good definition of the Huronian stratigraphy (Charbonneau *et al.*, 1973).

The 1974 survey covered NTS map-sheet 41 J ($82^{\circ}00'-84^{\circ}00'$W, $46^{\circ}00'-47^{\circ}00'$N). The survey was carried out with 5-km line spacing, aircraft speed of 200 km/hr and terrain clearance of 135 m. The spectrometry equipment used in this survey was the high-sensitivity (55,000 cc of NaI detectors), 4-window spectrometer which has been described previously (Darnley, 1970; Darnley *et al.*, 1971). Thus the survey parameters closely adhere to those specifications for the proposed Federal-Provincial Uranium Reconnaissance Program, which is expected to begin in 1975.

Figure 1 is a simplified map of the geology of the Blind River map-sheet (after Ayres *et al.*, 1970). A contour map of the uranium distribution for the same area determined by airborne gamma-ray spectrometry is shown in Figure 2. The contour map shows anomlies over the disturbed ground around the mine locations on the north and south limbs of the Quirke Lake syncline. Otherwise the Huronian rocks do not show as high uranium levels on the airborne contour map (with these survey and data compilation parameters) as does the granitic area to the north. However, a greater amount of detail can be seen on the radiometric profiles, than on the contour maps. The profile in Figure 3 shows some increase in uranium level over the north limb of the syncline, a narrow spike over the lower Huronian rocks on the south limb and a broad high over the granitic rocks to the north.

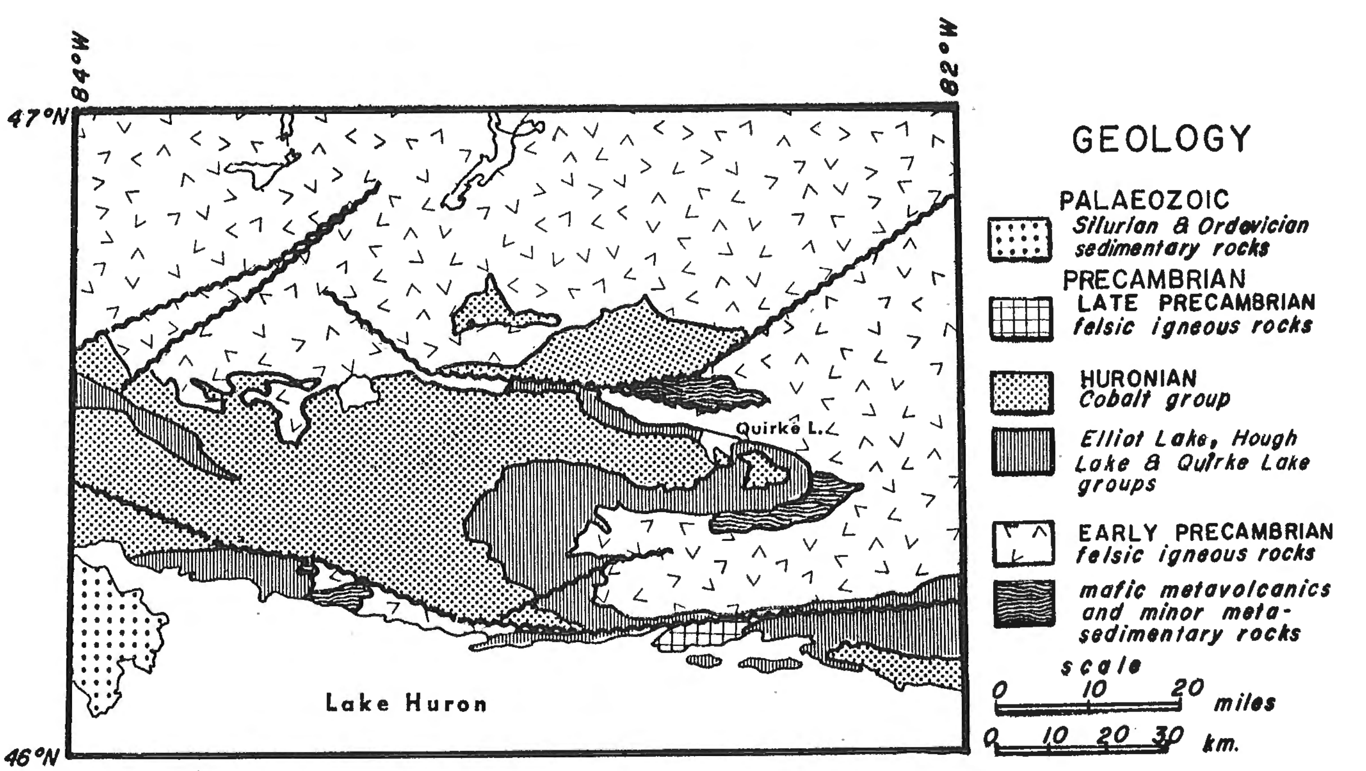

Figure 1. Geology of the Blind River map-sheet, 41 J (after Ayres *et al.*, 1970)

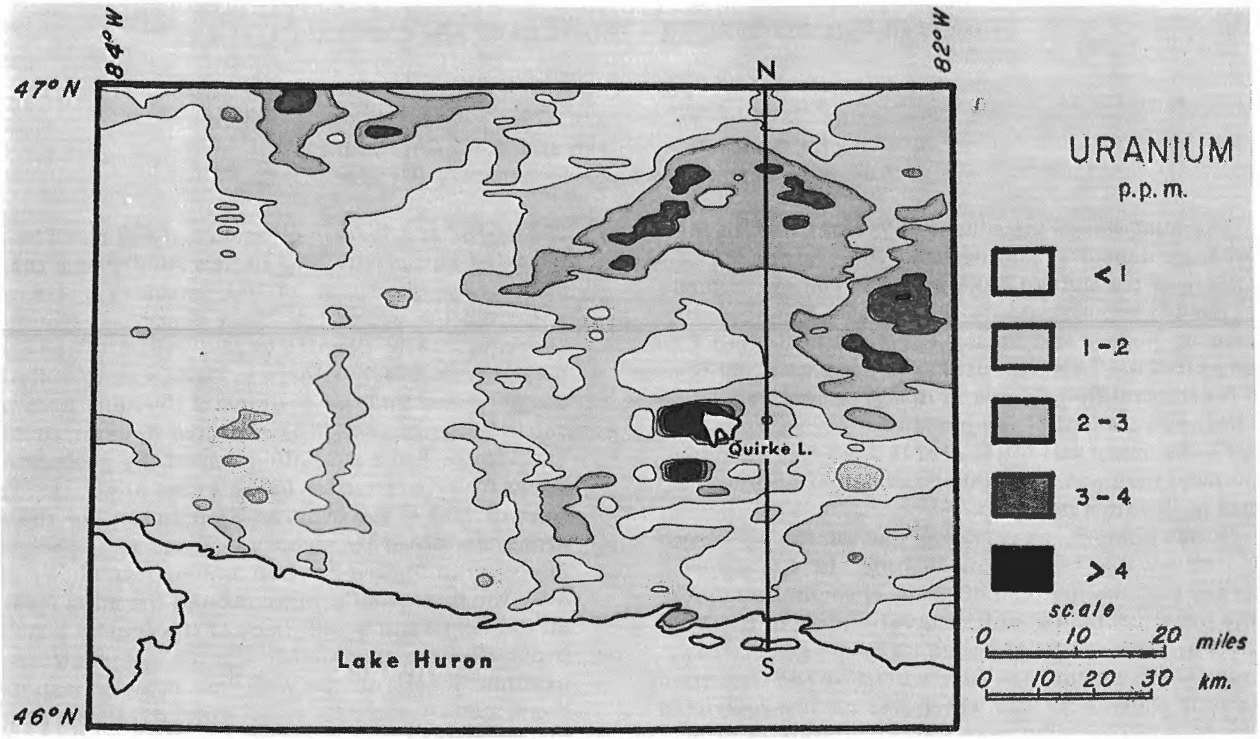

Figure 2. Contour map showing the Uranium distribution pattern over the Blind River map-sheet, determined by airborne gamma-ray spectrometry. The line N-S indicates the flight line location for the radiometric profile on Figure 3.

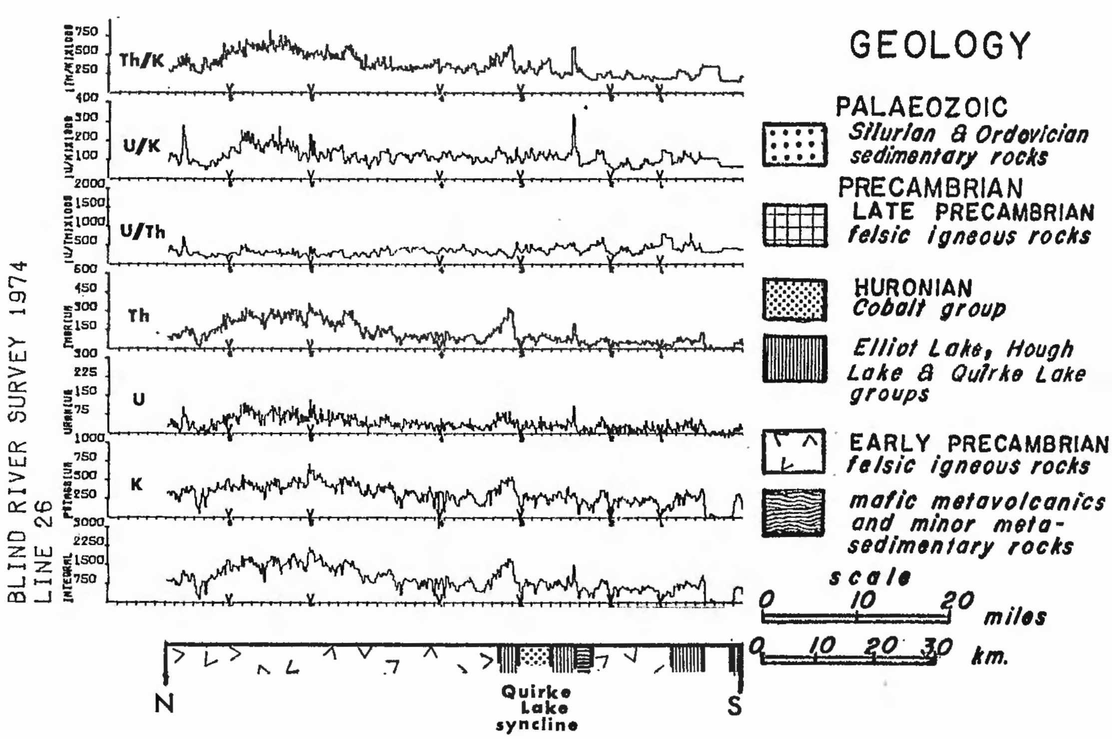

Figure 3. Radiometric profile along flight line N-S shown on Figure 2.

On the contour map, the granitic pre-Huronian terrain shows a prominent increase in uranium level over a broad zone located between 25 and 50 km to the north and northeast of Quirke Lake, and also in a zone 70 to 100 km northwest of Quirke Lake. The average surface uranium concentration measured by airborne spectrometry over these two large granitic zones is approximately 3 ppm. However, it should be borne in mind that a considerable percentage of overburden cover is included in the spectrometer field of view, and this affects the average surface concentration shown by the contour map. Consequently, actual bedrock uranium levels would be significantly higher than 3 ppm (Charbonneau *et al.*, 1973). A compilation of the ground and laboratory measurements which were made by Roscoe and Steacy (1958), Bottrill (1971) and the present authors, confirmed the airborne pattern of uranium distribution and has shown that the large zones of more radioactive granite likely average from 10 ppm to 15 ppm uranium.

The delineation and aerial mapping of these uranium-enriched granitic zones resolves any disagreement between the work of Roscoe and Steacy (1958) and Bottrill (1971). Apparently Roscoe and Steacy collected samples within the uranium-enriched zones while Bottrill collected data within an area of low uranium content peripheral to the Quirke Lake Syncline.

If the Elliot Lake area were virgin territory, then the normal sequence of exploration activities might have been the following. A reconnaissance (5-km line spacing) airborne survey, carried out first, would have detected a broad zone enriched in uranium north of the Huronian rocks. This would have attracted uranium exploration activity to the area for follow-up work. A detailed follow-up airborne gamma-ray spectrometer survey, such as that of Darnley and Grasty (1971) with 0.5-km line spacing would have produced good definition of the Huronian stratigraphy (Charbonneau *et al.*, 1973) indicating the basal Huronian rocks as the most promising exploration targets.

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LORAN "C" DEMONSTRATION, AUGUST 14, 15, 1974

Project 730007

P. Sawatzky
Resource Geophysics and Geochemistry Division

The U.S. Department of Transport is planning to expand and improve its Loran C navigation system. They are hoping that Canada will join them in providing this service for all of North America. To facilitate this the U.S. Coast Guard who is the agency responsible for this navigation system, offered to demonstrate the system to prospective users in Canada. Because Computing Devices of Canada is an agency that is distributing Loran C (built by Decca) equipment in Canada, they organized the demonstration that took place at Trenton.

For the purpose of the demonstration, a Hercules C 130, one of many that the U.S. Coast Guard has equipped with Loran C, was taken out of regular service for this purpose. It was emphasized that the equipment installed in it was in no way different or superior to that used in any of their similarly equipped aircraft. They had an ADL-21 M and an ADL-81 Loran receiver. The ADL-21 M receiver was connected to a general purpose navigation computer, similar to the Decca TANS computer. For the purpose of the demonstration the ADL-81 and the computer had been mounted in the main cabin to facilitate the business of letting people see the system. Normally they are located on the flight deck.

The demonstration consisted of three parts:

1. Pinpoint the Canadian Coast Guard ship "Spindrift" that was patrolling about ten miles south of Toronto harbour, by means of Loran C.

2. Go to the Peterborough area and demonstrate Loran C controlled approaches to the local airport (Fig. 1).

3. Return to the "Spindrift", determine its position again using Loran C and compare the two positions with the position fixes obtained by the ship, using radar.

The airport approach demonstration was conducted as follows; An Initial Point 10 miles from the Touchdown Point were programmed into the computer as way points in terms of latitude and longitude. The Initial Point was then selected, and the aircraft flown to it so that it was approached on an easterly heading. Upon reaching this point, the Touchdown Point was selected, and the pilot then flew the aircraft on instruments to the Touchdown Point. In each case the aircraft was brought to about fifty feet above the end of the runway. This was repeated several times. The C 130 was then flown back to the location of the "Spindrift" which had continued on a southerly heading to a new location.

After the two sets of position determinations of the ship by the aircraft, they compared notes. For the first set of position determinations, they agreed within 0.2 nautical mile, for the second, the difference was about 0.3 mile. The difference probably was due to a shift in the Loran C pattern, due to variations in soil conductivity. The stations used for the test were located on the East Coast of the United States (Fig. 2). It should be noted here that each set of position determinations of the ship by the aircraft did not vary by more than 0.1 mile. In other words, the repeatability of the system was extremely good.

The C 130 then returned to Trenton and made several approaches to the Trenton airport, similar to those that were made at Peterborough. This completed the demonstration.

In conclusion, I was quite impressed with the repeatability of the system. For survey use a monitor station would be required, and for best results the noted correction could be transmitted to the survey aircraft. This could result in extremely accurate flight lines or actual position determination.

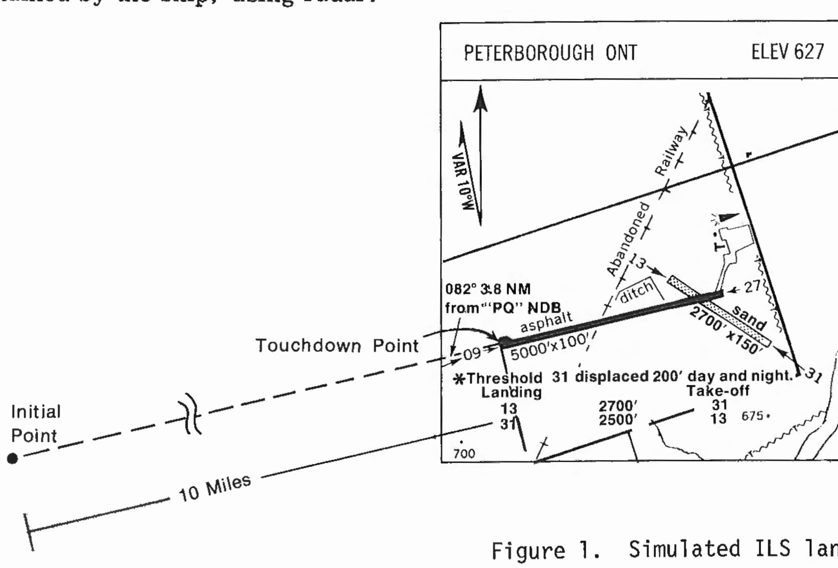
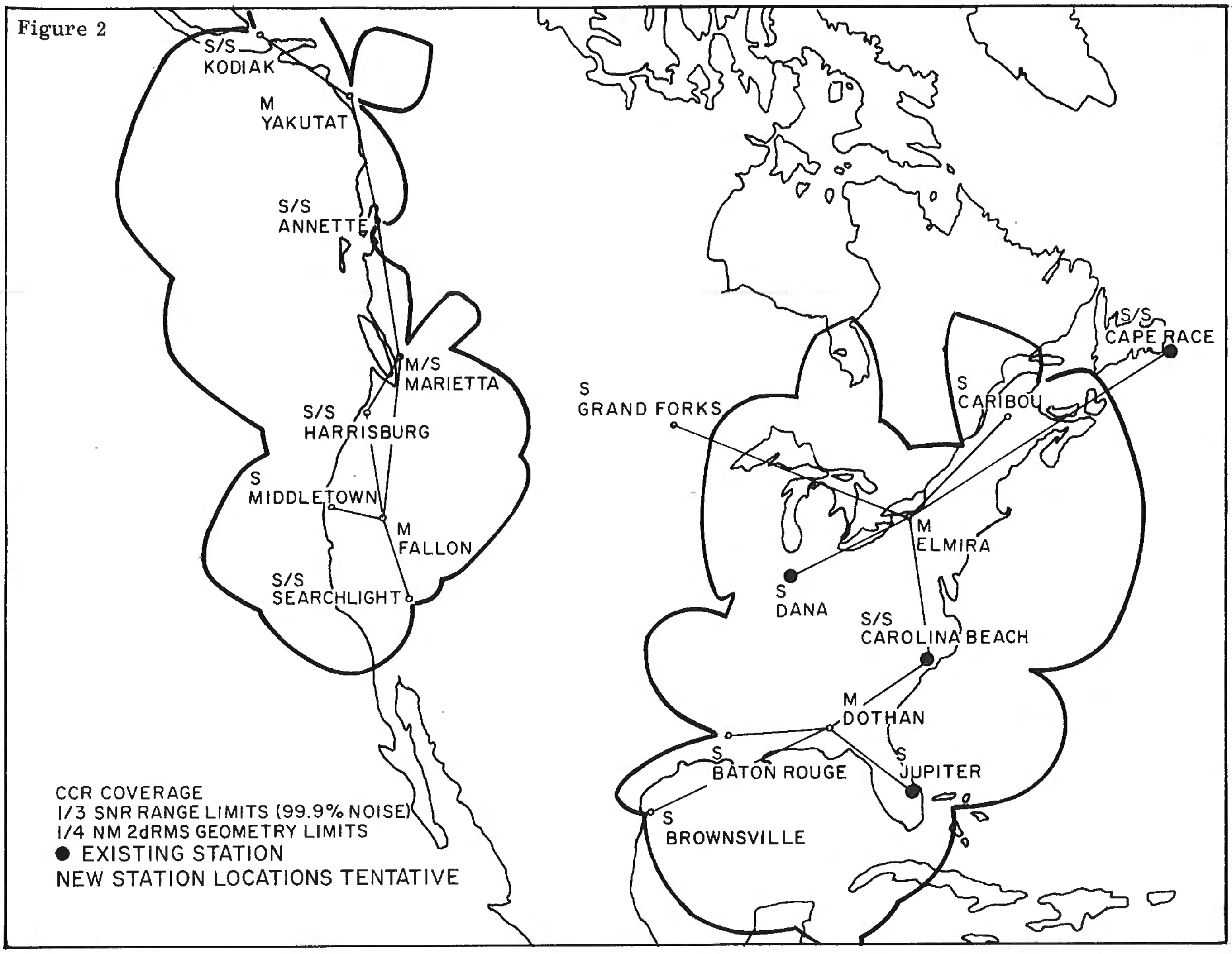


Figure 1. Simulated ILS landings at Peterborough.

Figure 2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KODIAK
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YAKUTAT
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FALLON
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SEARCHLIGHT
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GRAND FORKS
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CARIBOU
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CAPE RACE
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ELMIRA
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DANA
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CAROLINA BEACH
M
DOTHAN
S
BATON ROUGE
S
JUPITER
S
BROWNSVILLE
CCR COVERAGE
1/3 SNR RANGE LIMITS (99.9% NOISE)
1/4 NM 2dRMS GEOMETRY LIMITS
● EXISTING STATION
NEW STATION LOCATIONS TENTATIVE

36. FABRICATION OF AN INBOARD DIGITAL-RECORDING VERTICAL GRADIOMETER SYSTEM FOR AEROMAGNETIC SURVEYING, A PROGRESS REPORT

Project 680081

P. Sawatzky and Peter J. Hood
Resource Geophysics and Geochemistry Division

Aeromagnetic survey techniques have been under active development in the Geological Survey of Canada since the first airborne magnetometer was introduced shortly after World War II by modification of submarine detection equipment. This development work and its subsequent utilization in aeromagnetic surveys by the Survey staff eventually led to an aeromagnetic survey program for the whole of the Canadian Precambrian Shield which was jointly funded by the Federal and Provincial governments. The specifications for these aeromagnetic surveys and for those carried out as part of a contribution to overseas aid programs through the Canadian International Development Agency have been constantly improved upon over the years. This improvement in the aeromagnetic state-of-the-art has only been possible because the Geological Survey of Canada has maintained a viable group of electronic engineers and technicians (together with others skilled in related arts, such as computer science) who have been actively engaged in the development of survey equipment and techniques. In more recent years, this activity has been strengthened by the acquisition of a survey platform, namely a Queenair B80 aircraft, to carry out experimental high resolution aeromagnetic surveys.

One problem that has been troublesome over the years is the elimination of the small, time-variable variations of the earth's magnetic field due to sunspot activity, which are unavoidably recorded during aeromagnetic surveys in addition to the magnetic anomalies due to the underlying geological formations. This problem becomes more serious when high resolution aeromagnetic surveys are carried out, and the diurnal activity itself can be quite strong especially in northern Canada (*see* for instance Sawatzky *et al.*, 1974). The most direct way of removing the effect of such diurnal activity is to make gradient measurements using two magnetic sensors separated by a short distance. In addition to the elimination of the diurnal field variations, gradiometer measurements have a number of other advantages which relate to their value in geological mapping programs, and these have been outlined in the companion article by Hood et al., in this publication. In brief, vertical gradient maps are a better aid to geological mapping than the more classical total intensity maps.

However the reader may wonder why aeromagnetic gradient measurements were not made many years ago. The reason is that it was not until magnetometers, namely the optical absorption variety, with the required sensitivity were introduced in the early 1960's, that meaningful gradient measurements were feasible. In the United States, soon after the introduction of optical absorption magnetometers a helicopter-borne gradiometer system was constructed by Varian Associates for Pure Oil Company and a fixed-wing system was also fabricated for Aero Service Corporation (Hood, 1970). However both these systems utilized free-flying birds separated by about 100 feet so that both these towed gradiometer systems were very much limited by turbulence. This drawback made the systems costly to operate because flights were usually limited to early norning and late evening. It should be pointed out however that the towed bird system avoided magnetic compensation problems, and that a large vertical separation was necessary to obtain the gradient sensitivity necessary for oil exploration surveys i.e. to map the small gradients which would

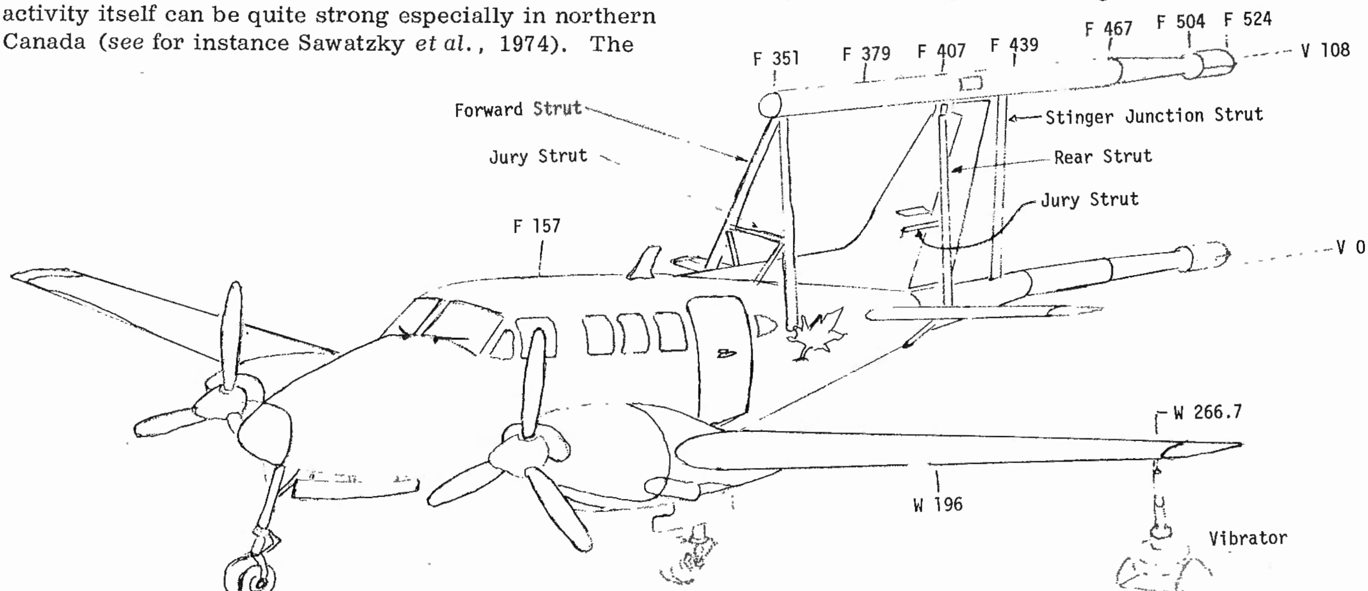

Figure 1. Ground vibration survey arrangement.

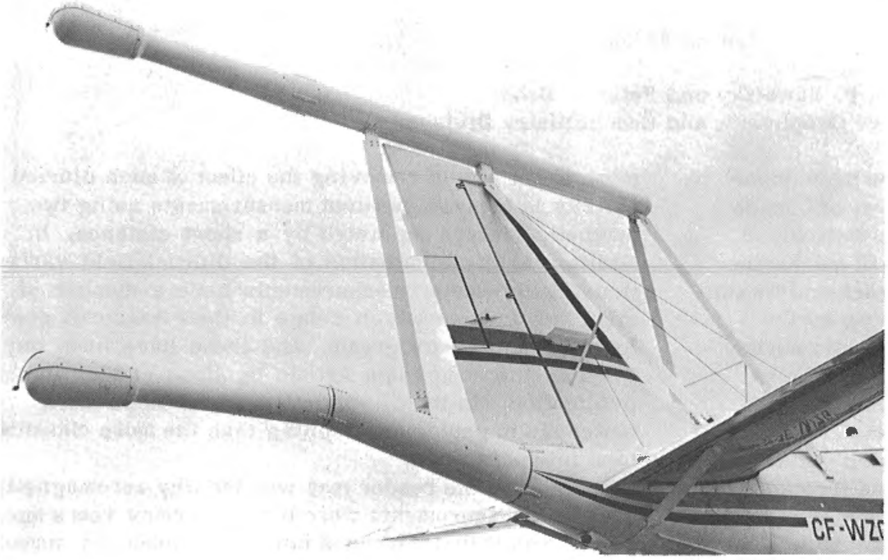

Figure 2.

Twin-boom arrangement for the vertical gradiometer system on the tail of the GSC Queenair B80 aeromagnetic survey aircraft.

be produced by igneous basement rocks beneath a thick sedimentary cover. However the large separation meant that in mineral exploration surveys of Precambrian areas that the difference between the two magnetometer readings would deviate somewhat from the true gradient.

The Geological Survey's vertical aeromagnetic gradiometer system is designed to map vertical contacts between large outcropping rock formations having a minimum effective susceptibility of about 500×10^{-6} emu/cc, which is typically the case for many areas of the Canadian Precambrian Shield. In order that the airborne system not be turbulence-limited and that the difference reading (divided by the sensor separation) would correspond closely to the actual gradient reading, an inboard gradiometer was decided upon. With the physical dimensions of the tail section of the present survey aircraft, the largest separation of the two magnetometer heads that is feasible is 2 metres (the separation is actually 2.08 metres).

The initial aeronautical engineering study and subsequent installation of the twin-boom system on the Queenair aircraft began in the late Fall of 1973, and was contracted out to industry.

In the spring of 1974 after the twin booms had been installed on the Queenair aircraft preliminary shake tests with a hand-held vibrator were carried out by Mr. T.R. Flint, and these tests showed that the top boom would resonate at a low frequency. At this point only the two forward struts and the stinger junction strut had been installed (Fig. 1). A comprehensive series of shake tests were then undertaken by Geological Survey personnel using equipment loaned by the National Research Council. The results of these subsequent tests, which were described in an internal report of the Resource Geophysics and Geochemistry Division by T.R. Flint, indicated that the installation required additional stiffening and bracing which was incorporated in the design by the addition of rear struts. Further skake tests showed a marked improvement in the design. Prior to the flight tests, several weeks were spent installing accelerometers and recorders; then the system was calibrated. The flight tests showed that the aircraft still handled well, but it was slower by about 10 per cent and its single engine performance had been reduced considerably. The test flights also indicated that the struts themselves were vibrating at certain air speeds in a manner similar to a plucked string. These vibrations had been anticipated and short jury struts (Fig. 1) had been installed during the vibration trials. Consequently these struts were made permanent, and further flight trials were carried out to demonstrate that the installation was safe to fly. Upon completion of the tests in June, 1974, the engineering drawings and flight test reports were submitted to the Ministry of Transport for approval. Figure 2 shows the final gradiometer configuration on the GSC Queenair B80 aircraft. In addition to the instrumentation for the flight tests, the electronic instrumentation for the gradiometer itself has been completed mainly through the efforts of D. Olson and A. Dicaire. The sensitivity of the airborne gradiometer system is 0.004 gamma per metre. A high resolution digital magnetometer system has also been completed for ground monitoring of the diurnal variation. The ground monitor records the time, the date and the magnetic field to an accuracy of ± 0.004 gamma. A television camera system has also been installed in the survey aircraft for flight path recovery.

During the past season the 28 volt DC auxiliary ground power unit used to supply power to the aircraft for starting and for ground testing of the survey system began requiring an undue amount of maintenance. In addition spare parts were becoming difficult to purchase and were consequently expensive. To replace the present APU, a 7 HP Briggs and Stratton gasoline engine and a 200 ampere DC aircraft generator were purchased. These units together with a voltage regulator and some aircraft relays have been assembled into a much more reliable ground power unit. The present engine should be much easier to repair because parts for it are generally available.

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37. PRELIMINARY EXPERIMENTS IN MARINE RESISTIVITY NEAR TUKTOYAKTUK, DISTRICT OF MACKENZIE

Project 670041

W.J. Scott
Resource Geophysics and Geochemistry Division

Introduction

During the spring and summer of 1974 marine resistivity soundings and profiles were carried out in three lakes on the Tuktoyaktuk peninsula and on Kugmallit Bay near Tuktoyaktuk.

The spring trials consisted of six resistivity soundings done through the ice, of which three were on Kugmallit Bay (1, 2 and 6, Fig. 1), two on Grass Lake (4 and 5, Fig. 1) and a sixth (3) on Kidney Pond near Grass Lake, not shown on Figure 1. The summer work involved two soundings, one on Grass Lake (7, Fig. 1) and the other on Kugmallit Bay (8, Fig. 1). In addition, the summer work included a number of resistivity profiles, made by towing an array behind a slowly moving boat.

The spring soundings were made in the same manner as soundings carried out on land, except that the electrodes, instead of being planted on the surface, were lowered through holes drilled in the ice and suspended at the base of the ice.

The summer soundings were taken by boat. A Schlumberger array was used. One boat was anchored at the centre of the array to carry the transmitter and receiver, while two other boats pulled out the current leads and tended the current electrodes. Both current and potential electrodes were supported at the water surface by buoys. The summer profiles were taken by towing a Wenner array behind a slowly-moving boat and taking readings at timed intervals.

Inflatable rubber boats 19½ feet in length were used as both electrode tenders and instrument carriers.

For the spring work and most of the summer as well, the electrodes were pieces of ¼" brass stock, bent in the shape of a thin U with legs about 30 cm long. Tin cans were tried during the summer, but were found to offer no advantage. Since the receiver potential values were quite stable, no attempt was made to use porous pots as electrodes, although these will be tried in future ezperiments.

The receiver for both winter and summer work was a standard McPhar R-103 resistivity receiver. The transmitter was a Huntec Lopo, modified in timing to produce a square wave output with a fundamental frequency of 0.3125 Hz. Current levels up to 500 ma were used, although most of the readings were made with currents of 100 ma.

Results

Table 1 presents in summary form a first interpretation of the sounding data, together with the available control for comparison.

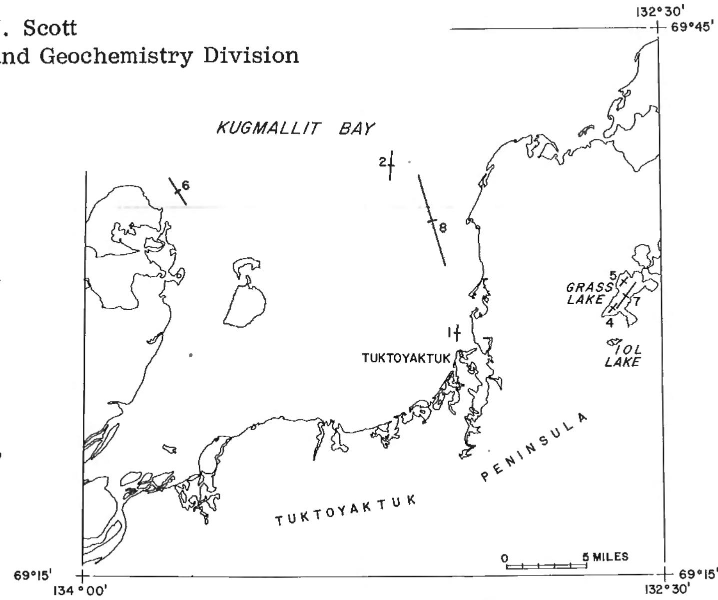

Figure 1. Map showing locations of soundings and profiles near Tuktoyaktuk, N.W.T.

1. Kugmallit Bay

Three spring soundings and one summer sounding were done on Kugmallit Bay. Figure 2a shows one of the spring soundings, and Figure 2b the summer one. The spring sites were those at which holes had been drilled by Hunter and Judge (pers. comm.) to look for the top of permafrost. The summer site was chosen for uniform water depth and ease of navigation (i.e. visibility of the DEW Line radome at Tuktoyaktuk).

The interpretations of the three spring-time soundings (Table I) agree reasonably well with the sparse control available, except for the depth to permafrost in sounding 6. The curve for the data of this sounding is not well-fitted, and a large discrepancy in depth is not surprising. More refined interpretation based on computer techniques will be made during this winter.

The water resistivities obtained from interpretation of the spring soundings may not be very reliable, as small variations in the depth of the potential electrodes made large differences in observed potentials for small values of AB/2. This variation was not observed for larger values of AB/2.

The spring-time soundings show a variable thickness of low-resistivity sediment overlying a layer of very high resistivity identified as permafrost. Since the unfrozen sediment has resistivities of the order of 3 ohm-m, the most that can be said of the high-resistivity layer is that the resistivity contrast is effectively infinite and that the high-resistivity value is probably greater than 300 ohm-m. The thickness of this layer

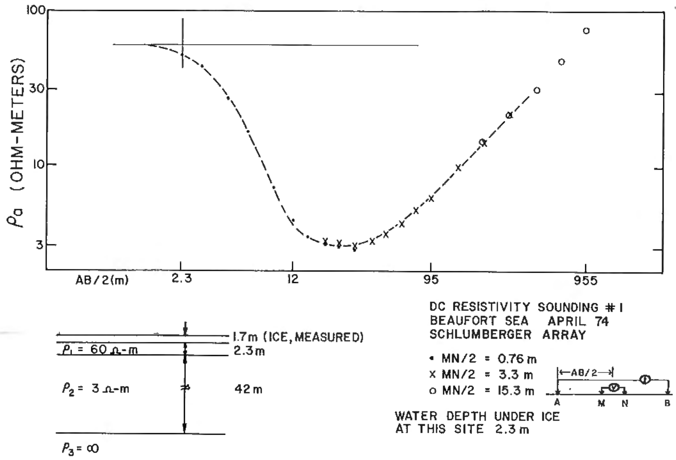

Figure 2a. DC resistivity sounding data on Beaufort Sea, April 1974. The dashed line linking the data points corresponds to the layered model shown below the curve.

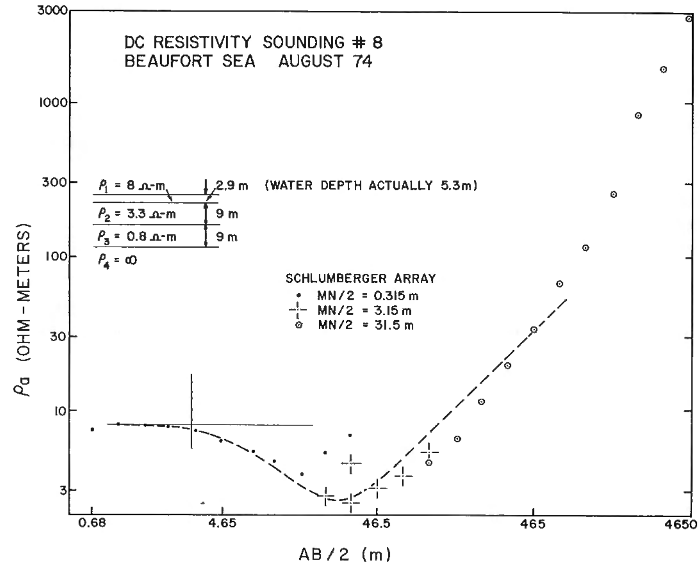

Figure 2b. DC resistivity sounding data on Beaufort Sea, August 1974.

is difficult to determine. A reasonable limit might be of the order of 300 to 400 m, but no evidence of this is seen even at AB/2 values of 1, 500 m. A theoretical study is planned for this winter to determine the AB/2 value required to penetrate such thicknesses.

The summer-time sounding was undertaken primarily to try for greater AB/2 values, up to a maximum of 4, 650 m. Unfortunately the summer sounding proved unreliable, for reasons which will be discussed below.

2. Grass Lake

At the time of the spring work, Grass Lake had frozen to the bottom, and in places up to 3 decimetres into the bottom sediments. The spring soundings were carried out by inserting the electrodes into the unfrozen sediment exposed at the bottom of holes drilled through the ice and frozen sediment. The two spring soundings were on resistivity lows indicated by an airborne E-Phase survey (Barringer, 1973) which were expected to correlate through taliks underlying at least part of the lake. Figure 3a shows one of the spring soundings, and Figure 3b the summer one.

Although no control is available on Grass Lake, the interpreted resistivities and depths from the winter work are consistent with drilling results on land between Grass and IOL Lakes (Rampton and Walcott, 1974a, b; Scott, unpubl. data). The material identifications in Table 1 are based on the land drilling data. In both spring soundings on Grass Lake, the ρ_a obtained for the largest AB/2 values was probably influenced by the proximity of the shore. In Figure 1, the length of the line indicates approximately the maximum span of the soundings. Thus the sudden rise in ρ_a at AB/2 values of 304 and 457 m is ascribed to the proximity of shore and near-surface permafrost rather than to the presence of permafrost under the lake.

Interpretation of the early (i. e. low AB/2 value) part of the summer sounding (Fig. 3b) agrees well with those of the two spring soundings. However, at greater AB/2 values, there is considerable scatter in ρ_a values, and the results are probably as unreliable as those of the summer sounding on Kugmallit Bay.

Figure 4 shows the results of two profiles made along the line of the summer sounding, with Wenner arrays of 5 and 15 m. At the ends of the line, nearshore, apparent resistivity values are quite high, and the presence of permafrost is thus indicated. Along the major part of the profile, however, ρ_a values are quite low, agreeing well with the values from the soundings. A further profile at a = 15 m was run across Grass Lake, crossing soundings 4 and 7, and penetrating into the southeast bay. The results on this profile resembled those on the first profile line. It appears that along these profile lines there is no permafrost within a few metres of the bottom, except very near the shore.

3. Kidney Pond

One spring-time sounding was carried out on Kidney Pond, a small body of water about 1 km south of Grass Lake. Kidney Pond is so small (200 m x 50 m) that the results were indecisive, as nearly all large AB/2 values reflect the influence of the shores of the pond.

4. IOL Lake

In an effort to outline the distribution of near-bottom permafrost, six Wenner profiles were surveyed during the summer on IOL Lake (Fig. 1) with an a-spacing of 5 m. The results are shown schematically on Figure 5. Apparent resistivities ranged from 30 ohm-m to 500 ohm-m with most values concentrated at the low and high ends of the range, and very few values observed between 50 and 200 ohm-m. A level of 150 ohm-m was

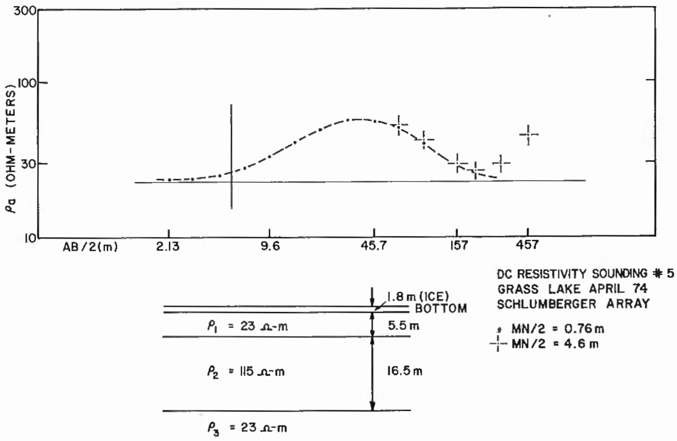

Figure 3a. DC resistivity sounding data on Grass Lake, April 1974. The dashed line linking the data points corresponds to the layered model shown below the curve.

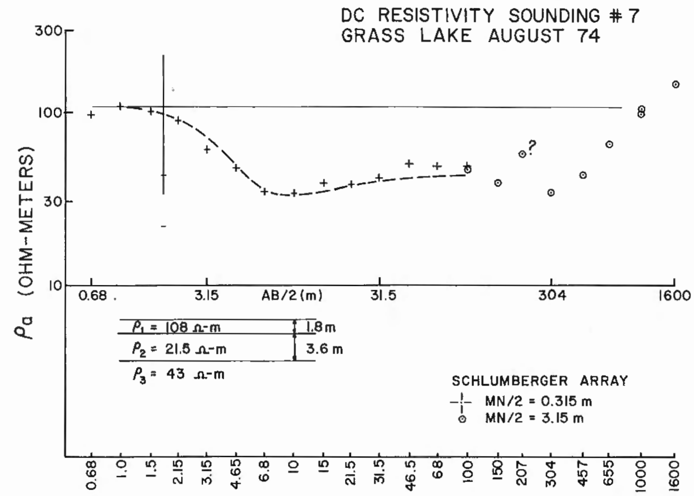

Figure 3b. DC resistivity sounding data on Grass Lake, August 1974.

TABLE I

Preliminary Interpretation of Soundings

SDG	PLACE & SEASON	CONTROL: Thicknesses Ice (m)	CONTROL: Thicknesses Water (m)	Depth to Permafrost (m)	ρ water from sample (Ω-m)	INTERPRETATION: ρ_1 (Ω-m)	t_1 (m)	ID	ρ_2 (Ω-m)	t_2 (m)	ID	ρ_3 (Ω-m)	t_3 (m)	ID	ρ_4 (Ω-m)	t_4 (m)	ID
1	Kugmallit Bay Spring	1.7	2.3	54	24	60	2.3	water	3	42	Unfrozen sediment (saline?)	∞	?	Permafrost depth=46 m			
2	Kugmallit Bay Spring	2.1	3.6	> 52	-	64	3.7	water	1.6	93	Unfrozen sediment (saline?)	∞	?	Permafrost depth=99 m			
6	Kugmallit Bay Spring	1.1	1.4	67	26	35	1.3	water	2.7	110	Unfrozen sediment (saline?)	∞	?	Permafrost depth=113			
8	Kugmallit Bay Summer	-	5.3	-	-	8	2.9	water	3.3	9	Unfrozen sediment	0.8	9	Unfrozen sediment	∞	?	permafrost
4	Grass Lake Spring	1.3	C	-	-	25	3.6	unfrozen clay	62	54	Unfrozen sands & gravels	25	?	Unfrozen sands			
5	Grass Lake Spring	1.3	0	-	-	23	5.5	unfrozen clay	115	17	Unfrozen sands & gravels	23	?	Unfrozen sands			
7	Grass Lake Summer	-	1.7	-	-	108	18	water	21.5	3.6	Unfrozen clay ?	43	?	Unfrozen sands & gravels			
3	Kidney Pond (near Grass Lake) Spring	2.0	1.2	-	-	124	2.1	water	12.4	2.1	Unfrozen organics?	∞	?	Edge of Pond			

chosen arbitrarily to represent the division between permafrost (ρ_a > 150 Ω-m) and non-permafrost (ρ_a > Ω-m) zones. The transition from permafrost to non-permafrost on each profile appeared to coincide with increases in water depth. The distribution of permafrost shown in Figure 5 agrees approximately with that deduced by Hunter (pers. comm.) from refraction seismic measurements.

Discussion

Both summertime soundings suffered from the problem of current leakage. Some of the wire used in the current leads was somewhat aged, and patched in many places. Prior to the work the wire was inspected closely, and all cuts and splices were taped first with self-vulcanizing rubber tape and then with

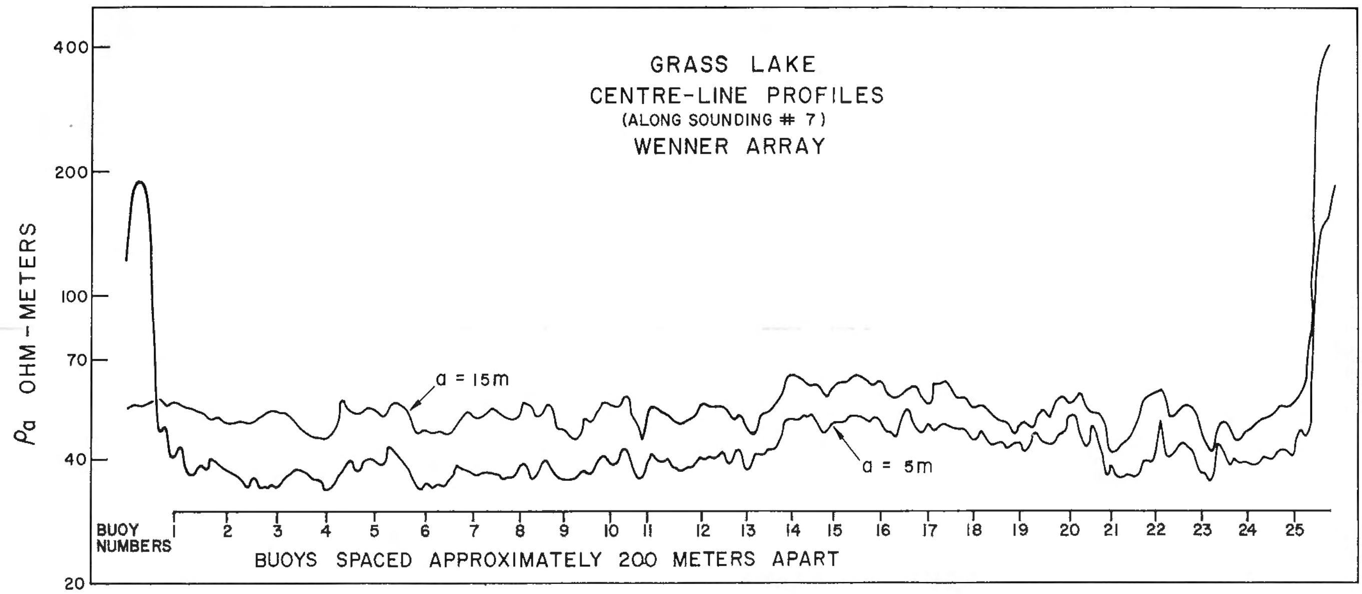

Figure 4. DC resistivity profiles on Grass Lake, along the line of the sounding shown in Figure 3b.

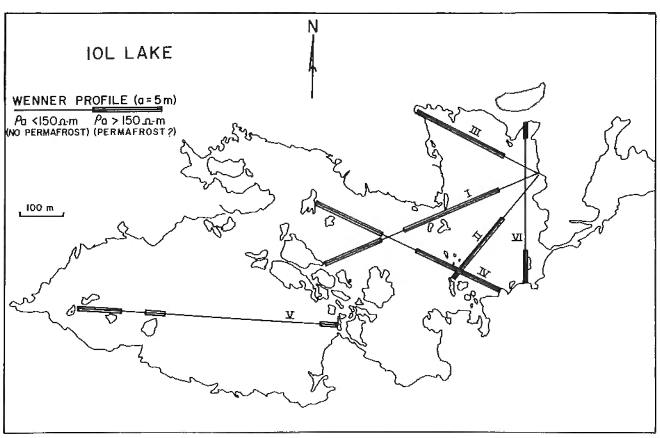

Figure 5. Map of DC resistivity profiles on IOL Lake, August 1974, showing interpreted distribution of permafrost.

standard plastic electrical tape. Erratic readings at large AB/2 values in sounding 7 were attributed to current leakages from specific splices, which were retaped as well as possible. However, the repair jobs were badly strained during the recovery of wire from the bottom after sounding 7, and it was observed during sounding 8 that for large AB/2 values the resistance between the two current leads with the electrodes out of the water was only two or three times that with the electrodes immersed in the water. Consequently it is felt that particularly for large values of AB/2, the results of soundings 7 and 8 are at best unreliable and at worst useless. Attempts will be made this winter to correct the results for leakage on the assumption of a line-source of current, but the outcome is not viewed with optimism, since it is unlikely that the leaks are uniformly distributed along the wire.

The spring-time soundings, on the other hand, are of reasonably high quality. Since the work was done in early spring, while daytime temperatures were still around -20°F to -40°F, the ice surface was dry, and current leakage was not a problem. Over the length of a sounding, water depth typically varied less than ten per cent and values of ρ_a obtained for different MN/2 but the same AB/2 varied only slightly. Unfortunately the contrast between permafrost and non-permafrost resistivities was so great that very large values of AB/2 may be required to probe beneath the permafrost. Further experiments are planned for this spring on sea ice, both in Kugmallit Bay, and hopefully farther out to sea.

From a logistical point of view, it appears that deep marine soundings may well be more efficiently carried out with a dipole-dipole rather than with a Schlumberger array. The consensus among the crew handling the wire this summer was that six miles of wire was beyond the limit for efficient operation. The disadvantage of a dipole-dipole array is the requirement for higher transmitted power levels, which calls for a motor-generator unit, and a general increase in scale, which in turn precludes the use of small inflatable rubber boats such as were employed this summer. Experiments are planned for next summer, in which both Schlumberger and dipole-dipole arrays will be employed.

The resistivity profiling technique appears most promising. The experiments this year were limited by the fact that the present receiver is single-ended, and thus cannot tolerate small signal levels when both receiver electrodes are far from the receiver location. By next summer it is expected that this problem will have been overcome. Larger arrays will be employed (i.e. larger values of a), and attempts will be made to use multiple a-spacings simultaneously. In these experiments comparisons will be made among various arrays.

Conclusions

The most interesting outcome of these preliminary experiments is that marine resistivity is not only feasible but also potentially very rewarding. Both profiling and sounding techniques appear to offer considerable subsurface information, some of which may not be available through other geophysical techniques.

The results of the work described here are sufficiently encouraging to warrant further experiments in the coming season. Further evaluation of the technique must await the results of this work.

Acknowledgments

The spring-time work was carried out by the author with the able assistance of D.C. Butterfield (GSC) and Ranley Felix (PCSP, Tuktoyaktuk). The name Grass Lake arises from a joke perpetrated by Mr. Felix and not recognized by the author until too late.

The summertime work was carried out by D. Eberle (Geological Survey of Germany), Colin Mathieson, Barry Malmsten, Alan Cox and Euan Mathieson (students employed by the GSC for the summer) and the author. Special thanks are due Mr. Cox for his selfless dive into the Beaufort Sea to free one of the boats at a critical point in the carrying out of sounding no. 8.

Initial encouragement to experiment with marine resistivity came from J.R. MacKay (UBC) and J.A. Hunter (GSC).

The names of lakes in this paper are strictly abritrary, and have no official standing.

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Project 730004

A.K. Sinha
Resource Geophysics and Geochemistry Division

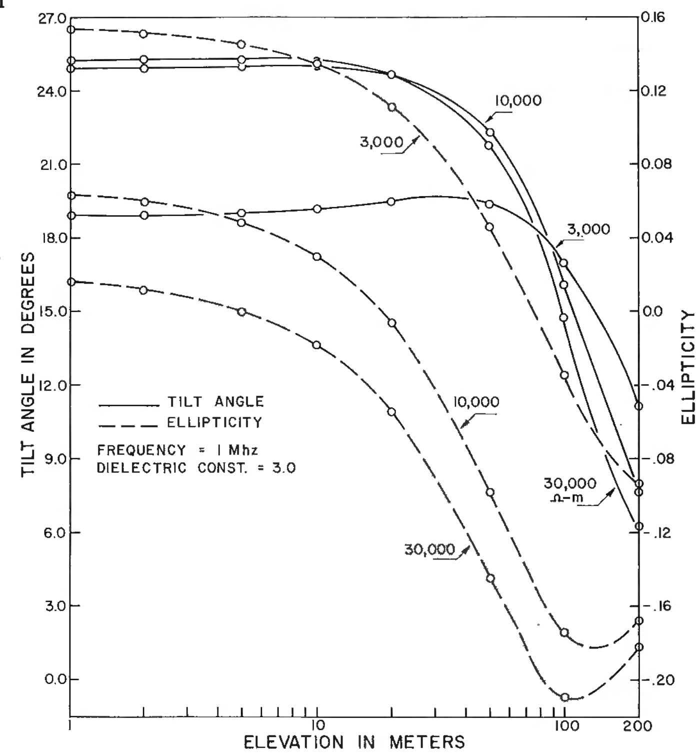
Plane-wave electromagnetic fields have often been used as sources of excitation in geophysical exploration The most important applications have, of course, been their use in telluric and magnetotelluric methods where natural E.M. fields are used. Of late, another source of plane-wave E.M. field has become available for geophysical use. Several powerful naval radio transmitters have been installed in various parts of the world in the last decade for communication with submerged submarines. The transmitting frequencies of these stations are mostly in the VLF range (15-25 KHz). In recent years other military transmitters (50-100 Khz) navigational transmitters (200-400 Khz) and broadcast stations (400 Khz-1. 5 Mhz) have also been used as sources of excitation. At distances of several wave lengths from these transmitters, the wave is practically plane. The plane-wave interacts with any conducting body including a conducting earth producing a secondary field which results in the elliptical polarization of the wave. The electrical constants of the ground may be obtained from the tilt and ellipticity of the field.

The development of airborne techniques for the measurement of wave tilt has been achieved recently, in which the wave tilts are measured simultaneously at three widely-spaced frequencies from VLF (15-25 Khz) to broadcast band frequencies (400 Khz-1 Mhz). The altitudes of the aircraft are normally about 100 m, somewhat less over especially flat terrain. The interpretation is based on determining the apparent resistivity of the medium (Wait, 1962; McNeill and Hoekstra, 1973) from the formula

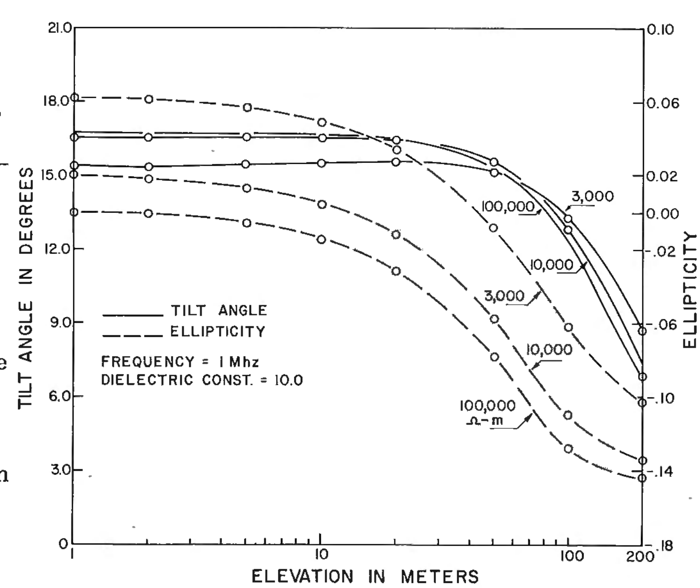
$$\text{Wave tilt} = E_x/E_z\big|_{z=0} = (1 + j)\left(\frac{\omega\varepsilon_0\rho_a}{2}\right)^{\frac{1}{2}}$$

where ω, ε_0 and ρ_a represent the angular frequency, permittivity of air and the apparent resistivity of the ground, and j is the imaginary operator. Two assumptions are implied in the interpretation process: (a) the quasistatic assumption (negligible displacement current) is valid in the whole frequency range, and (b) the influence of the altitude of the aircraft on the measured wave tilt is negligible. The purpose of this paper is to examine these assumptions and present some numerical results to show the dependence of wave tilt on the height of observation and on the dielectric constant of the ground.

The starting point for this analysis is the generalized expression for the wave tilt over a medium (Norton 1937). It was checked by computer simulation that the first assumption of neglect of displacement current is valid up to 100 Khz, beyond which they are no longer negligible. Thus the implied assumption that only conduction currents need to be considered even at



Figures 1 and 2. Variation of the tilt angle and the ellipticity with the elevation of the aircraft at different dielectric constants.



broadcast band frequencies seems to be rather questionable. The second assumption was also critically examined by obtaining the tilt angle and ellipticity of the elliptically polarized field at various altitudes by computer simulation.

Figure 1 shows a plot of the tilt angle (in degrees) and ellipticity against the altitude of the aircraft at a frequency of 1 Mhz, a typical broadcast bank frequency assuming a dielectric constant of 3.0 for the ground. Three resistivity values, typical of the permafrost terrains are considered, e.g. 3,000 Ω-m, 10,000 Ω-m and 30,000 Ω-m. The solid and the dashed lines represent the tilt angle and ellipticity respectively. It is clear from Figure 1 that for relatively highly resistive media ($\rho \simeq 10,000$ Ω-m), the influence of altitude on the tilt angle is negligible up to 20 m. However the ellipticity (presently available equipment does not measure this) variation is even sharper. The influence of altitude was seen to be extremely small at lower frequencies up to 100 Khz and for lower resistivity values. In the intermediate frequency range (200 - 400 Khz) the tilt angle values showed a small rise with altitude before coming down, similar to that shown for the 3,000 Ω-m line.

Figure 2 shows a similar plot of tilt angle and ellipticity versus the altitude of the aircraft at the same frequency of 1 Mhz but for a different dielectric constant of 10.0. The rate of fall-off of the tilt and ellipticity is smaller in this case than when the dielectric constant was 3.0. It is seen that when the resistivity is, say, 3,000 Ω-m, the altitude of the aircraft must be greater than 50 m before the influence of altitude becomes serious. For larger resistivity values, however, the altitude of the aircraft must be less than 20 m before the effect becomes negligible. Hence the importance of considering the elevation of the aircraft in the interpretation process becomes obvious. In general, the neglect of the aircraft elevation will result in an estimate of resistivity of the ground that will be lower than the true value. The reverse is the case with ellipticity, i.e. the neglect of the effect of altitude on ellipticity will result in a higher estimate of the ground resistivity.

This study, therefore, clearly points to the need for the altitude of the aircraft to be taken into account in the interpretation of airborne wave tilt measurement data particularly when the frequencies involved are in the broadcast band range and where the expected ground resistivities are high.

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Project 730004

A.K. Sinha
Resource Geophysics and Geochemistry Division

Permafrost underlies a substantial part of the northern hemisphere above the 60° latitude below both the land and sea. In most areas of northern Canada, they are distinguished by high resistivity and moderate dielectric constant values. Although several electrical and electromagnetic (EM) techniques have been used to determine the extent and depth of permafrost, they have met with only moderate success. DC soundings over permafrost terrains encounter problems in sending sufficient amount of current into the ground and sending them deep enough to know the depths of permafrost zones. VLF methods have also been tried with limited success, but the frequency of VLF stations may be too low to achieve sufficient resolution of the strata. Thus the solution would seem to lie in a non-contact, variable frequency EM method so that depth penetration and resolution would be controlled by varying the frequency of the exciting current. The field procedure would also be simplified (especially in winter) since there would be no need to drive the current through the resistive upper layer by using contacting electrodes.

One way of determining the resistivity and dielectric constant of a homogeneous medium, or the apparent resistivity and apparent dielectric constant of a layered medium by multifrequency dipoler sounding has been reported earlier (Sinha, 1974). Unfortunately, it is not always easy to extract information about the electrical constants of a layered medium from the apparent resistivity and apparent dielectric constant values. Therefore, further studies to solve the inverse problem of determining the electrical constants of a two-layer medium have been undertaken.

Most engineering studies over permafrost terrain are aimed at determining the nature of the subsurface up to depths of 50-100 feet or less from the surface. Generally, in this depth range there would be only two layers distinct enough to be recorded by surface measurements. In winter, the top layer will be the frozen active layer and permafrost, and the bottom layer will be unfrozen sediments. The contrast in their electrical properties would be quite large in most areas, e.g. the conductivity contrast between the unfrozen and the frozen layers is likely to be in the range of 10-300 or even higher in some areas. In summer, on the other hand, we would have active layer at the top and the permafrost below. However, in such a situation, most of the currents (especially in medium frequency range) would be absorbed in the top layer and the bottom layer might remain invisible.

Some results of our numerical simulation on a computer of the first type of permafrost models follow. As discussed earlier (Sinha, 1974; in prep.) the minimum coupled system 2 (one coil horizontal, the other vertical) response is most regular and easiest to interpret.

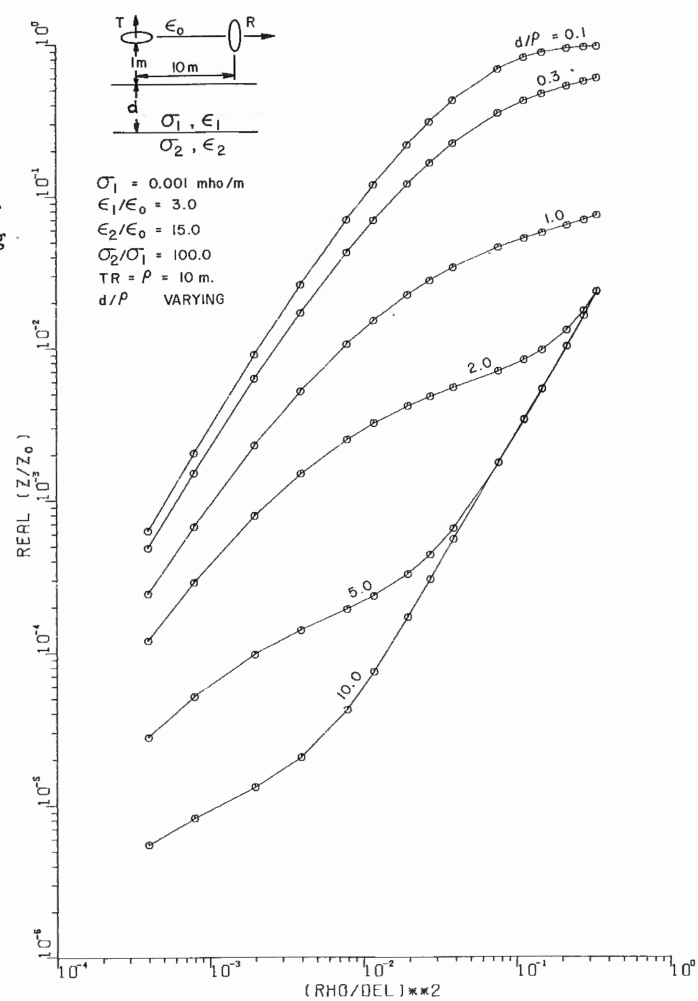

Figure 1. Plot of the real part of (Z/Z_0) against the parameter $(\rho/\delta_1)^2$ for System 2 over a two-layer earth for a conductivity ratio of 30.0 and a dielectric constant of 3.0 for the top layer.

All the results in this paper would pertain to this system assuming a transmitter-receiver separation of 10 m, altitude of the coils over the ground of 1 m and a frequency range of 1 Khz to 1 Mhz to assure reasonable depth penetration and resolution of the data.

Figure 1 is a plot of the real part of the mutual coupling ratio (Z/Z_0) against the dimensionless parameter $(\rho/\delta_1)^2$, where ρ and δ_1 refer to the coil separation and the generalized skin depth in the top layer respectively. The electrical constants of the layers have been indicated in the diagram. The variation of Re (Z/Z_0) has been plotted for six values of

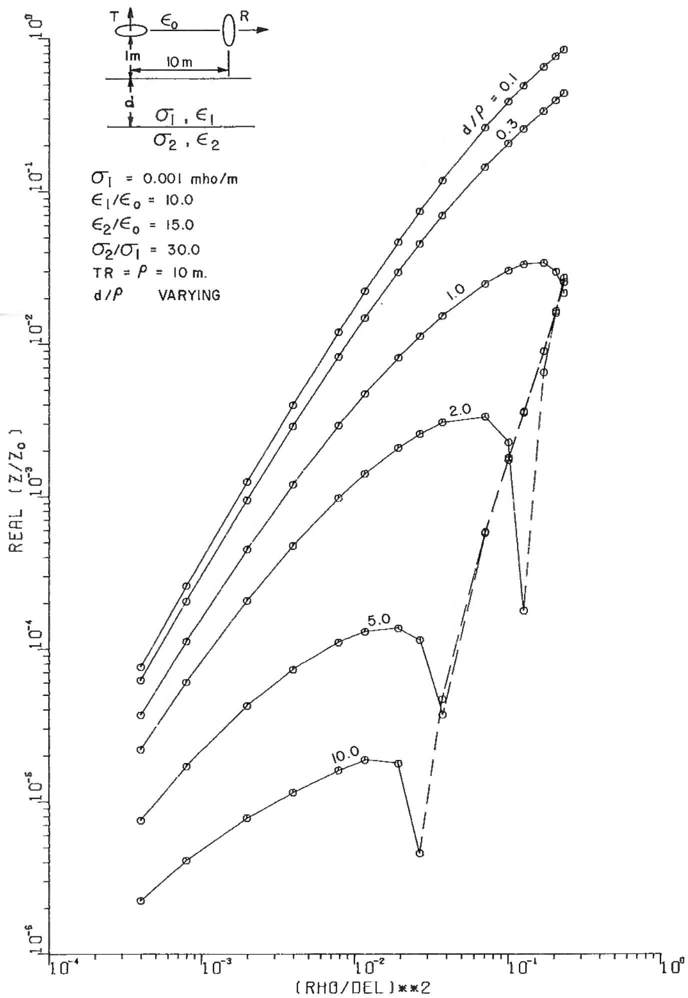

Figure 2. Plot of the real part of (Z/Z_0) against the parameter $(\rho/\delta_1)^2$ for System 2 over a two-layer earth for a conductivity ratio of 30.0 and a dielectric constant of 10.0 for the top layer. The dashed lines are reversed in sign.

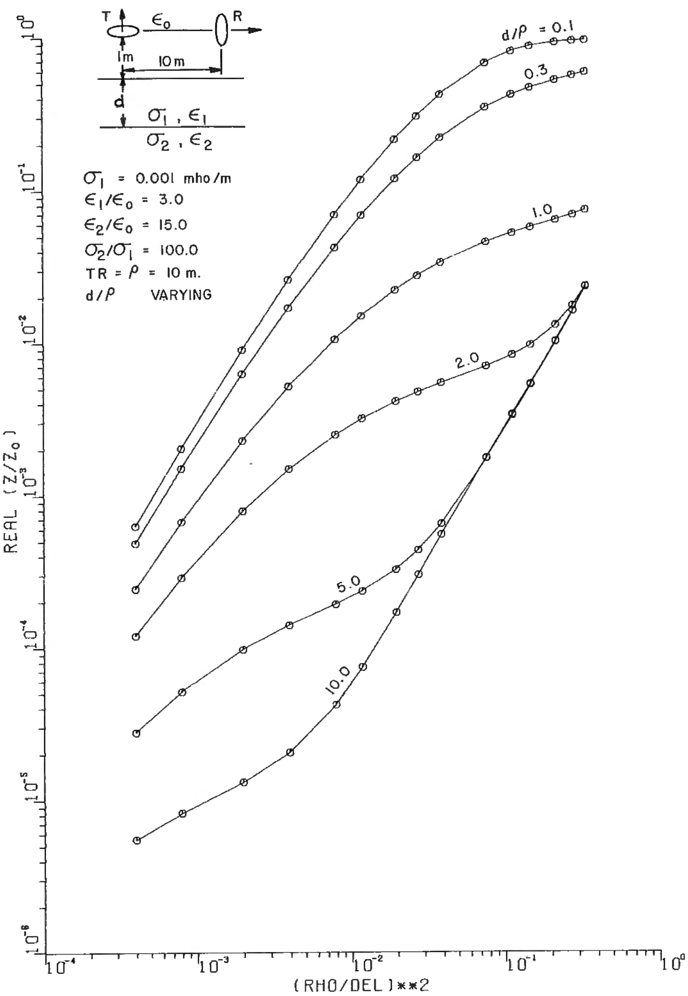

Figure 3. Variation of the real part of (Z/Z_0) with the parameter $(\rho/\delta_1)^2$ for System 2 over a two-layer earth for a conductivity ratio of 100.0 and a dielectric constant of 3.0 for the top layer.

d/ρ, i.e., the ratio of the thickness of the top layer to the coil spacing. The curve for $d/\rho = 0.1$ indicates a situation where the top layer is very thin, resulting in very strong bottom layer influence. However, at higher frequencies, when (ρ/δ_1) increases, the current flows more and more in the top layer. Then the curve turns and approaches the limit for the resistive top layer. As the d/ρ ratio increases, the effect of the top layer increases too. For example, when $d/\rho = 10.0$, the effect of the top layer predominates but the bottom layer influence is still visible, especially at lower frequencies. Thus, as the frequency is increased, it tends to follow the curve for $d = \infty$ since almost all the currents are now confined to the top layer. For values of d/ρ in between these two extremes, they show a transition from the curve for $d \to 0$, i.e. bottom layer predominant to the curve for $d \to \infty$, i.e., top layer predominant as the frequency increases.

Figure 2 shows the variation of Re (Z/Z_0) against $(\rho/\delta_1)^2$ for the same two-layered model as before except for the fact that the dielectric constant of the top layer is not 10.0. It has been seen from computer modelling for a homogeneous dielectric that as the dielectric constant and frequency increases, Re (Z/Z_0) decreases continuously going from positive to negative values. The same effect is seen here. The dashed lines indicate the values that have been reversed in sign. The response for $d/\rho = 0.1$ and 0.3 remain almost the same as the ones in Figure 1 since they are most affected by the bottom layer which has not changed. For larger d/ρ values, the effect of the top layer becomes more important and so the higher dielectric constant of 10.0 begins to produce negative values of Re (Z/Z_0) at higher frequencies. At very high values of frequency, when the top layer is contributing almost all the signals, the response values merge together indicating the response for a homogeneous dielectric whose dielectric constant is 10.0.

Figure 3 indicates the response for a two-layer medium, the parameters of which are identical to that in the first case, except for the fact that the conductivity ratio is now 100 instead of 30. The shape of the response curves are remarkably similar to that in Figure 1, but the magnitudes are larger in this case. The larger σ_2/σ_1 ratio in this case is reflected in the spread between the response curves for $d \to 0$ (low frequency asymptote of $d/\rho = 0.1$) and that for $d \to \infty$ (high frequency asymptote of $d/\rho = 10.0$). Thus this factor may provide us with an idea about the conductivity contrast σ_2/σ_1.

For interpretation, the measured Re (Z/Z_0) in the field should be plotted against the parameter P (ρ^2 x frequency) on double-log paper with the same cycle length as that in the theoretical curves. The field curve should be compared with appropriate theoretical curves and shifted along the X axis until a match is obtained. The value of σ_2/σ_1 is obtained from the value of σ_2/σ_1 for the theoretical curve and the parameter d from the value of d/ρ of the theoretical curve with the match is made. The value of σ_1 is obtained in a similar fashion from the values of (ρ_2/δ_1^2) and P at lower frequencies after the match is obtained. If the Re (Z/Z_0) stays positive at all frequencies, the dielectric constant of the top layer is likely to be less than 6.0. When negative values of RE (Z/Z_0) are present, curve matching, or using the homogeneous dielectric curves at higher frequencies may be used to obtain $\varepsilon_1/\varepsilon_0$. However, it is difficult to determine the dielectric constant of the bottom layer since at lower frequencies, when the bottom layer does affect the response, the displacement currents are negligible. At higher frequencies, when displacement currents are important, the skin depth limits the penetration of the wave. This inherent problem seems to rule out any easy method to determining $\varepsilon_2/\varepsilon_0$ from the mutual coupling ratio variations.

This type of null-coupled EM system can also be made into a hand-held one-man operation instrument with a smaller coil separation of 2-3 m or may be mounted on a non-conducting sledge with the large coil separation of 10 m and towed by a powered vehicle for rapid survey. Since the frequency range of this equipment is suggested to be from 1 Khz to 1 Mhz, it may be useful as a general mapping device over any type of frozen or unfrozen terrain.

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Determination of ground constants of permafrost terrains by an electromagnetic method. In prep.

PART A: PORTABLE SATELLITE IMAGERY RECEIVING FACILITY, TUKTOYATUK, DISTRICT OF MACKENZIE

Project 700089

S. Washkurak
Resource Geophysics and Geochemistry Division

A NOAA (National Oceanic Atmospheric Administration) VHRR (Very High Resolution Radiometer) satellite receiving capability was established at the EMR Geomagnetic Observatory complex at Blackburn, Ontario, last October in co-operation with the Radio Engineering Section of the National Research Council. A computer controlled 8-foot parabolic antenna was able to receive data when transmitted from the satellite in the non-multiplexed real time mode from 15° elevation, providing coverage from Baffin Island to Florida. It was also determined that manual tracking of the satellite is possible by preplotting the satellite track to obtain the approximate azimuth and elevation angles and maximizing the automatic gain control voltage. The antenna beam-width of the 8-foot parabola is 5.8 degrees. It also helps to monitor the transmitted SR (scanning radiometer) data on 137.5 MHz to anticipate the approximate position and time of the satellite with the broad beam VHF antenna.

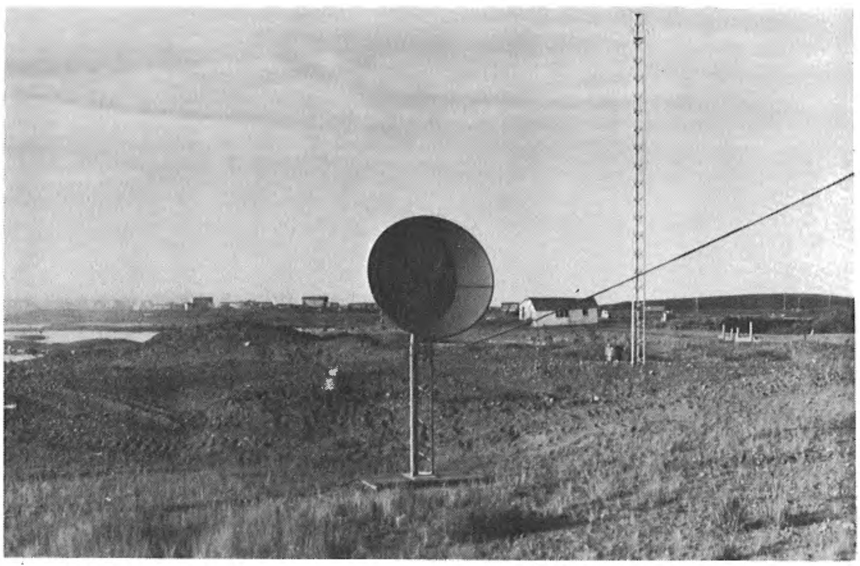


Figure 1. Portable six-foot solid parabolic antenna to receive VHRR at Tuktoyaktuk, N.W.T.

The VHRR data is recorded on a Sangamo Sabre III tape recorder at 30 inches per second with a frequency response band from DC to 20 KHz. The video information with the appropriate synchronizing and sweep circuits is displayed on a high resolution cathode ray tube and photographed with Polaroid 107 film or Polaroid 105 high resolution positive-negative film.

Two lightweight portable satellite receiving stations were installed at Tuktoyaktuk, N.W.T. in late August. One to receive the conventional APT data transmitted on 137.5 MHz and an experimental VHHR station using a solid six-foot parabolic antenna. Some VHRR imagery was obtained but due to wind loading on the solid 6-foot diameter dish (Fig. 1) and other tracking problems, the APT imagery was used to assist co-ordination of ship and flight movement by the Polar Continental Shelf Project. Instead of a solid parabolic antenna it is proposed to use a modified (UHF) Ultra High Frequency TV antenna with $\frac{1}{4}$ inch wire mesh added to provide proper reflection at the VHRR frequency of 1697.5 MHz (Fig. 2).

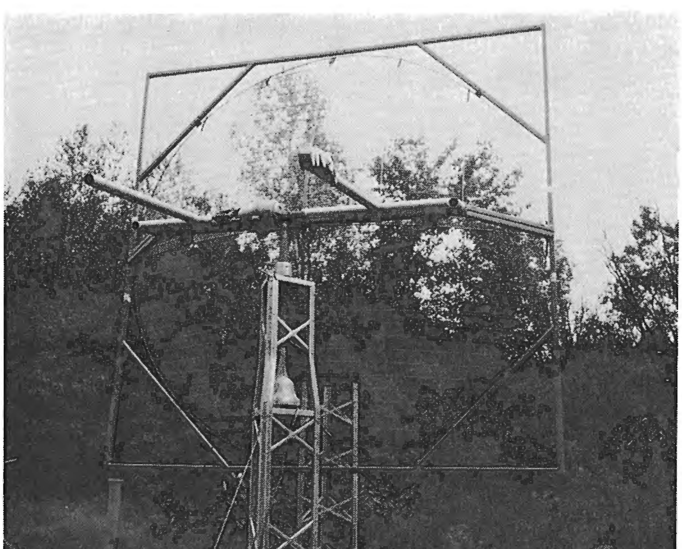


Figure 2. Portable eight-foot wire mesh parabolic antenna to receive VHRR satellite data.

Azimuth and Elevation drive is obtained from two aluminum Cornell Dubilier Ham II Rotor systems. The whole off-the-shelf antenna system is lightweight and by collapsing in dimension below 52 inches can be shipped by conventional air carrier and easily assembled by two men. A modified hifi stereo tape recorder using the popular 565 phase lock integrated circuit as described in the March 1974 issue of Wireless World to modulate and demodulate the VHRR data can be used

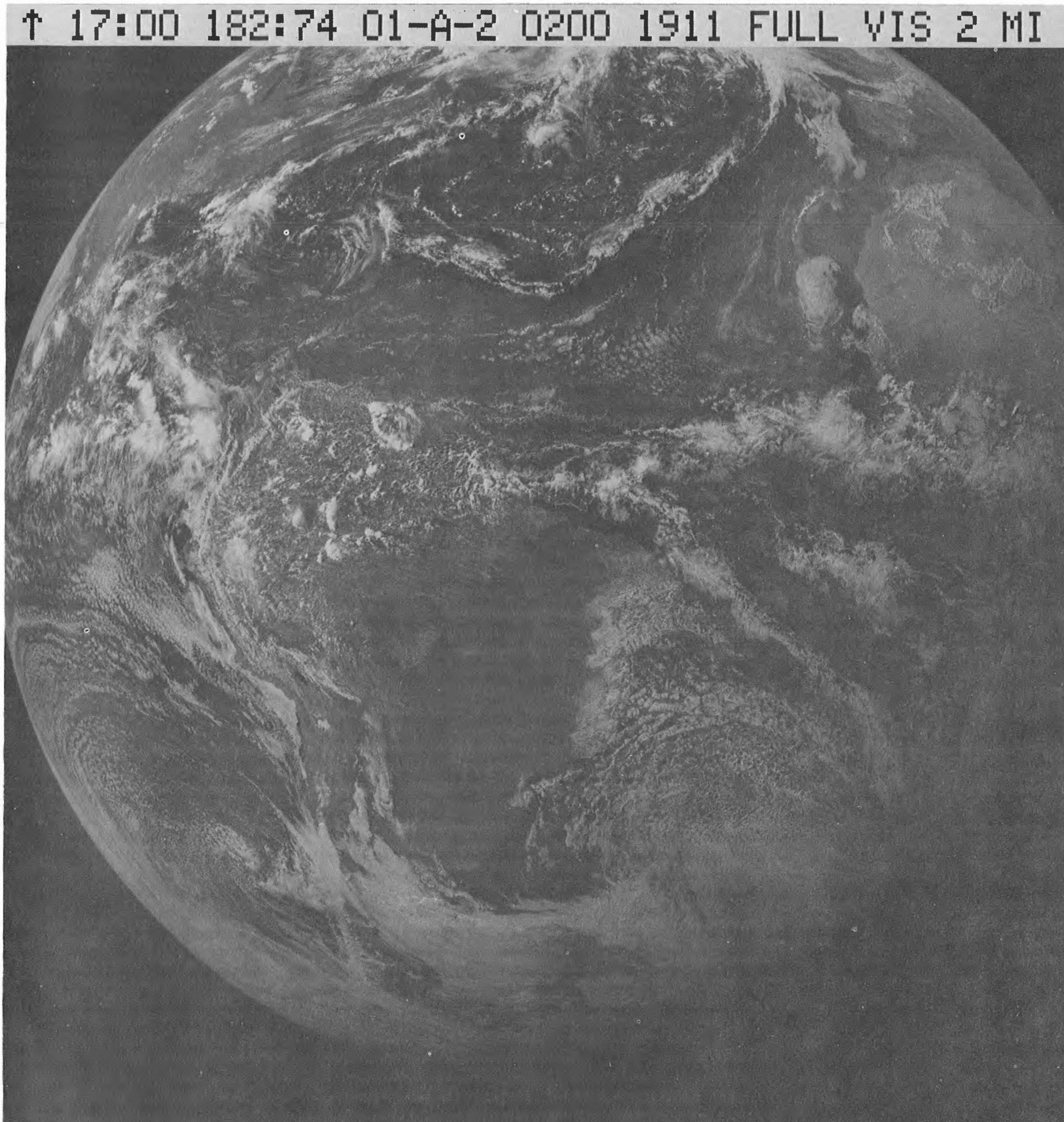


Figure 3. SMS meteorological satellite view of earth disc showing Sahara dust clour over the Atlantic, July 1, 1974.

instead of the large bulky FM instrumentation recorder normally used to record the DC to 35 KHz data.

ITOS-G will be launched by NASA on October 28, 1974 into a 1460-km geocentric orbit. It will be another in a series of improved Tiros-M type operational satellites to expand the operational capability of the ITOS system. On achieving successful orbit it will be designated NOAA IV. The primary objective will be to provide global daytime and nighttime direct readout imagery data with the scanning radiometer (SR). The spacecraft will also be capable of supplying global atmospheric temperature soundings and very high resolution radiometer (VHRR) coverage of selected areas in either a direct readout mode or a tape record mode. It is hoped that with two operational NOAA satellites flying, arrangements can be made to designate one satellite to provide continuous high resolution imagery over the Arctic Islands in a direct read mode so that small portable stations can receive VHRR data in isolated areas.

A secondary objective will be to monitor solar proton intensity on a routine basis which is directly related to magnetic storm activity.

We wish to acknowledge the financial and manpower assistance provided by the Polar Continental Shelf Project to establish the first VHRR satellite receiving station at Tuktoyaktuk, N. W. T.

PART B: GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE (GOES) SYSTEM, EMR GEOMAGNETIC LABORATORY, BLACKBURN, ONTARIO

Two Synchronous Meteorological Satellites (SMS) are scheduled to be placed in earth synchronous orbit by NASA in late 1974 and early 1975. One will be orbited over the Atlantic and the other over the Pacific providing overlapping coverage of the earth's disc to ± 70° latitude with one-half-mile ground resolution in the visible and 4-mile resolution in the infrared with the Visual Infrared Spin Scan Radiometer (VISSR).

SMS-A was launched May 17, 1974 and placed in a synchronous orbit 45° W longitude at an altitude of 19, 323 nautical miles. A typical representation of field of view and visible imagery data presentation of these satellites is presented in Figure 3. Note the white shaded area over the Atlantic off the bulge of Africa which represents a Sahara dust storm that eventually drifted across the Atlantic to Florida. This is the first of several second generation synchronous satellites to be launched by NASA and other countries including Japan, ESRO (European Satellite Organization) and the USSR to provide a global data collection system under the auspices of the World Meteorological Organization. After launch and checkout these operational satellites will be renamed Geostationary Orbiting Environmental Satellites (GOES).

Figure 4. SMS sixteen-foot parabolic antenna at EMR Geomagnetic Laboratory, Blackburn.

Besides providing high resolution visual and infrared (VISSR) data of the earth disc every hour, the GOES spacecraft will measure the magnetic field, electron, proton and X-ray flux by means of the Space Environmental Monitc (SEM) systems. Also data collection from remote platforms and distribution of low resolution weather facsimile environmental data to small 6-foot parabolic satellite receiving stations will be transmitted. Correlation of the magnetic field and flux measurements of the sync satellite with the polar orbiting solar flux measurement of NOAA IV could prove very useful for airborne magnetic survey programs with the discontinuance of magnetic storm forecasts available from NOAA at Boulder, Colorado.

Atmospheric radon is known to originate predominately from land surfaces and persistent strong temperature inversions are capable of trapping minute radon concentrations to 300 metres. An hourly cloud or wind movement indication in conjunction with X-ray flux indication from the synchronous satellite might be useful in providing data for reducing background count for radiometric surveys. A 16-foot diameter parabolic antenna Figure 4 has been set up at the EMR Geomagnetic Laboratory to evaluate the feasibility of a portable satellite receiving station to receive stretched VISSR and magnetic and flux data from GOES satellites.

I wish to acknowledge the pleasant co-operation and technical support of Chuck Vermillion of Goddard Space Flight Center and Bob Popham, APT Coordinator of National Oceanic Atmospheric Administration, Washington, D. C.

A. Environmental Marine Geology

41. LITTORAL PROCESSES AND SEDIMENT DYNAMICS, MAGDALEN ISLANDS, QUEBEC: JULY - AUGUST, 1974

Project 740009

E.H. Owens
Atlantic Geoscience Centre, Dartmouth

Introduction

Data were collected simultaneously at two sites on the barrier beaches of the Magdalen Islands, in the Gulf of St. Lawrence, to monitor process variables and geomorphological changes over a 28-day period. These sites were selected because they offer an opportunity to study two distinctly different littoral environments simultaneously. The west-facing barrier coast (Fig. 1a) is exposed to the dominant and prevailing winds from the northwest, while the east-facing barrier is a relatively sheltered environment affected only by

Table 1a

		Hours	% time	Ave. Speed (kph)	Max. Speed (kph)	Wind Run (km)	% time Speed >25 kph	Longest period onshore winds >25 kph (hrs.)
Onshore Winds	East	294	44	20.5	76	2004	8.3	24
	West	348	56	22.9	58	2654	20.8	42

Table 1b

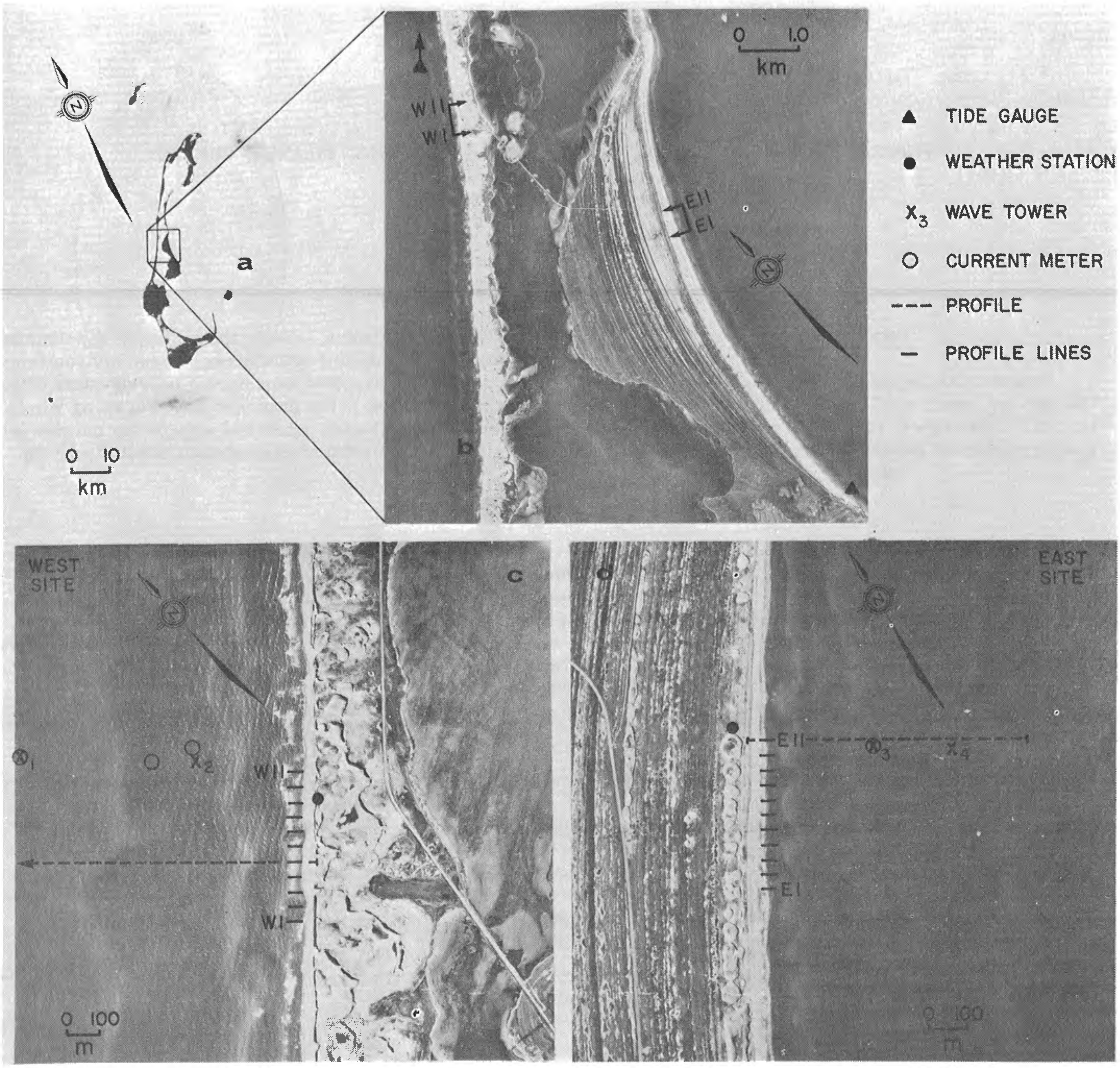
		Ave. Significant Wave Ht. (cm)	Max. Significant Wave Ht. (cm)	% time Significant Wave Ht. >90 cm	Ave. Wave Period (seconds)
Wave Data	East*	35	190	7.1	4.2
	West**	49	230	14.0	4.1

Table 1c

			Hours	% time	Ave. Speed (cm/sec)	Max. Speed (cm/sec)	Current Run (km)	% time Current >50 cm/sec
Longshore Currents	East	to North	470	69	18.5	112	314	4.0
		to South	210	31	20.9	79	158	1.8
	West	to North	315	53	25.2	90	286	22.0
		to South	282	47	23.6	60	239	4.5

* No. 1 wave tower
** No. 4 wave tower
} *see* Figure 1c and 1d.

Table 1a. Summary of onshore wind data July 30 to August 27, 1974. Location of anemometers indicated on Fig. 1c and 1d.
b. Summary of wave data recorded from the two outer towers.
c. Longshore current data. Current run is the multiple of current velocity and time.



a. Magdalen Islands (National Air Photo Library, ERTS image, E-1395-14244-7, 22-8-73; 1: 1,000,000).
b. Study Area (National Air Photo Library, A13477-52, 1952; 1: 60,000). Limits of the study sites indicated by the arrows.
c. West Coast Site (National Air Photo Library, A21672-108, 14-6-70; 1: 9,500).
d. East Coast Site (National Air Photo Library, A21672-152, 14-6-70; 1: 9,500).

Figure 1. Location of study sites.

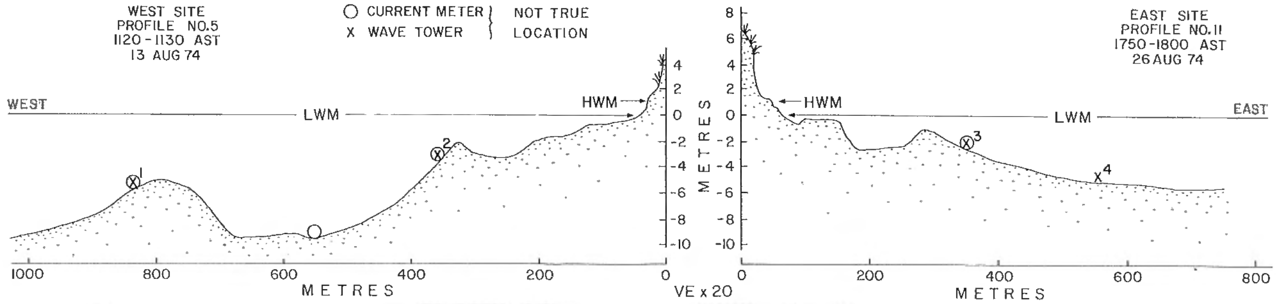


Figure 2. Beach and nearshore profiles of the west and east study sites. The location of the wave towers and current metres are shown in relation to the nearshore bottom morphology.

storm waves out of the northeast and by modified Atlantic swell which passes through Cabot Strait. In addition to the objectives (1) investigating the relationships between littoral processes, sediment dynamics and morphological variations, and (2) comparing the exposed and sheltered environments, the two sites will be reoccupied during November-December 1974 in order to (3) determine seasonal variations in processes and morphology.

Data Collection

At each site 20 process variables were monitored every three hours from July 30th to August 24th on the west site and from July 30th to August 27th on the east site. Meteorological data were collected from two weather stations (Fig. 1c and 1d) and the tide data were recorded by two gauges installed at adjacent wharfs (Fig. 1b). Wave data were monitored using four 3 m resistance wave staffs mounted on specially designed towers. The two outer towers were positioned in 6 m of water, seaward of the nearshore bars (Fig. 2). Two inner towers were located in depths of 3 m. Wave height and period were monitored directly using strip chart recorders set up in huts on the beach. Four current metres were placed on the bottom (Fig. 1c and 1d), although one mounted on the outer west side tower was displaced by storm waves within the first week. Other parameters that were monitored included barometric pressure, breaker variables, longshore current, and groundwater elevation.

Eleven profile lines were established on each site at 50 m intervals (Fig. 1c and 1d). The profiles were surveyed during low tide on alternate days and extended to water depths of 1.5 m, using the pole and horizon method (Emery, 1961). Echo-sounder profiles were run along six lines at each site whenever wave conditions were suitable.

Preliminary Data Analysis

As the gulf is largely protected from waves generated in the North Atlantic, wave conditions are controlled by winds generated by pressure systems. During the period of observations five low pressure systems passed over the Gulf of St. Lawrence. Although no intense storms (less than 980 mb) crossed the region, strong winds (greater than 25 kph) were

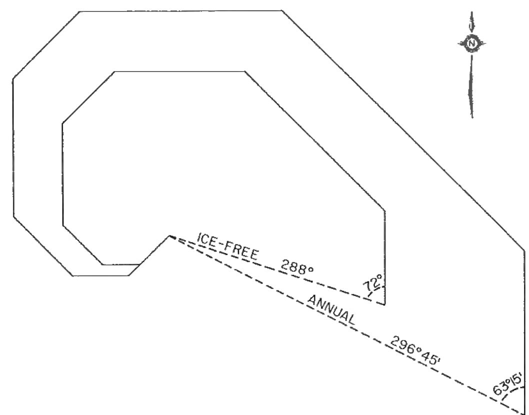


Figure 3. Vector diagram of winds greater than 25 kph derived from data collected at Grindstone, M. I., 1933-68. The vector was computed by weighting the mean monthly wind speed frequency classes. The ice-free period is defined as April to December.

common, with a maximum recorded speed of 76 kph over a 30 minute period (Table 1a). The summary of wind data and a weighted vector (Fig. 3) show a higher frequency and higher velocities of winds from the west-northwest. The weighted vector indicates that during the ice-free period, the prevailing direction of winds greater than 25 kph, was from 288° (west-northwest). It is also important to note that the frequency of storm winds is greatest during the winter months and that wave generation is greatly impeded by the presence of sea ice during the period January to March. Wave height and wave period were closely related to wind velocity. After the longest storm, which lasted 42 hours, the significant wave height on the west coast rapidly decreased from a maximum of 230 cm to 50 cm within 36 hours. The distance of breaking waves from the swash line varied with wave height. The largest waves observed during the study (Table 1b) broke near the No. 1 wave tower, approximately 600 m from the beach. During storm wave conditions little energy reached the beach due to the shallow offshore zone because only the small waves (less than 50 cm wave height) could pass over the offshore bars without breaking.

Although the beach profile and echo-sounding data have not been processed at this time it is evident that there was little change in beach morphology during the passage of storms despite the high energy conditions. Greater variation was observed in the adjacent nearshore areas as wave action was effective in moving large volumes of sediment on the submarine bars.

The direction of currents in the littoral zone (Table 1c) was dependent on the angle of refracted wave approach which was determined largely by the nearshore topography. In general, the prevailing direction of littoral drift at both sites was to the north. One disappointment during this project was the loss, at the beginning of the study, of the current metre at the outer-west-site wave tower. During diving, at this tower, bottom currents greater than 50 cm/sec to the northeast were common. The pattern of bedforms at the tower was very variable with ripple crest spacing ranging from 5 to 40 cm, and ripple heights varying between 3 and 10 cm. The two other current metres on the west site (Fig. 2) provided accurate velocity data but the current direction was difficult to interpret due to the small size of the vane which was constantly affected by orbital wave motion. In the trough, currents up to 50 cm/sec over a 10 minute period were recorded, with instantaneous velocities in excess of 100 cm/sec. Echo-sounder profiles in the trough indicated the presence of a series of asymmetrical sand waves migrating to the northeast. The crest spacing of these sand waves was approximately 100 m with a wave height of approximately 1 m. Current velocities recorded at the metre adjacent to the inner-west-site wave tower were higher than those monitored in the trough; this metre was removed on August 15th following burial. The data from the east-site current metre has yet to be analyzed.

Discussion

A comparison of the data from the two sites shows distinct differences, particularly in terms of the amount of energy available to redistribute nearshore and littoral sediments. It is expected that this will be accentuated during the winter months, when wind velocities are greater and a much higher percentage of winds are from the west-northwest. The morphology of the nearshore bars is very different, even though offshore gradients are similar on both coasts. The larger bar and trough system, on the west coast, is exposed to the highest waves, which generate strong bottom currents. On the east coast, onshore storm winds are less frequent and wave heights are lower, as a result the bars develop in shallower water. The prevailing direction of storm-wave approach is from the westerly quadrant. On the west coast this generates nearshore and littoral currents which transport sediment towards the northeast. As most wave energy is concentrated on the outer bars during storms, current velocities in this zone are higher than longshore currents measured at the same time. The shallow nearshore bars protect the beach from storm wave action and no major morphological changes were observed on either coast during the study period. Comparison of maps computed from the profile data will enable detection of any small-scale morphological changes.

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1961: A simple method of measuring beach profiles; Limnol. Oceanogr., v. 6, p. 90-93.

Project 740012

G. D. Patton
Atlantic Geoscience Centre, Dartmouth

One aspect of sedimentary environmental geology is the study of the interaction of forces which produce a given set of geological features. Resolving the genetic relationship between forces and sedimentary features has been under consideration for some time, but analyses of natural situations which are in dynamic equilibrium have met with considerable difficulties, in many cases due to the large number of variables.

The Bay of Fundy, with its record tidal range and swift currents has been of interest for some time; however, little research on the sedimentary dynamics of the nearshore areas has taken place. The Bay of Fundy has a large number of estuaries that, because of the high tidal range, extend for many kilometres inland. The form of these estuaries and their associated sedimentary features are largely controlled by the tides and the currents associated with them, but to date, little interest has been shown in the genetic relationships between sedimentary features and hydrodynamics in this type of an environment.

Rivers entering the Minas Basin of the Bay of Fundy invariably show a strong tendency to meander in their lower reaches. Characteristically, the estuaries wind through exposures of till and sandstone or shale outcrops and in many places are bordered by low-lying, flat, salt marshes. The salt marshes are flooded during spring tides. The rivers have gently to steeply sloping mud, sand, gravel or boulder banks and, in the river bed, sand and gravel bars. The strong currents and violent turbulence associated with ebbing and flooding tides produce a variety of bedforms in the estuaries including large- and small-scale scour features, ripples, megaripples and sand waves.

A number of rivers entering the Minas Basin have been dammed near their mouths by causeways. This project was undertaken to determine what effect these dams may have had on the geodynamics of the estuarine system in Minas Basin. The project has the following objectives:

(1) To determine which sedimentary structures and features are particularly associated with unmodified estuaries in the Bay of Fundy.

(2) To relate these features to tides and currents and associated parameters such as suspended sediment loads, salinity, etc.

(3) To determine what constitutes a dynamic equilibrium condition for unmodified estuaries in a high tidal range environment.

(4) To investigate the effect of winter conditions on estuarine sediments which may be exposed to freezing temperatures for 50% of the time and then submerged under the rising tide.

(5) To evaluate the effects of man-made causeways on coastal and estuarine hydrodynamics and geodynamics.

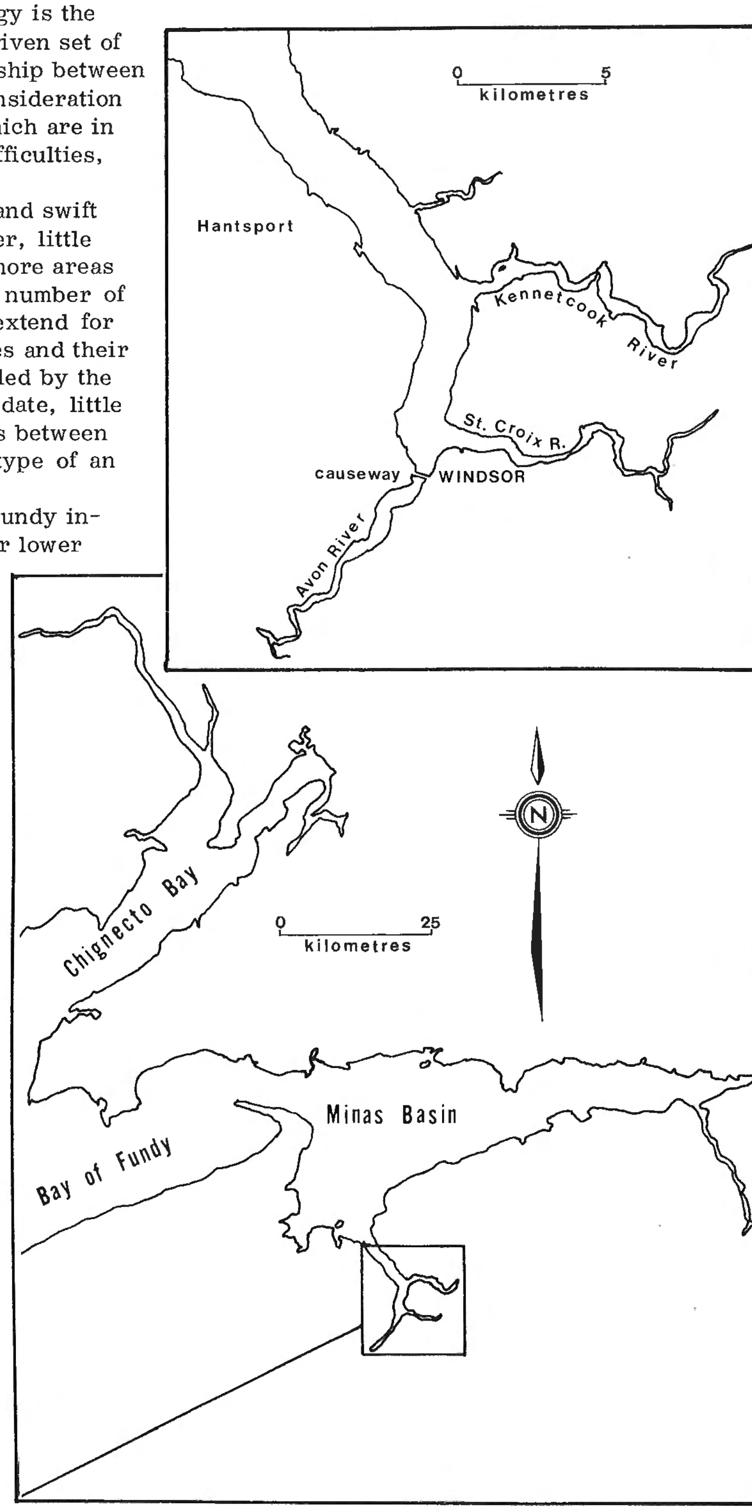

Figure 1. Location of study.

(6) To interpret modifications in sedimentary structures as a result of altering the tidal flow.

(7) To determine the factors which govern the amount of time required for the system to reach equilibrium after the construction of a causeway.

The 1974 season was spent principally in a reconnaissance study of the Kennetcook and Avon River estuaries near Windsor, N. S. The object was to determine what techniques would be practical and applicable to studies of estuaries in a natural condition, or in a modified state. The Kennetcook is free of man-made obstacles near its mouth and is considered an unmodified river, whereas the Avon, dammed in 1970 by a causeway, has been dramatically disrupted.

The most dramatic feature developed as a result of the building of the causeway was an extensive mud flat adjacent to and seaward of the causeway, but separated from it by a channel about 10 m deep. The mud flat represents an accumulation of more than 3. 5 million m^3 of mud since 1970, in an area through which flowed more than 1. 5 million metric tons of water prior to the construction of the causeway.

Studies of the Kennetcook River and of the mud flat and surrounding areas on the Avon estuary involved extensive echo-sounder surveys on both rising and falling tides. The bars of the Kennetcook were sampled at low tide, but this method of sampling proved impossible on the Avon mud flat owing to extreme difficulty in traversing the sediment. Underwater grab sampling and coring appear to be the best methods for obtaining samples from an area of such soft consistency. A current metre mounted on a metal davit anchored to a concrete slab appeared to be ideal in the Kennetcook River where the bed is predominantly sand, but it proved to be impossible to keep the entire apparatus from being covered with shifting sand in one tide. Other methods for anchoring current metres are under consideration. Suspended sediment samples were taken at a number of locations by means of a Nansen bottle.

Despite difficulties encountered because of strong currents and soft terrain, a number of observations can be made concerning the nature of the estuarine geodynamics in the Windsor, N. S. area:

(1) The Kennetcook River, essentially an unmodified river, is characterized by strong currents on both the rising and falling tides. These currents are capable of destroying entirely any bedding features formed on the previous tide.

(2) Depending on the direction and velocity of the current, a number of bedforms may result in a given area, ranging from parting lineations to sand waves. Echo-sounding has shown that megaripples with amplitudes greater than 1 m and wavelengths greater than 10 m may have their crests completely reversed with each rise and fall of the tide.

(3) Shoreline erosion is proceeding at a rapid rate, and while sand may remain in the bed of the river, finer particles are moved to the mouth of the estuary.

(4) The mud flat near the causeway on the Avon River can be considered the direct consequence of two things:

a) The area is no longer swept by a tidal prism of water at each tide.
b) The configuration of the sandbars in the Minas Basin to the north deflects the incoming tide which would have the greatest destructive effect on the mud flat.

(5) The cohesion of the mud itself may in part explain why the mud flat exists while surrounded by considerable currents on both rising and falling tides.

(6) The mud flat has become inhabited by a fairly prolific fauna, principally brachiopods, which attests to its relative stability. At low tide these brachiopods are found at a depth of about 20 cm in the mud.

(7) Considerable erosion is taking place throughout the general marsh land within a few kilometres of the causeway. In a number of areas, including the mud flat itself, there has been considerable deposition in the four years since the causeway was built.

(8) The configuration of the sandbars in the Minas Basin adjacent to the Avon estuary has changed markedly in the last four years.

It is evident that the building of a causeway in 1970 at Windsor has significantly changed the geodynamics of the estuary, and the effects appear to be farther reaching than must have been estimated at the time of construction.

The data obtained during this reconnaissance study will be used to develop techniques for a more detailed study of the Windsor area, and to expand the study to other areas of the Bay of Fundy in which there are comparable situations. Further work will include measurement of other parameters which may affect behaviour of tides in estuaries.

43. GEOLOGICAL ENVIRONMENT OF A METHANE-RICH RECENT SEDIMENTARY BASIN IN THE GULF OF ST. LAWRENCE

Project 740011

M.A. Rashid, G. Vilks and J.D. Leonard
Atlantic Geoscience Centre, Dartmouth

A comparison of the geochemical and geological characteristics of two sediment cores obtained from similar oceanographic conditions but differing in physiographic locations of Chaleur Trough, Gulf of St. Lawrence provided interesting contrasts. One of the cores collected from a depression contained dry hydrocarbon gas (methane) in the range of 5970-14230 ppm in comparison to 42-106 ppm in another core obtained from an open environment of the bay.

The sampling areas were within a zone of high primary production and the coring locations were 9-11 km from the nearest shoreline. Therefore the amount and source of organic matter delivered to the two coring sites is presumed to be similar. However the concentrations of preserved organic matter in the sediments of the basin was 2-8 times greater than the organic matter of the core representing the open environment. The mechanical size analysis indicated the presence of relatively well-sorted fine sediments in the entire core length of the basin whereas the sediments of the open environment were less sorted and coarse. Although both the cores contained similar major species of forams, the core from the restricted environment contained more species and individuals per gram of sediment. The faunal assemblages in this core were more diverse and the state of preservation of the species was excellent with no evidence of surface etching of the tests. The foraminiferal assemblages in both cores suggest that the sediments were deposited during Holocene.

The geological investigations tend to suggest a relatively fast rate of sedimentation in the depression. This resulted in the fast burial of organic compounds isolating them from the effect of oxidation and consequently assuring their preservation. These conditions lead to the development of anaerobic subsurface environment resulting in the production of high concentrations of methane through fermentative processes.

44. MARINE GEOLOGY OF THE NEARSHORE AND ESTUARIES OF CHALEUR BAY

Project 730092

C.T. Schafer
Atlantic Geoscience Centre, Dartmouth

Field sampling was conducted on board CSS DAWSON (Cruise 74-013) throughout Baie des Chaleurs, Chedabucto Bay, and Georges Bay. In Chedabucto Bay, 2 Lehigh cores, 5 piston cores and 4 electric drill cores were taken. In Georges Bay, 1 piston and 1 electric drill core were taken. In Baie des Chaleurs, 5 Lehigh, 7 piston and 5 electric drill cores were taken; as well 87 bottom grabs were obtained. A seismic survey was attempted; however, results were poor due to equipment malfunction.

To supplement the aforementioned shipboard sampling, nearshore sampling was carried out. Forty-seven bottom grabs were obtained between New Carlisle and Grande Riviere, and in Shipegan Bay.

No new information has thus far been extracted, however all data processed is in support of previous efforts. Four major zones have been established, based on foraminiferal species dominance: (1) nearshore polluted; (2) (a) nearshore non-polluted (b) offshore estuarine and (c) offshore gulf. Maps have been drafted of the above zones. None of the cores have yet been processed.

A preliminary survey and study of foraminiferal movements was carried out in Port Hebert. A total of 33 bottom sediment samples were collected. A preliminary study of repopulation of foraminifera into a sterile habitat was begun.

MOLLUSCA AND FORAMINIFERIDA OF PLEISTOCENE AND HOLOCENE SEDIMENTS IN EASTERN CANADA

Project 740082

Frances J. E. Wagner
Atlantic Geoscience Centre, Dartmouth

This project, to re-examine previously known fossil localities in the maritime provinces and to search for new ones, was begun in 1974 and involved field work in the province of Nova Scotia.

Early reports of Pleistocene and Holocene fossils in the province date back to the 1890's (Dawson, 1893, p. 177; Bailey, 1898, p. 20-21, 150). Recent investigators have been Grant and Nielsen (Grant, 1971; Clarke, Grant and Macpherson, 1972; Nielsen, 1974). In all cases only macrofossils (predominantly molluscs) have been recorded. No foraminifers are mentioned.

Samples were collected for the current project from 36 localities in the area between Yarmouth and Windsor, covering deposits of two ages. The material from the older deposits, which have been dated previously at ca. 38,000 years B.P. (Clarke, Grant and Macpherson, 1972), has been processed and more than a dozen molluscan species recognized. The presence of foraminifers with the molluscs has been established, and these will be studied by G. Vilks. No molluscs were observed in the younger (post-glacial) deposits, but samples were taken to check for foraminifers. Processing of these samples has not yet been completed.

The older deposits (ca. 38,000 years old) form a thin veneer along the coast in the Yarmouth-Digby area. At Gilbert Cove, seaweed in marine clay overlying these older sediments has been dated at 14,100±200 years B.P., somewhat younger than dates (14,300 - 16,500 years) for marine deposits in southwestern New Brunswick (Gadd, 1973). Future plans call for coring in Bay of Fundy between these two areas to attempt to establish the base of the marine sequence (post-glacial) and the chronology of events over the past 38,000 or more years.

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46. INGESTION OF BENTHONIC FORAMINIFERA BY LARGER INVERTEBRATES: FIELD SAMPLING

Project 740008

David A. Walker
Atlantic Geoscience Centre, Dartmouth

Work conducted thus far has formed a part of an overall investigation of diagenesis of foraminifera in sediments. The initial phase of the investigation consisted of examining the effects of ingestion of foraminifera by larger invertebrates, with emphasis on subsequent test structure and durability. Bottom sediment and invertebrate samples were collected during this reporting period. The following invertebrates were collected from Baie des Chaleurs: sea cucumbers (*Molpadia musculus*), sea urchins (*Strongylocentrotus drobachiensis*), brittlestars (*Amphipholis squamata*), sand dollars (*Ecninarachnus parma*), gastropods (*Aporrhais occidentalis*), polychaetes (*Nereis neathes virens, Nephthys incisa, Moldanopsis elongata, Cylmenella torquata, Pectinaria hyperborea, Praxillella gracilis, Amphitrite ornata, Trichochaeta multisetrosa, Lumbrineris fragilis, Ninoe nigripes, Trovisia dorbesi*), amphipods (*Lysiamassid* sp., *Ampelesia* sp.). The following invertebrates were collected from Port Hebert: sea urchins (*Strongylocentrotus drobachiensis*), hermit crabs (*Pagurus pollicaris*), starfish (*Asterias vulgaris, Henricia sanguinolenta*), rock crabs (*Cancer irroratus*), gastropods (*Buccinum undatum*). The following invertebrates were collected from Port Mouton: gastropods (*Buccinum undatum, Neptunea decemcostata*). The following invertebrates were collected from Pennant Point: sea urchins (*Strongylocentrotus drobachiensis*), gastropods (*Littorina littorea, Crepidula fornicata*).

To date only preliminary examination of the foraminiferal test surfaces has been conducted. Those invertebrates examined thus far are *S. drobachiensis, M. musculus, C. irroratus* and *A. vulgaris*. A major finding to date is that in no instance have arenaceous tests been altered. However, all calcareous tests were altered to varying degrees. The extent of etching on those tests extracted from *S. drobachiensis* and *A. vulgaris* was found to be mainly surficial, with a minor occurrence of mechanical breakage. Only mechanical breakage was evident on the tests from *C. irroratus*. The second major finding was that all calcareous foraminifers ingested by *M. musculus* underwent extensive chemical etching and pitting. Several tests were found completely dissolved, leaving only the organic template. Examination of the sediments in which *M. musculus* was collected showed very few calcareous tests. It is anticipated that continuation of this investigation will show further evidence of alteration of foraminiferal populations by certain larger invertebrates.

47. GEOMORPHOLOGY AND GLACIAL HISTORY OF HAMILTON BANK, LABRADOR SHELF

Project 730076

R.H. Fillon
Atlantic Geoscience Centre, Dartmouth

During the summer of 1973 the scientists and crew of CSS DAWSON under the direction of W.J.M. van der Linden, Chief Scientist, obtained 1100 km of 30 kHz deep-towed sparker profiles, 1200 km of sidescan sonar records and 2000 km of echo-sounding profiles over Hamilton Bank and adjacent areas. These data have recently been evaluated for the purpose of determining glacial and geomorphological history.

Relict glacial landforms are found to dominate the morphology of Hamilton Bank. Their freshness and distribution indicate that the entire bank was glaciated probably during the late Wisconsinan. There has been very little alteration of landforms during post-glacial times, therefore, it is unlikely that any portion of the bank was eroded in the surf zone during the post-Wisconsinan marine transgression. Although glacial landforms do not appear to have been much affected by erosional processes the present sediment distribution (van der Linden, 1974 and studies currently in progress) suggests that material in the surface layer has been redistributed under the influence of current and wave activity (Swift *et al.*, 1971).

End moraines are the most easily recognized relict landforms on Hamilton Bank. They are topographically rough, almost jagged and appear identical in transverse section to those described on the Scotian Shelf by King (1969), and King *et al.* (1972). End moraines following curvilinear trends can be traced across the Bank and along the marginal channels (Fig. 1). These are not considered to be terminal moraines because apparently unaltered glacial features occur to seaward. Moraines have not been found along the shelf edge.

Bathymetric charts (Monahan, in press) reveal a great many closed roughly circular depressions up to 3 km in diameter and about 10 m deep. Deep-towed sparker profiles and sidescan records indicate similar though smaller scale depressions over a large part of the bank seaward of the end moraine.

Comparison of these landforms with terrestrial glacial deposits from the Lake Melville area strongly suggests a close morphological and genetic relationship to kame and kettle topography. Stratified drift sampled in short cores (Slatt and Lew, 1973) provides additional evidence of similarity to terrestrial kame deposits. The features on Hamilton Bank will therefore be referred to in this report as sub-aqueous kames and kettles (*see* Fig. 1 for distribution). Because the bank does not appear to have been emergent during or after deglaciation, sub-aqueous kames and kettles must have formed in a method different from their terrestrial counterparts. It is suggested that sub-aqueous kames and kettles formed beneath a stagnant, grounded ice

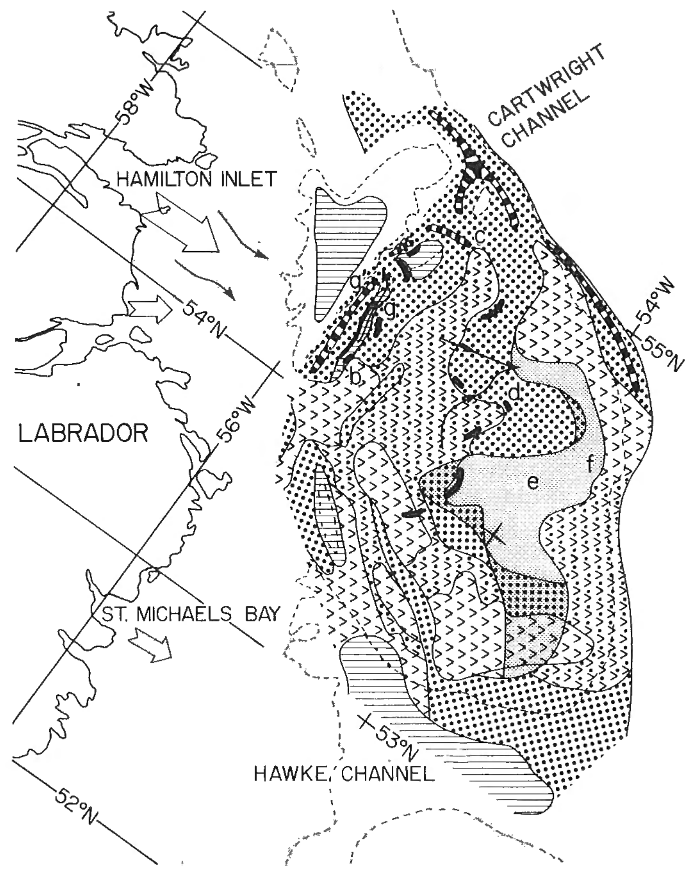

Figure 1. Physiographic-surficial geology map of the Hamilton Bank area. Heavy stippling indicates sub-aqueous kame and kettle topography, carats represent areas of ground moraine. Fine shading designates smooth outwash plain. Mixed heavy stippling and carats or fine shading indicate poorly developed or preserved kames and kettles (visible on sidescan records but not apparent from bathymetric profiles). Basins with ponded Recent sediments are represented by hachures. Small arrows delineate channels and large ones show general flow directions of continental ice (Prest *et al.*, 1967). Solid curvilinear bars represent end moraine. Linear kame features are portrayed as striped curvilinear bars. The dashed line is the 300 m contour and all areas completely enclosed by this contour are basins. Letters refer to typical sections that will be presented in a subsequent, more comprehensive publication.

sheet where irregular bottom melting produced water filled crevasses and sub-ice cavities in which glacial debris accumulated forming piles of stratified drift. Where supporting masses of ice remained bottomed, sub-aqueous kettle holes developed surrounded by sub-aqueous kame deposits. The idea of cavities beneath the ice sheet on Hamilton Bank is supported by the presence of what appear to be sub-ice meltwater channels winding across the sub-aqueous kame and kettle zone (Fig. 1). One large channel that plainly shows up on bathymetric charts terminates in a large kettle hole.

Immediately seaward of the relict meltwater channels is a large area that appears very flat on deep-towed sparker profiles. This region is interpreted on the basis of morphology and position as an analogue of an outwash plain. It is suggested that sand size and finer material transported out from beneath the stranded ice sheet through the meltwater channels spread seaward over the ice-free shelf by hyperpycnal flow. The effect of the prevailing Labrador current may be responsible for the increasing width of the submarine outwash plain in a southerly direction away from the major sub-ice channel (Fig. 1).

Landward of the sub-aqueous outwash plain, kame and kettle zone and end moraine complex is a region of relatively gently undulating topography (Fig. 1). This is interpreted as ground moraine formed as ice advanced to the point where formation of the end moraine took place.

Small patches of ground moraine situated near the seaward edge of the bank (Fig. 1) imply that initial retreat of the ice from a position at the shelf edge must have occurred rapidly by calving. Once the easternmost edge of what is now the sub-aqueous kame and kettle band was reached, however, deglaciation proceeded more slowly resulting in the obliteration of ground moraine and the formation of sub-aqueous kames and kettles. The ice front must have gradually retreated to a point landward of the end moraine site. The end moraine complex was produced during a subsequent ice readvance which is now marked by the large area of ground moraine landward of the end moraine. Within the area dominated by ground moraine and lying just along the landward edge of the Bank is a linear strip of sub-aqueous kame and kettle topography. It is inferred that when the ice front finally repeated from the end moraine position, it did so again very rapidly. Only along the landward edge of the bank did remnants of the ice sheet remain sufficiently long to develop sub-aqueous kames and kettles.

A complex distribution of end moraines, lateral moraines, kame and kettle topography and ground moraine in the marginal channels implies that deglaciation of the channels unlike the bank surface was not accomplished in only two stages. Ice in the channels being thicker probably remained after the bank had been deglaciated completely. It would have remained longest in Cartwright Channel which was fed directly by ice flow from Lake Melville-Hamilton Inlet (Prest *et al.*, 1967). The distribution of moraines indicates that a sizable ice lobe between the main ice tongue in Cartwright Channel and the northwestern edge of the bank stagnated and readvanced at least three times subsequent to deglaciation of the Bank. Between this lobe and the active ice tongue, in a depression that was probably an ice-rimmed lake or fiord, a very large kame 70 km long, 6 km wide and about 100 m high developed. This feature appears similar in size, shape and structure (Vilks *et al.*, in press) to the outer portion of Cape Cod (Woodsworth *et al.*, 1934).

Absolute dates of deglaciation for the Hamilton Inlet portion of the Labrador Coast have not yet been determined. Estimates range from 16,000 to 14,000 years B.P. (Prest, 1970), to 10,000 to 8,000 B.P. (Wenner, 1947; Hodgson and Fulton, 1972).

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48. SEDIMENTOLOGICAL STUDY OF THE GOLDENVILLE FORMATION, NOVA SCOTIA

Project 730083

I.M. Harris
Atlantic Geoscience Centre, Dartmouth

A bed-by-bed study of sedimentary structures in the Goldenville Formation (lower Paleozoic flysch) was undertaken in an area of well-exposed coastal sections near the village of Sheet Harbour, Nova Scotia. This work, together with an earlier study in the same area (Harris, 1971), provides new insights on the sedimentology and geologic relations of the Goldenville Formation.

The Goldenville Formation consists of alternating layers of sandstone (dominantly fine- to medium-grained) and finer-grained beds. The sandstone constitutes about 70 per cent of the rocks of the formation and occurs in beds 1 cm to more than 50 m thick. In outcrop, the beds are characteristically continuous along strike. The formation is at least 6000 m thick (Faribault, 1914; Taylor, 1967) and outcrops intermittently over an area of 50,000 km^2. The base of the formation is nowhere exposed. The derivation, depositional history and tectonic setting of this great volume of sediment are controversial topics that bear on the Paleozoic evolution of southeastern Atlantic Canada, as discussed below.

The rocks of the Goldenville and the structurally conformable, overlying formations were folded, intruded and regionally metamorphosed during the Devonian Acadian Orogeny (Poole, 1967; Poole *et al.*, 1970). The major folds collectively form a distinctly arcuate pattern that is evident on geologic maps of the region (e.g., Weeks, 1965; Fyson, 1966, Fig. 1; Harris and Schenk, 1968, Fig. 1; Schenk, 1970, Fig. 1). Intrusions, ranging from granite to quartz-diorite in composition, cut across the folds without changing the fold trends (Poole *et al.*, 1964). K-Ar and Rb-Sr ages determined for the intrusions range from 318 to 417 m.y., with a peak at 370 m.y. (Fairburn *et al.*, 1960; Fairburn *et al.*, 1964; Lowden *et al.*, 1963; Leech *et al.*, 1963; Cormier and Smith, 1973; Reynolds *et al.*, 1973). In the study area, the rocks have been affected by chlorite-grade, regional metamorphism; metamorphic grades tend to be higher in other parts of the outcrop area (Taylor and Schiller, 1966).

Fossils are generally lacking in the rocks of the Goldenville Formation and in the slaty rocks of the conformably overlying Halifax Formation, but very poorly preserved graptolites (probably *Didymograptus*) in the Goldenville Formation (Schenk, 1970; Poole, 1971) and rare specimens of *Dictyonema flabelliforme* (Eichwald) in erosional outliers of the Halifax Formation (Crosby, 1962; Campbell, 1966; Smitheringale, 1973) indicate a probable Early Ordovician age for these strata. K-Ar ages of 476±19 m.y. and 496±20 m.y. for detrital muscovite from samples of Goldenville sandstone in the study area (Poole, 1971; Wanless *et al.*, 1972) contrast with the younger ages obtained for more highly metamorphosed rocks and granitic intrusions in adjacent areas. The detrital muscovite determinations possibly represent the approximate time of deposition or diagenesis, rather than the age of the cratonic source rocks or the timing of post-diagenetic thermal events.

Previous workers have suggested a number of possible environments of deposition for the Goldenville and overlying Halifax Formations. Most agree with a marine, geosynclinal (presumably eugeoclinal) setting. Woodman (1904) believed that the sea was moderately shallow and occasionally turbulent during deposition of the Goldenville Formation, but that either water depth increased or the source area lowered to accomodate deposition of the shaly Halifax Formation. Malcolm (1929) invoked a combination of heavy precipitation alternating with short periods of drought, changes in shore-current velocity and direction, and variations in subsidence rates. Douglas *et al.* (1938) equated graded sedimentation units with varves, presumably glacial. Crosby (1962) also hypothesized seasonal fluctuations. Phinney (1961) suggested that the Goldenville and Halifax sediments were deposited by turbidity currents that flowed from the southwest. Campbell (1966) proposed that the sediments accumulated in a well-defined, northeastward plunging, deep-sea trough. Taylor (1967) suggested that northwestward-moving turbidity currents filled an initially deep-marine basin, so that the sea became shallow and muddy during deposition of the Halifax Formation. Schenk (1970) proposed that the sediments were moved into the area by sediment gravity flows (as defined by Middleton and Hampton, 1973), creep and slump, but were reworked by contour-flowing currents that flowed in an arcuate pattern from southwest to northeast. Harris (1971) favoured sediment gravity flows as the principal mechanisms by which the Goldenville sediments were deposited and suggested that the arcuate paleocurrent trend is partly a result of tectonic effects. Harris also considered that the Goldenville sandy flysch was deposited in submarine fans, while coeval Halifax sediments accumulated in upslope areas between major distributary channels. Schenk (1973) later drew attention to the striking similarity of the Goldenville and Halifax lithologies to present, abyssal plain turbidites and continental rise contourites of the western North Atlantic, as described by Horn *et al.* (1971). This comparison supports the concept that the Goldenville and Halifax sediments accumulated in a deep-marine setting, although portions of the Halifax Formation may have accumulated in relatively shallow water, especially the upper Halifax strata that grade vertically into neritic deposits of the White Rock Formation (Smitheringale, 1973). Whether the sequence is ensialic or ensimatic is uncertain; however, tectonic and petrologic considerations indirectly support the former possibility (Schenk, 1971, p. 1236; Smith, 1974, p. 655).

Schenk (1970, 1971) proposed that deposition was related to a continental source area and that this source area has since been removed by continental drift. He correlated the stratigraphic and tectonic development of eastern North America with that of western Africa in support of his contention that the source area of the Goldenville and Halifax sediments is presently represented in northwestern Africa (Schenk, 1971, 1972a, 1973). This hypothesis is supported by the presence of diamictites containing faceted and grooved clasts in the White Rock Formation. These glacially derived units possibly developed as a direct result of the Upper Ordovician glaciation that affected much of Africa and South America (Schenk, 1972b). On the basis of paleomagnetic evidence and tectonic considerations, McKerrow and Ziegler (1973) proposed that northwestern South America rather than northwestern Africa collided with North America during the Acadian Orogeny; hence, the Goldenville and Halifax sediments conceivably may have had a South American derivation.

The present study has drawn liberally upon the previous work referred to above, particularly Schenk's (1970) comprehensive treatment of the regional sedimentology. Considerations on the geological evolution of the area in the light of plate tectonic theories will be published at a later date. Detailed observations in the study area have brought to light the following characteristics of Goldenville sedimentology that hitherto were either unrecognized or incompletely interpreted: (1) Dewatering, slump and slide structures are present in a majority of the sandstone beds. These features, together with the common occurrence of deeply-tooled groove and prod marks, prominent scour-and-fill structures, channels, and relatively large intraformational clasts (mudstone rip-ups), suggest rapid deposition from high-energy currents, commonly followed by foundering of the sediments and expulsion of entrapped water. (2) Recurring patterns of sedimentation (megarhythms) suggest deposition within megachannels and in the distributary areas of prograding submarine fans. (3) The mean paleocurrent trend, inferred from measurements of directional sole markings, is closely parallel with the principal trend of folds in the study area. On the regional scale, Schenk (1970) found that the paleocurrent direction generally parallels the arcuate trend of the major folds. Because the paleocurrent and structural trends are apparently interrelated, the early development of the main folds may have been controlled by the geometry and distribution of the sandstone beds. (4) The Goldenville sediments were derived from a metasedimentary and plutonic (mainly granitic) source area. Some minerals that might be expected from such a provenance are rare or absent, including K- and Ca-feldspars and garnet (although these minerals have been reported from other areas; e.g. Benson, 1967; Schenk, 1970). A low content of such minerals is not uncommon in flysch sandstones, and may be attributed to diagenetic alterations (Von Engelhardt, 1967; Walker and Pettijohn, 1971).

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GEOMORPHOLOGY OF FLEMISH CAP, FLEMISH PASS, AND THE NORTHEASTERN GRAND BANKS OF NEWFOUNDLAND

Project 730081

R. F. Macnab
Atlantic Geoscience Centre, Dartmouth

Hydrographic surveys of the Grand Banks of Newfoundland and the Flemish Cap-Flemish Pass region have been carried out on a systematic basis for the past several years. A re-examination of all sounding records collected over a portion of these surveyed areas (Fig. 1) was initiated by the Bathymetric Research Unit (now the Geoscience Mapping Unit) of the Canadian Hydrographic Service, Ottawa. The purpose of this examination was twofold:

1) to assist with contour interpretation in the construction of a detailed bathymetric map. For further guidance, a drawing was prepared in which the profiles as actually observed were placed in their correct planimetric positions and drawn in parallel perspective (Fig. 2).
2) to categorize bottom topography according to the appearance of the echograms.

From the analysis performed in support of 2 above, it was possible to classify several individual features, such as slope breaks, steps, notches, etc. It was also possible to differentiate between six different bottom categories; each category could be identified from a characteristic combination of surface shape, apparent reflectance, and overall configuration. Some portions of the records defied classification due to roughness, and these were assigned to a seventh category, designated as "rough". The approximate distribution of these bottom categories is shown in Figure 3. This type of presentation has been termed a "meso-morph map", because it subdivides the sea floor into zones

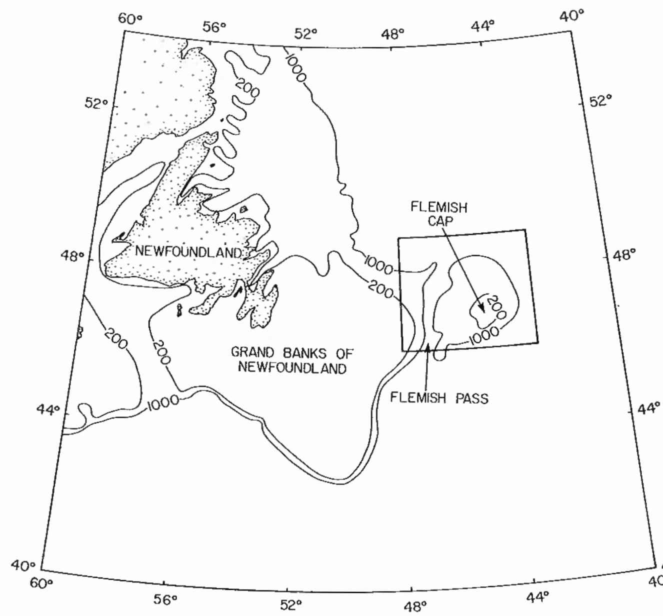


Figure 1. Index map of Newfoundland and the Grand Banks. Heavy lines enclose the study area.

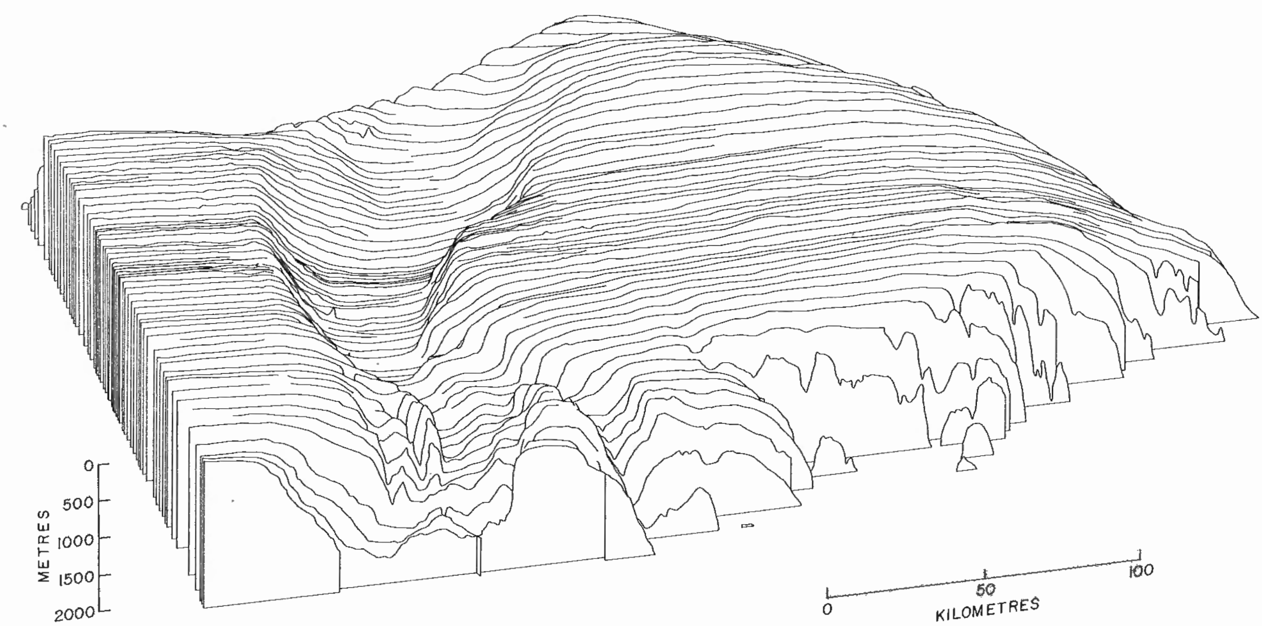
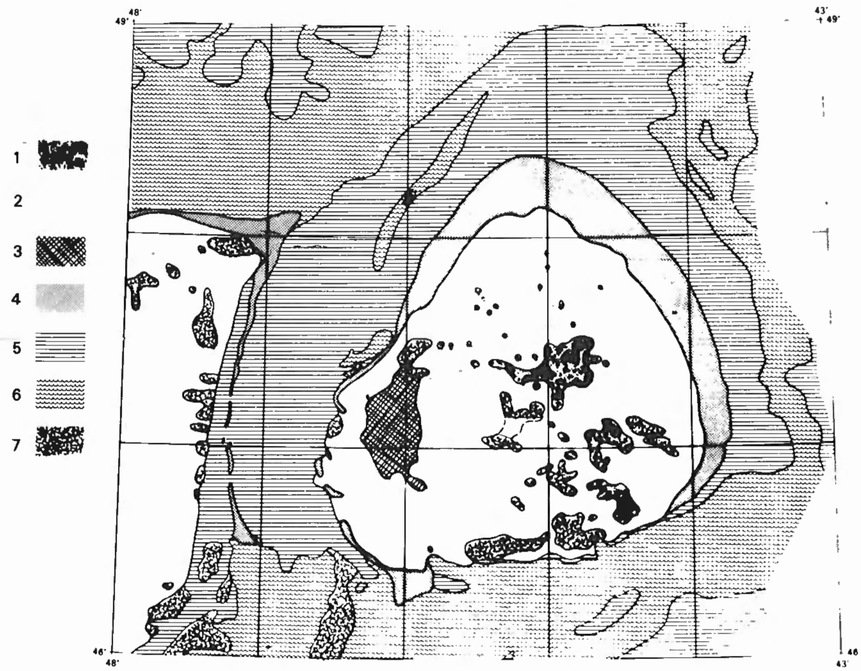


Figure 2. Parallel perspective drawing of bathymetric profiles observed in the study area.



1 Incised 2 Flat 3 Blocky 4 Scoured 5 Smooth 6 Undulated 7 Rough

Figure 3. Meso-morph map of Flemish Cap and Flemish Pass, showing distribution of various bottom types according to their medium-scale morphological characteristics.

characterized by their medium-scale morphology. A coloured version of this map at a scale of 1: 500,000 will soon be published by the Canadian Hydrographic Service, with a companion map which portrays the bathymetry. These two maps will be useful as bases for further geological interpretation. They also have considerable practical application, as guides for geological sampling programs, bottom fishing, drilling, and route selection for submarine cables and pipelines.

Full details on the results of this investigation will appear in a forthcoming Geological Survey of Canada publication.

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50. A REGIONAL GEOPHYSICAL SURVEY OF THE LABRADOR SEA

Project 730081

R.F. Macnab and S.P. Srivastava
Atlantic Geoscience Centre, Dartmouth

As a continuation of the offshore hydrographic-geophysical surveys described in previous Reports of Activities (Macnab, 1974; Grant and Macnab, 1974), a regional survey was undertaken in 1974 to define the broad tectonic framework of the Labrador Sea. This represented a departure from the past practice of conducting detailed surveys over smaller areas. The change in approach was prompted by a) the immediate scientific benefits to be gained from a regional survey, and b) the need for a regional picture in the planning and execution of future detailed surveys.

Continuous bathymetric, magnetic, and gravimetric measurements were obtained over tracks spaced 37 km (20 n.m.) apart and perpendicular to the spreading axis of the Labrador Sea. Additionally, seismic reflection measurements were obtained on every portion of track situated on the Labrador continental shelf, and at 74 km (40 n.m.) intervals over the deep ocean basin. Track locations are shown in Figure 1.

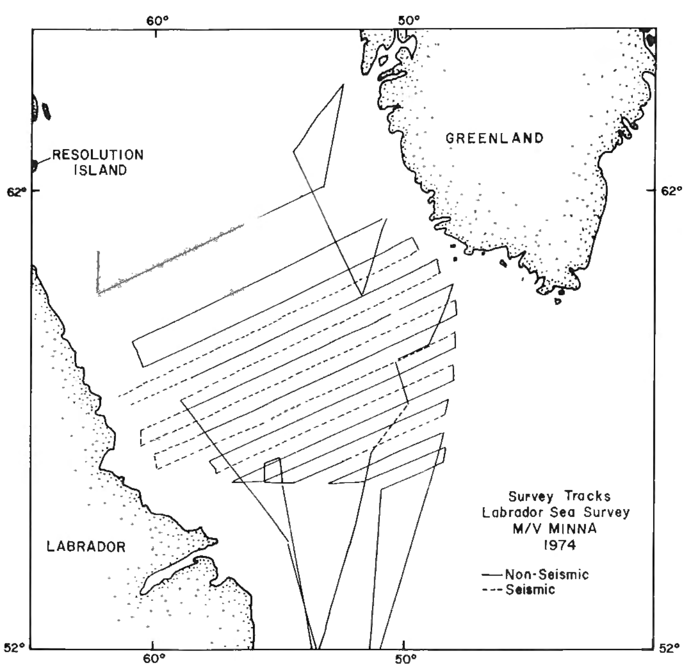

Figure 1. Survey tracks of the MV MINNA in 1974.

All measurements were obtained on board the Motor Vessel MINNA, a 2300-ton ice-strengthened freighter chartered for the third successive season by the Atlantic Oceanographic Laboratory (an Environment Canada component of the Bedford Institute of Oceanography). As in previous years, the ship's two cargo holds were utilized for working and storage spaces: two air compressors, a portable seismic workshop, and an AC generator were installed in the forward hold; six portable modules, consisting of a computer trailer, storage container, gravity labs, drawing office, and operations centre (the latter housing most of the electronic instrumentation) were fitted in the after hold.

Primary positioning throughout the survey was provided by a combination of Loran-C and satellite navigation, which gave ship's positions with an estimated accuracy of 200 m or better.

For backup and intercomparison studies, three gravimeters were installed on the ship: a Graf-Askania Model GSS-2 belonging to the Atlantic Geoscience Centre; a LaCoste and Romberg air/sea meter Model S-39 with inertial platform, owned and operated by the Gravity Division of the Earth Physics Branch, EMR; and an Askania Model GSS-3, belonging to the Deutsches Hydrographisches Institut, Hamburg, Germany. The last meter, as well as some professional and technical support, were provided as part of the Canadian-German

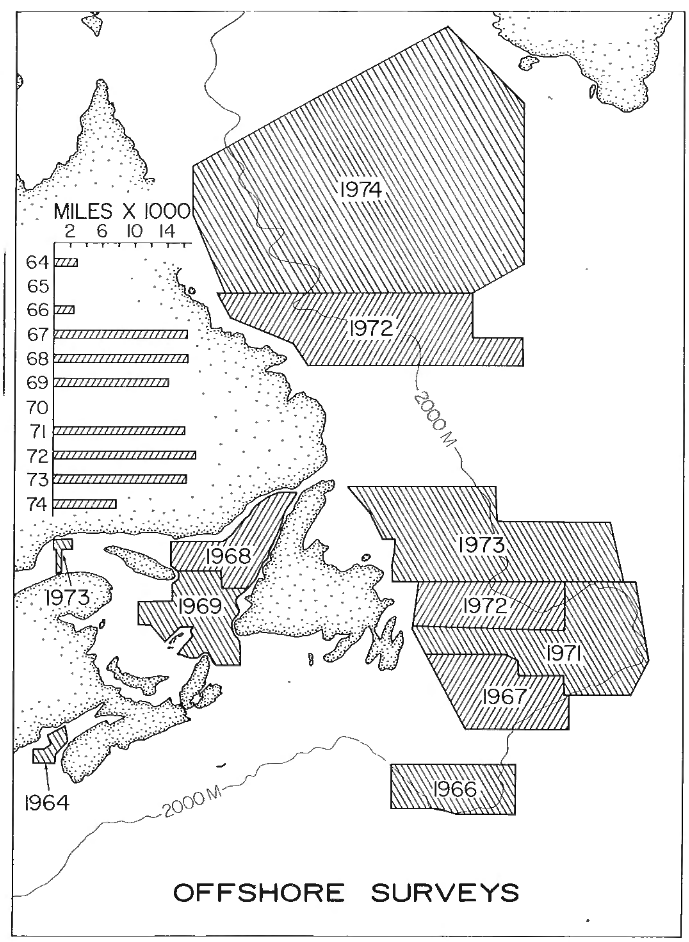

Figure 2. Survey coverage to date.

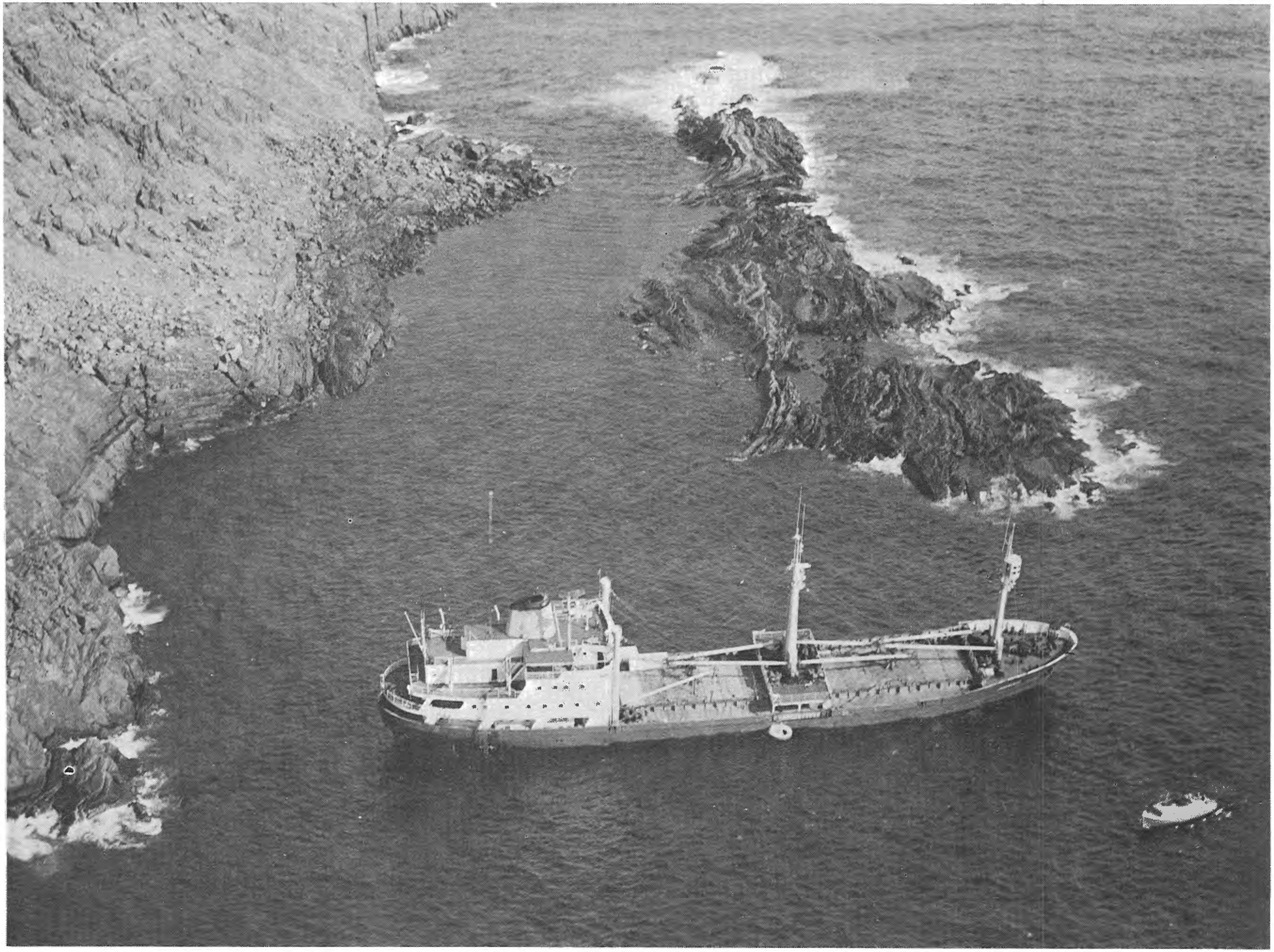

Figure 3. End of a survey: MV MINNA aground in Brewer Bay, Resolution Island. All survey data and most equipment were removed, but the ship itself was declared a loss. (BIO photo 3280-6).

agreement on scientific and technical co-operation. For the purpose of calibrating gravimeters, port calls were arranged in Lewisporte and St. John's, Newfoundland, and in Godthaab, Greenland.

Magnetic data were collected with a towed proton precession magnetometer. For the purpose of applying diurnal corrections, daily variations were monitored by a station magnetometer which was installed and operated in Cartwright, Labrador, in co-operation with Eastcan Exploration Limited.

Seismic equipment consisted of 40 and 300 cubic-inch guns, selected according to water depth, and a 100-foot single section hydrophone streamer. Returns were filtered and recorded simultaneously on dry paper and magnetic tape recorders.

Disaster struck the project and forced its early termination when the MINNA went aground off Resolution Island. The ship had anchored in Brewer Bay to put a party of men ashore for calibration of a secondary navigation system slated for use in the northern part of the Labrador Sea. Strong tidal currents caused the vessel to drag anchor and swept her onto a sunken ledge. In spite of the immediate and wholehearted assistance rendered by two Ministry of Transport vessels, all efforts to free the MINNA proved fruitless, and her owners, Karlsen Shipping Company Ltd. of Halifax, were forced to abandon ship. Fortunately, it was possible to remove most of the man-portable scientific and survey instrumentation, and to salvage all data which had been collected up to that time. Some 300 separate items of equipment with a collective weight of several tons were eventually transferred ashore, then loaded onto three Canadian naval vessels and the Canadian Scientific Ship BAFFIN for shipment back to Dartmouth.

The grounding of the MINNA represents a serious setback to the ten-year-old offshore surveys program, and considerable effort will be required to re-mobilize the project if and when a replacement vessel becomes available. One fortunate aspect, however, is that most of the 1974 survey proposed for the Labrador Sea was completed before the accident. In addition to extending substantially the coverage begun on an earlier BIO survey cruise (*see* Fig. 2), the new data complements the information gathered on cruises sponsored by other organizations (Srivastava, this publication, report 52).

The MINNA gravity data show a large minimum in the centre of the Labrador Sea. A comparison of gravity and seismic profiles indicates that this minimum lies between two ridge crests which form the mid-Labrador Sea ridge. It thus appears that the gravity low evident in all profiles marks the position of the median valley in the Labrador Sea. Large negative gravity anomalies were observed near the Greenland and Labrador Coasts. The cause of these anomalies is not yet known. The magnetic data show good correlation of anomalies from profile to profile, and a fairly smooth field over the median valley. These data present the best evidence to date of magnetic lineations in the Labrador Sea.

The survey has also delineated the extent of the mid-ocean canyon in the northern Labrador Sea. The seismic data clearly reveal that the canyon's flanks in all cases have the same shape on all profiles, with the western flank standing almost 50 to 60 m above the eastern flank. The canyon floor itself is 80 m below the western bank and 25 m below the eastern bank. The depth below sea level of the canyon floor increases to the south.

Further analysis and final processing of the data are underway. The final data in digital form and all seismic records will be released through the Geological Survey Open File.

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GEOLOGICAL STUDIES OF BAFFIN BAY, DAVIS STRAIT, AND ADJACENT CONTINENTAL MARGINS

Project 730078

D.I. Ross and R.K.H. Falconer
Atlantic Geoscience Centre, Dartmouth

On July 17th, CSS HUDSON left the Bedford Institute of Oceanography pier on the first leg of its 1974 Arctic Cruise. The cruise was developed to provide new data for this project and other related projects in the Geological Survey of Canada (for example, 730077, 730031, 740013, 730053, 670031, 730006, 680081).

The cruise had the following primary objectives:

(1) to define the extent of continental crust off northern Labrador and Baffin Island and to determine the geological structure across the transition from continental to oceanic crust.

(2) to further investigate the occurrences of Tertiary basalts on the Western Greenland Shelf in conjunction with work being carried out by the Greenland Geological Survey.

(3) to carry out a regional geophysical survey of northern Baffin Bay and southern Nares Strait obtaining seismic and potential field data as far north into Kane Basin as practical.

(4) to obtain information on geomorphology and bottom sediments of the Arctic sounds and fiords and whenever possible to obtain samples and data on past as well as present day marine beaches.

(5) in co-operation with industry to evaluate the use of the Bedford Institute rock core drill in the Arctic environment and to carry out a program of bedrock drilling in Lancaster Sound, northern Baffin Bay and Davis Strait.

(6) to carry out a program of seismic measurements and bottom sampling in Barrow Strait in co-operation with the Polar Gas Consortium to evaluate possible pipeline routes.

(7) to carry out a program of shallow seismic, sidescan sonar and bottom sounding in the inshore area around northern Somerset Island using the Hudson barge.

(8) to extend the studies in the Labrador Sea in an effort to obtain information on the history of the opening of the Labrador Sea-Davis Strait area.

(9) to obtain samples and information on the bottom fauna in the abyssal depths of the Labrador Sea and Baffin Bay.

The cruise will terminate on November 1st, 1974. This report summarizes the work completed during the

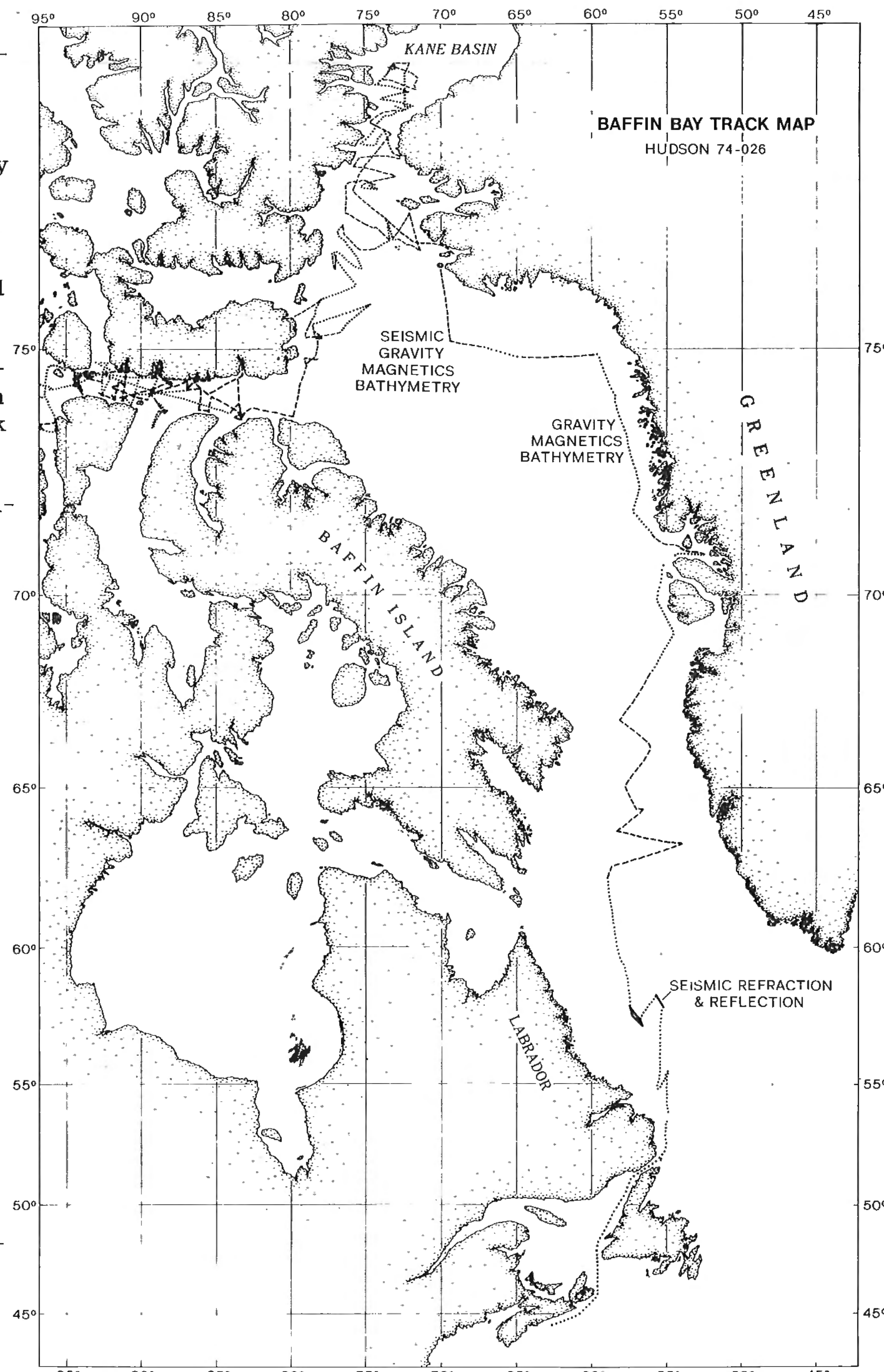

Figure 1. Track map of CSS HUDSON cruise 74-026 phases I and II.

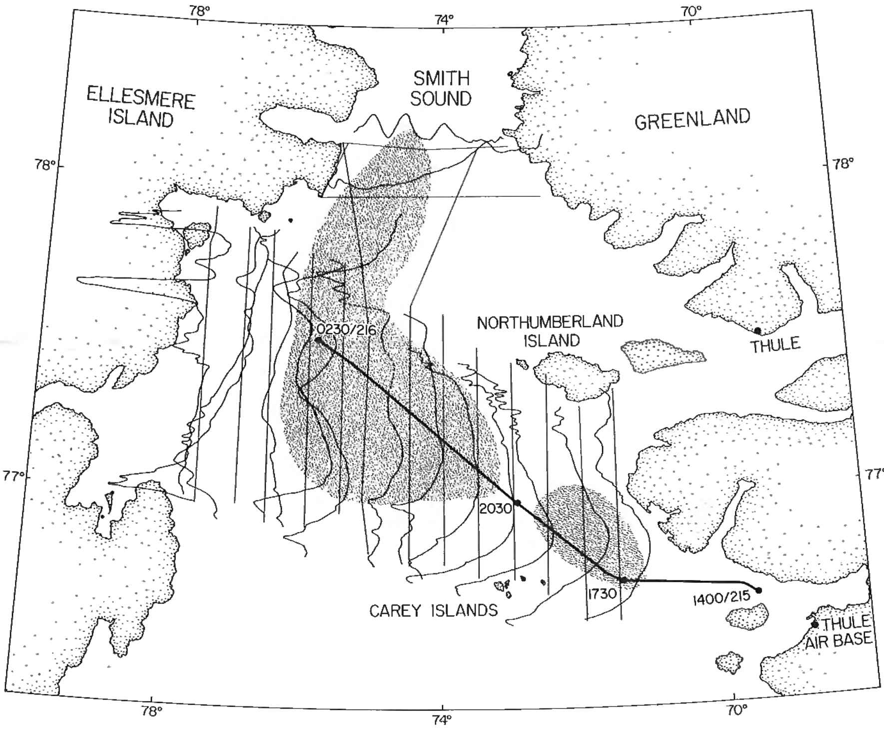

Figure 2

Aeromagnetic anomaly profiles obtained by Hood and Bower (this publication, report 24) showing Hudson Track along the axis of the previously proposed basin. Shading indicates the sedimentary basins mapped during cruise 74-026.

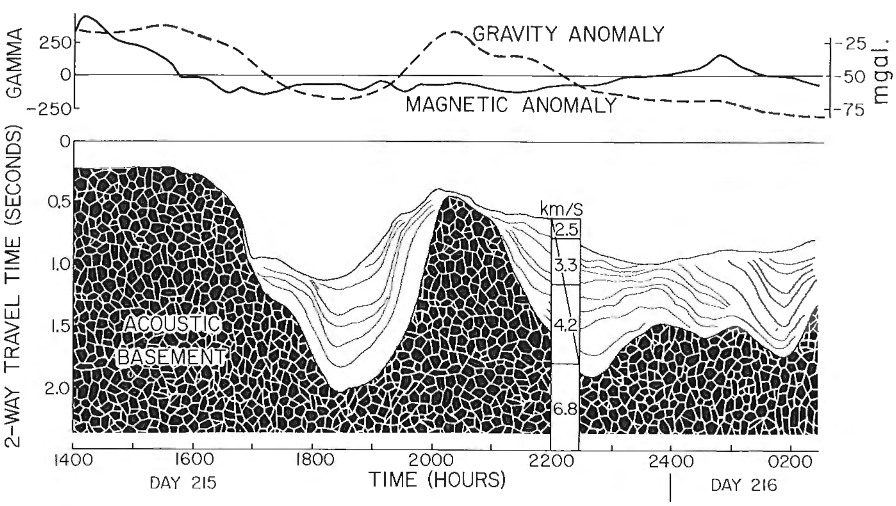

Figure 3

Line drawing of seismic reflection record, magnetic and free air gravity anomalies along track shown in Figure 2. The acoustic basement shown in the line drawing is not necessarily a continuous crystalline basement although the preliminary interpretation is that the structural high is associated with a basement feature running between the Carey Islands in the south and Northumberland Island in the north. Vertical section indicates preliminary results of an expendable sonobuoy.

first two phases of the cruise (July-August, 1974). Figure 1 shows a track map for the two phases.

Two seismic refraction lines were shot using explosives east of Nain Bank off northern Labrador. These two lines were to complement the work carried out under project 730077 on the CSS DAWSON in 1973. Together with the earlier refraction lines these additional deep water lines complete the section across the continental margin. An additional short refraction line was carried out along the basement high running northeast towards Davis Strait. This line was shot using the 1000 cu. in. airgun only, and was not reversed. Results of the refraction work are reported elsewhere in this report (van der Linden and Srivastava, *see* this publication, report 54).

Seismic reflection data in the Davis Strait showed a continuation of the mid-Labrador Ridge up into the Strait area. Although the data obtained during the first phase was insufficient to define the northern limit of the ridge and its relationship to the shallow Davis Strait sill, there is an indication of continuation of a basement high up onto the sill. Offsets along this basement high make it unclear whether or not the high is a continuation of the mid-Labrador ridge farther south. Sedimentary basins occur between the basement high and the continental margins on either side. These basins are filled with flat-lying sediments underlain by a thick layer of highly disturbed relatively opaque sediment. Additional information will be obtained during the last part of the cruise to supplement data already obtained in Davis Strait.

On the West Greenland Shelf additional seismic control was obtained along Umanak Fjord, north of Disko Island, and across the Melville Bay graben. The seismic line along Umanak Fjord complements the work reported by Ross and Henderson (1973) and Denham (1974). It shows the offshore extension of the Ikorfat fault system and the eastern boundary of the offshore basalts. It also shows complex faulting within the basalt sequence, similar to that observed in the basalts immediately onshore on Nugssuaq Peninsula, but it provides no clear evidence of a basalt/Precambrian boundary immediately west of the fiord as proposed by Denham.

Rocks were obtained from two dredge sites on the western Greenland Shelf. At the first site, located in the northern area of the basalt province as defined by Ross and Henderson, some 10% of the haul contained basalts. At the second site, east of the Melville Bay graben, at 74°N, only Precambrian granites and gneisses were obtained.

A port call at Thule Air Base provided an opportunity for calibrating the shipborne gravimeter before proceeding north into the Northern Bay-Smith Sound-Kane Basin area. In the spring of 1974, Hood and Bower (*see* this publication, report 24) had supplemented earlier marine magnetic measurements in this area by carrying out an aeromagnetic survey of the area. The aeromagnetic survey confirmed the suggestion of Keen and Barrett (1973) of a sedimentary basin trending northwest from Thule across northern Baffin Bay.

On leaving Thule HUDSON ran a seismic reflection line approximately along the axis of the proposed sedimentary basin. The position of this line is shown in relation to Hood's magnetic profiles in Figure 2, and in Figure 3 seismic, gravity and magnetic records obtained along the line are given. The magnetic data along our line is in complete agreement with that of Hood's but the seismic data clearly shows that the simple basin predicted on the basis of the magnetic data in fact consists of two well-developed basins isolated by a structural high. Data obtained on the other lines in the region indicate that the western basin is part of a north-south trending arcuate basin which extends south for some 100 km from the southern end of Smith Sound. Thus the structural trend of this basin is very different to that predicted on the basis of magnetic data alone. Within the basin considerable local structure is apparent on the seismic records suggesting a somewhat complex history. Smith Sound itself contains very little sediment cover on a bottom of some complexity. Although east-west trends are apparent in the topography as reported by Keen *et al.* (1971), local variations in topography preclude the possibility of following these trends over significant distances.

Initial trials of the electric rock core drill were carried out during the 12 days spent in Northern Baffin Bay. The main attempts at bedrock recovery were carried out during the 15 days spent in the Lancaster Sound area. A total of 12 holes were drilled in water depths to 1700 ft. The results of this drilling program, and that to be carried out in the last phase of the program, are covered by a government-industry agreement and will not be released before 1976. Both deep seismic and shallow high resolution seismics were obtained in Lancaster Sound and eastern Barrow Strait. It will be used to complement earlier information in both structural and surficial studies. In addition some 32 core, 37 bottom grab, and 23 camera stations were completed.

While HUDSON was working in Lancaster Sound, the Hudson barge was put off at Cunningham Inlet on the northern coast of Somerset Island to carry out some coastal work under the direction of C.F.M. Lewis. This work involving sidescan sonar, bottom sounding, sampling and some seismic refraction work is reported elsewhere in this report (Taylor and Lewis, this publication, report 138).

Seismic reflection data and a series of bottom stations were obtained across the northern end of Peel Sound, and a series of bottom stations were obtained on another line between Lowther and Russell islands. This work was carried out as part of the terrain studies for the eastern Arctic pipeline. Representatives from Polar Gas Consortium participated on this phase of the work. Preliminary results of this and other terrain studies carried out during the cruises are reported by Blake and Lewis (*see* this publication, report 102).

During the third phase of the cruise carried out during September 1974 seismic refraction lines were shot in the eastern end of Lancaster Sound, along the Baffin Island margin in the vicinity of 72°N and in the sedimentary basin in eastern Davis Strait. A magnetic survey of a 160 km by 40 km area in the central Baffin Bay was completed using a moored station magnetometer for control. A program of coring and biological dredging was also completed. The results of this phase of the cruise and the last phase to be conducted in Labrador Sea will be reported later.

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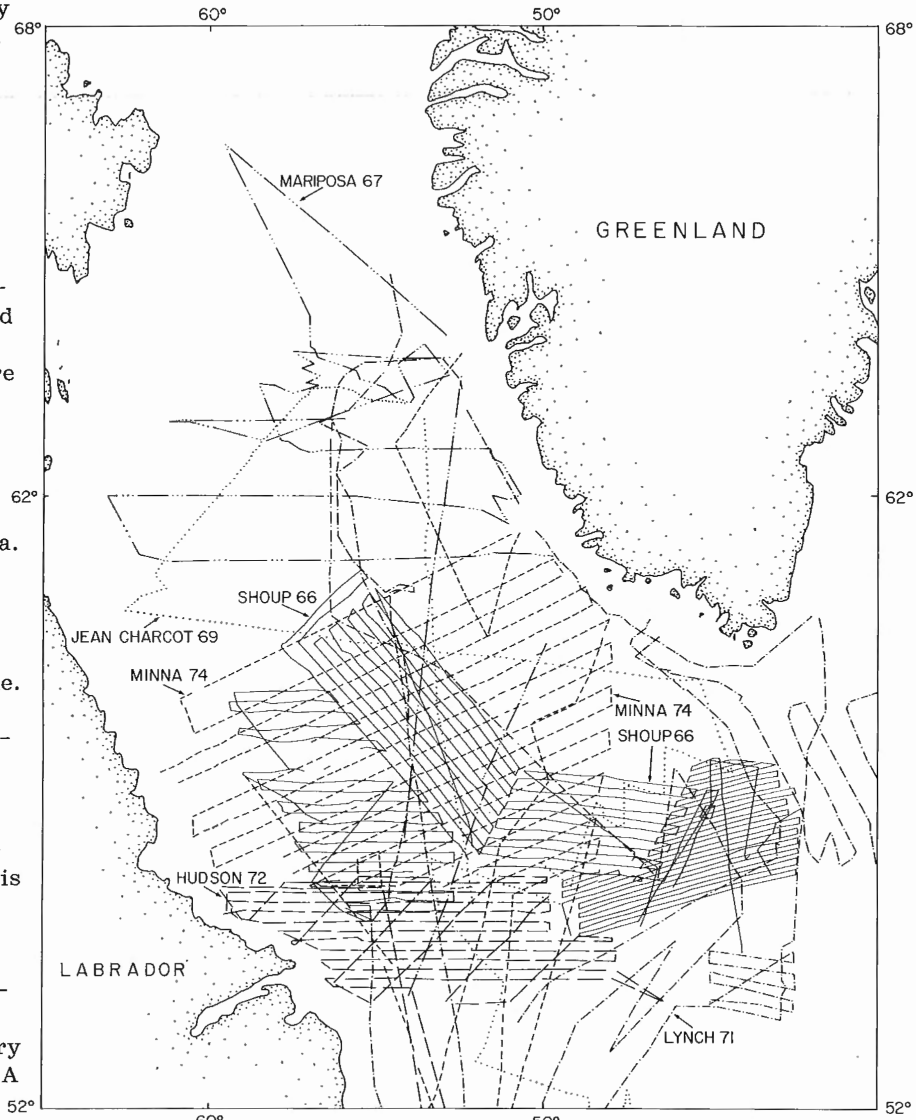
Project 740013

S.P. Srivastava
Atlantic Geoscience Centre, Dartmouth

The geometry and time of opening of the Labrador Sea have been discussed by several authors in the past decade or so. In the majority of these publications the times of commencement and termination of sea floor spreading in the Labrador Sea are largely based on the correlation of marine magnetic anomalies with the well established time scale of Heirtzler *et al.* (1968). Such a method has been found to be fairly accurate for instances where anomalies exhibit prominent characteristics which can easily be correlated with the Heitzler time scale. This method, however, becomes weaker where magnetic anomalies exhibit complex patterns. The Labrador Sea is one of these areas.

It was not possible until recently to satisfactorily correlate anomalies from widely spaced tracks in the Labrador Sea. The purpose of this study is to compile all available magnetic data in the Labrador Sea (1) to establish the trend of the magnetic anomalies and (2) to number them according to the Heirtzler time scale. We have now compiled a map using data which were made available to us by various agencies. Figure 1 shows a composite track plot of all the data which was used in this compilation. The data collected during the MINNA-74 and SHOUP-66 cruises have been most valuable in this compilation. In the northern Labrador Sea the magnetic anomalies show a good correlation from track to track and are symmetrical with respect to the mid-Labrador Ridge. However, in the southern part of the area the anomalies show a very confused and non-symmetrical pattern. A detailed survey of this area to delineate the trend of the anomalies has been planned for this year.



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53. AN ASSESSMENT OF THE METHODS USED IN APPLYING DIURNAL CORRECTION TO MARINE MAGNETIC DATA

Project 720108

S. P. Srivastava
Atlantic Geoscience Centre, Dartmouth

Temporal variations of the earth's magnetic field were monitored at shore-based stations at Cartwright on the Labrador Coast from June to August, 1974 and at the Bedford Institute between May and November, 1974. The recordings from these stations will be used in applying a correction to the marine magnetic data.

Further experiments to monitor these variations from specially designed magnetometers housed in moored surface buoys were carried out from September to October, 1974 during the course of the detailed magnetic surveys of small areas in Baffin Bay and the Labrador Sea.

A paper (Srivastava, 1974) summarizing our results obtained from various experiments to date was presented at the Canadian Geophysical Union meeting held in St. John's, Newfoundland.

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CRUSTAL STUDY OF THE LABRADOR CONTINENTAL MARGIN

Project 730077

Willem J.M. van der Linden and S.P. Srivastava
Atlantic Geoscience Centre, Dartmouth

Gravity, magnetic and seismic data collected in October 1972 (BIO 72-025 HUDSON) across the central Labrador margin were compiled into maps and a preliminary interpretation was prepared (van der Linden and Srivastava, in press). A detailed analysis of the gravity and magnetic data was started.

Profiles of free air and isostatic anomalies across the continental margin show large gradients in the gravity field with a maximum gradient, oblique to the coast, over a basement high under Hamilton Bank (Cartwright Arch). A large gradient in the isostatic anomalies in this region is attributed to a coast-parallel buried escarpment, with shallow basement on the seaward side and deep basement on the landward side. A magnetic quiet zone, roughly 200 km wide, separates a pattern of chaotic high frequency anomalies over the shelf from parallel oceanic anomalies over the Labrador Basin. It appears that part or all of this quiet zone is continental in nature. Model computations are carried out now to verify this interpretation.

Three refraction lines off northern Labrador obtained in July 1974 (BIO 74-026 HUDSON) complement seismic data obtained in August 1973 (BIO 73-027 DAWSON) (Fig. 1). A first analysis of the results confirms that the Labrador margin is underlain by foundered continental crust over a 300-400 km wide zone. A basement ridge (Wade *et al.*, in press), extending southeastward in the northwest Labrador Sea, is interpreted as a continental fragment that did not subside as much as basement on the landward side. A southward extrapolation of this basement ridge suggests that it may be similar in structure and lithology to Orphan Knoll and Flemish Cap, off the east coast of Newfoundland.

A tentative diagrammatic view of the structure of the basement and overlying sedimentary sequences over the Labrador margin is given in Figure 2.

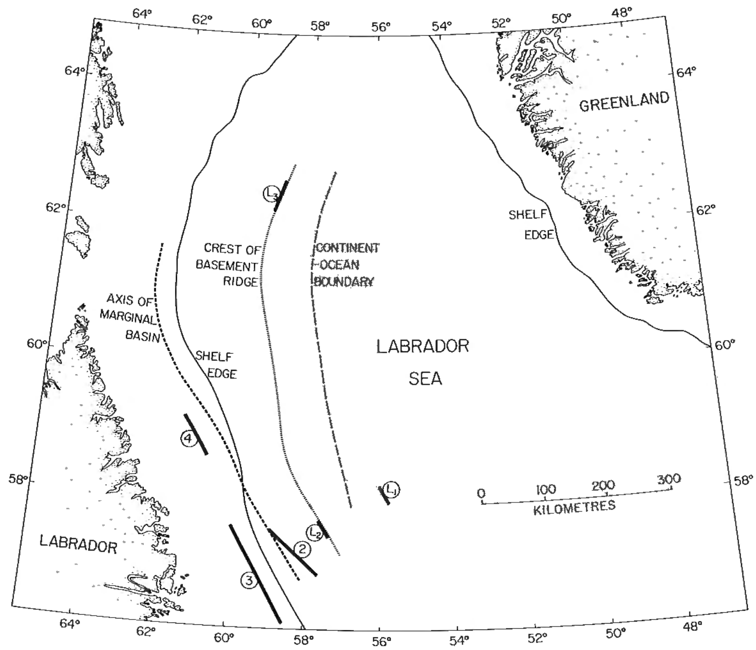

Figure 1. Positions of refraction lines in the northern Labrador Sea, shot in 1973 (lines 2, 3 and 4) and 1974 (L_1, L_2 and L_3). The shelf edge, the crest of a buried basement ridge (*after* Wade *et al.*, in press) and the inferred continent-ocean boundary are shown.

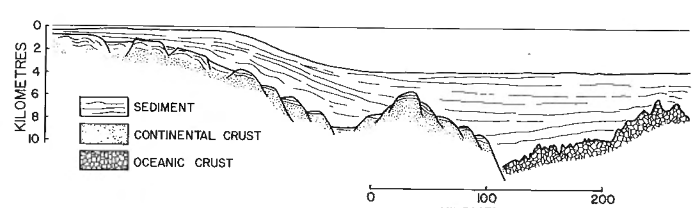

Figure 2. Diagrammatic interpretation of the structure of the Labrador continental margin as derived from seismic (refraction and reflection), gravity and magnetic data.

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55. INTEGRATED STUDIES ON MINERAL RESOURCE APPRAISAL IN THE BEECHEY LAKE BELT OF THE NORTHERN SHIELD

Project 730009

E. M. Cameron
Resource Geophysics and Geochemistry Division

The appraisal of mineral resources has, for a variety of reasons, become of increasing concern to governments. The concept of the exhaustion of nonrenewable commodities in the not too distant future, most vigorously propounded in the "Club of Rome" report, has attracted criticism from earth scientists. Whatever the merits of this criticism, this work has served as a powerful catalyst to more serious study of the future availability of mineral resources. The "energy crisis" has more recently focussed attention on the gap between anticipated demand and supply of petroleum and also uranium (Nininger, 1974; Darnley, 1974).

Mineral resource appraisal is not, of course, a new field. Indeed, the appraisal of the mineral potential of an area or prospect has always been the essential first stage in exploration. What is novel in some recent studies is that an attempt has been made to quantify the appraisal. This may be called mineral resource estimation. In Canada there have been two principal approaches to mineral resource estimation. In the first, statistical methods have been used to integrate a variety of expert opinion on a region (e.g. Barry and Freyman, 1970). The second has emphasized geomathematical analysis of existing geological data (e.g., Agterberg *et al.*, 1972).

These two approaches have validity for the better explored parts of Canada. For more remote areas, however, there is generally insufficient geoscience information on which to base estimates. For these regions a preliminary requirement is to acquire the necessary data. There is some advantage to this, for the investigator may choose to obtain the data most appropriate to his need. It is inevitable that the methodology used to acquire these data will differ little from those used in mineral exploration, including geological, geophysical and geochemical surveys and even some drilling (Darnley, 1974). There is, however, an important difference between this type of resource estimation and mineral exploration. In the former, the knowledge gained by the detailed investigation of a few anomalies will be used to obtain probabalistic estimates of the mineral potential of many other anomalies in the same region or geological environment. This project was concerned with such a detailed investigation of a geochemically anomalous area in northern Canada.

Since 1969 the Geochemistry Section has been developing methods of geochemical reconnaissance for the northern Shield based on lake sediment sampling. In 1972 a full-scale test survey was carried out over 36,000 square miles of the Bear and Slave Provinces of the Shield (Allan *et al.*, 1973). A sample density of one per ten square miles was used. This survey proved the approach to be rapid and economical and the data correlated well with the known distribution of mineralization (Allan *et al.*, 1972; Cameron and Allan, 1973). However, as a relatively new technique, there was some hesitancy in interpreting anomalies not associated with known mineralization. Also there was a need to convert the geochemical data into a form suitable for resource estimation.

To answer the first of these questions, a follow-up study was carried out in the summer of 1973 to investigate anomalies in the eastern part of the Slave Province (Cameron and Durham, 1974a, 1974b). The study showed that an important group of multi-element anomalies (principally Zn-Cu) were associated with previously unmapped volcanic rocks. One interesting target, believed to contain zinc-, copper-, lead-, silver-, and gold-bearing massive sulphides, was identified (the Agricola Lake, or "Y" anomaly).

This anomaly was chosen in 1974 for detailed geological, geophysical and geochemical studies. The principal objective was to investigate the most suitable methods for follow-up and interpretation of lake sediment anomalies. However, the scope of the work was broadened to allow a fairly complete "case history" examination of exploration methods on the permafrost environment of the northern Shield. In addition, the geochemical party took the opportunity to assess the feasibility of operating a sophisticated geochemical laboratory in a quite remote location; to study the extent of present-day oxidation of sulphide bodies; and to investigate hydro-geochemical methods of exploration. During the summer aerial colour photography was obtained for the western margin of the Beechey Lake belt. As well as being of value for studies in the Agricola Lake area, this photography should be most useful for geological mapping and mineral exploration within the metavolcanic terrane of this belt. Further studies were carried out on the Lineament Lake uranium anomaly (Cameron and Durham, 1974b). The Canada Centre for Inland Waters of the Department of the Environment used the base camp for preliminary studies on Arctic limnology.

Subsequent to Open File release of the 1973 field data (Cameron and Durham, 1973), a number of companies staked along the western margin of the Beechey Lake belt. This staking was mainly over metavolcanic rocks. During the 1974 field season, the Yava Syndicate (Conwest Exploration - Brascan Resources Ltd. - S.M. Roscoe) carried out surveys on the Agricola Lake area and drilled five holes into the geochemical target (Fig. 1).

Figure 1 shows the location of the various studies. All were centred on the "B" horizon massive sulphide prospect delineated in 1973. The geochemical soil study, the V.L.F.-resistivity, and the high sensitivity magnetometer surveys were carried out over the same 600 m by 375 m area. These three surveys used a 30 m by 15 m interval grid surveyed by transit and chain. The gravity survey was made over a rather larger area using an independently surveyed grid. Rock samples were collected from a still larger 1,560 m by 780 m area. In addition, water samples were collected from most lakes and streams in the Agricola Lake and Friday Lake drainage systems. Deep lake sediment samples were taken from the lakes to compare with the nearshore sediment samples collected in previous years. During this field season lake waters were collected and

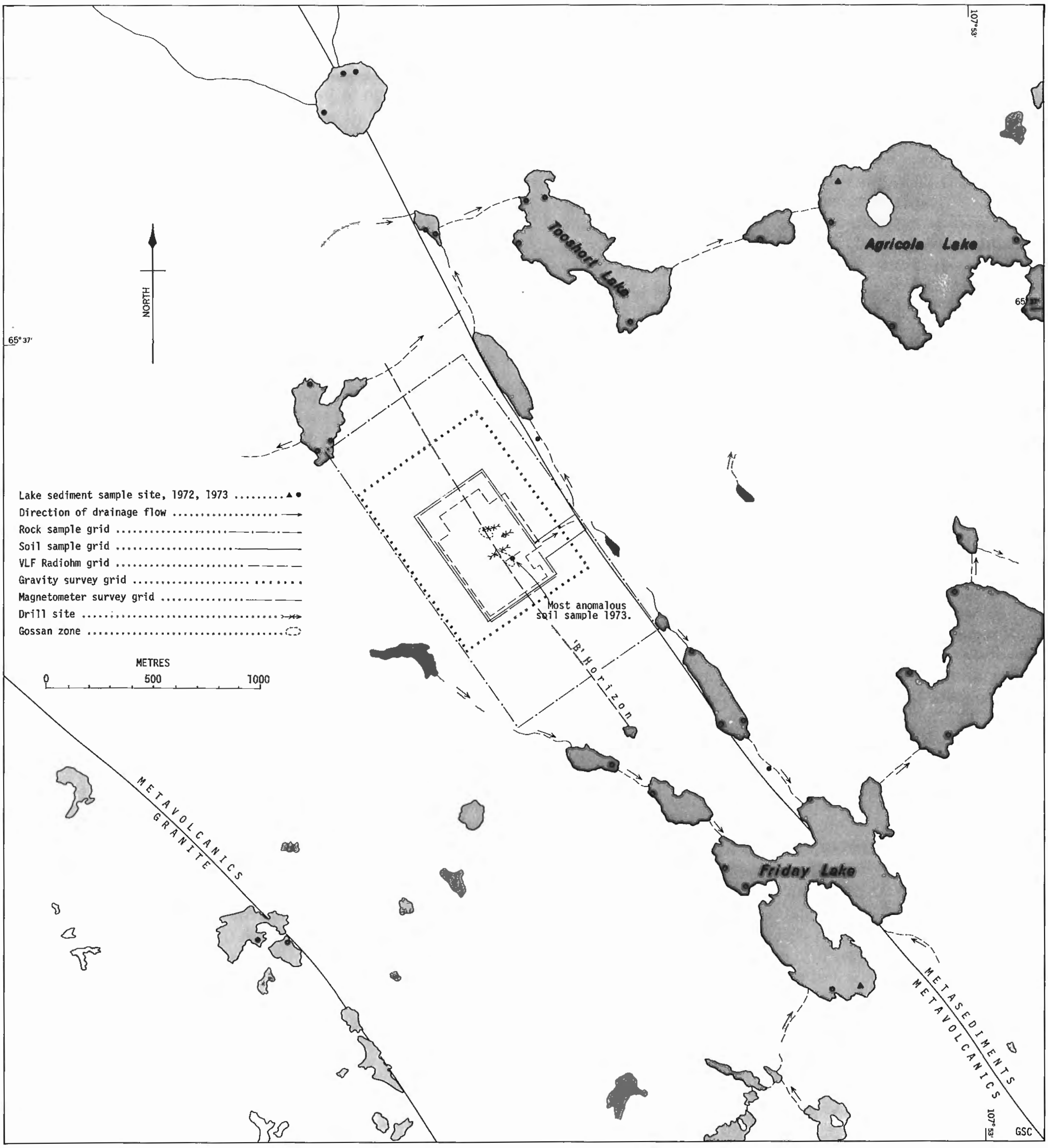

Figure 1. Study area, Agricola Lake, N.W.T.

analyzed from a 900-square-mile region around High Lake, 150 miles north-northwest of Friday Lake; from a 750-square-mile area around Agricola Lake; and from the Hackett River area 26 miles to the north-northwest.

Figure 2 is a geological map of the area of soil, V.L.F., and magnetometer surveys. It was prepared by A. Williams. This is an interim map, based on field information only. The geophysical studies, reported later in this volume, suggest a number of changes, mainly in the less well exposed parts.

Rock exposure is generally excellent in this area, overburden being thin in most places. This is flat country that might, in the absence of lakes, be described as featureless. The volcanic rocks produce the greatest relief, but even this rarely exceeds 30 m. The most obvious features of glaciation are eskers. These trend parallel to the dominant north-northwest strike of the rocks.

The area of soil, V.L.F. and magnetometer surveys is basin-shaped. The low ground in the centre is underlain by hydrothermally altered acidic to intermediate volcanic rocks and by exhalative sulphides of the "B" horizon (Cameron and Durham, 1974a, 1974b). The soils overlying the sulphides are of a buff, gossanous colour. Pyrite is very abundant in this area. Despite intensive search by a number of geologists, only trace quantities of sphalerite, chalcopyrite and galena were found at the surface. Since the drilling by the Yava Syndicate indicates that these minerals exist in quantity at depth, they have clearly been thoroughly oxidized at the surface.

The papers that comprise this section were compiled from data that were obtained in the field or became available shortly thereafter. The various

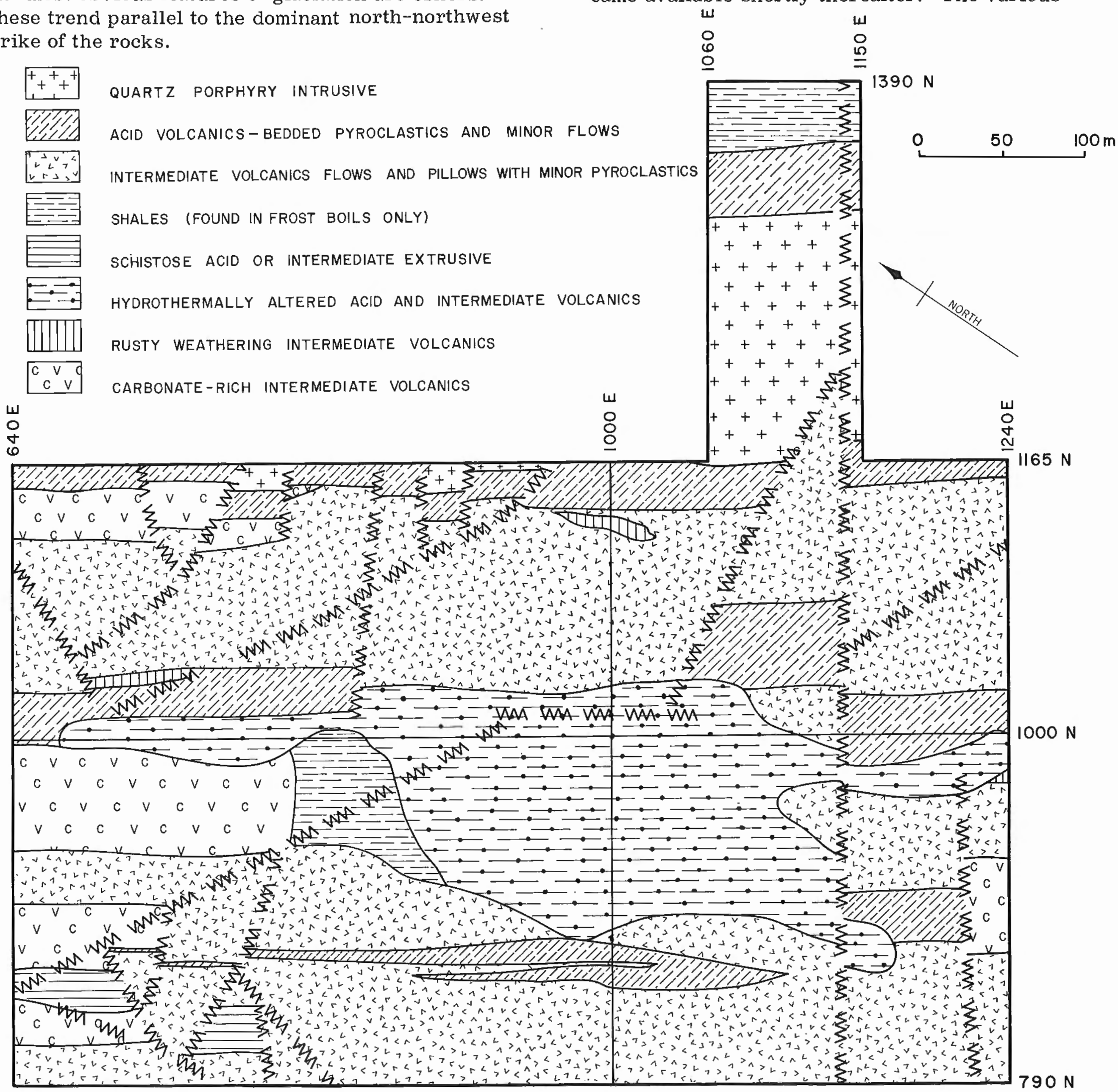

Figure 2. Geological map of the Agricola Lake massive sulphide prospect. Boundaries as for soil sample grid (Fig. 1).

authors have had little chance to compare their data with that of the others. Thus, no attempt has been made to synthesize the results. This will be done at a later date. However, these initial reports show that each method has some unique information to contribute to the understanding of the geological environment. Most important, the studies show that this northern permafrost environment is not as inimical to modern methods of mineral exploration as had previously been feared.

Camp was established on the northeastern shore of Friday Lake (Fig. 1). This is approximately 300 miles northeast of Yellowknife, the supply base. The camp was established after break-up in late June and was occupied by the geochemical staff until the onset of winter conditions in mid-August. The other investigators visited the camp for shorter periods, during breaks in their other field programs.

The main geochemical-geological party comprised:

- E.M. Cameron, party chief
- C.C. Durham, deputy party chief
- R.E. Horton, chief analyst
- Miss E. Ruzgaitis and Miss S. Costaschuk, analysts
- S.B. Ballantyne, hydrogeochemical sampling
- D. Lefebvre (Queen's University), geological mapping
- A. Williams, senior assistant, geological mapping and rock sampling
- J. Thomas and J. Spence, sampling, sample preparation
- Miss M.J. McKay and Miss M. Coutts, cook and cook's helper
- R. Watson, helicopter pilot and engineer.

The following persons visited the camp for shorter periods:

- J.B. Boyd and E. Garrison (Earth Physics Branch), gravity (July 9-23)
- J.B. Henderson and J. Osler, geological studies (July 9-19)
- W. Dyck, uranium geochemistry (July 9-23)
- I.R. Jonasson and R. Benson, sulphide mineral studies (July 9-23)
- W.J. Scott and D. Eberle, V.L.F.-resistivity (July 19-26)
- J.D.H. Williams (D.O.E.), limnology (July 19-29)
- L.J. Kornik, magnetometry (August 7-11)
- V.R. Slaney, aerial colour photography (based at Tundra Mine airstrip).

The author wishes to thank Dr. Arthur Darnley, for stimulating an interest in a multidisciplinary approach to resource evaluation. Mr. Robert Hornal has both encouraged and facilitated the work. Dr. S.M. Roscoe, Mr. K. O'Connor, and Mr. B.K. McKnight have provided useful comments on our interpretations of data obtained on the Yava claims. The field logistics were largely organized by Mr. Chris Durham. Finally, I am greatly indebted to my colleagues from a variety of fields who have so enthusiastically cooperated in this study.

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A GRAVITY INVESTIGATION WITHIN THE AGRICOLA LAKE GEOCHEMICAL ANOMALY, DISTRICT OF MACKENZIE

J.B. Boyd, R.A. Gibb and M.D. Thomas
Gravity Division, Earth Physics Branch

Introduction

Follow-up studies (Cameron and Durham, 1974a, b) in 1973 of a prominent Cu-Zn geochemical anomaly delineated by a regional lake sediment survey in 1972 (Allan *et al.*, 1973) outlined several targets for more detailed investigation. The targets occur within intermediate to acid volcanic strata of the Archean Beechey Lake sedimentary-volcanic belt which is the main belt in the eastern part of the Slave Province (Cameron and Durham, 1974b). One target in particular, located along a prominent gossan horizon, possessed several characteristics of stratabound, volcanogenic, massive sulphide mineralization. This target was selected for multidisciplinary study using a variety of geochemical and geophysical methods. Detailed geological mapping and airborne colour photography were also carried out. All of these activities were undertaken in the summer of 1974, during which time a massive sulphide body containing copper and zinc together with other metals was proved through drilling by the Yava Syndicate holding extensive claims in the area (Northern Miner, 1974). This report describes the results of the application of one geophysical technique, namely gravity, to the problem of orebody detection and appraisal.

The Gravity Survey

A primary grid for the gravity survey was chosen on the basis of the geochemical and geological findings of the 1973 follow-up studies. Five profiles spaced at 300 m intervals and of 700 m or 750 m lengths were selected normal to the gossan zone and local geological strike. The profiles were connected by an orthogonal base line running more or less along the gossan horizon. Shorter fill-in profiles were traversed in the latter part of the survey after examination of the initial data.

A total of 159 gravity stations were occupied comprising 10 regional stations and 149 traverse stations. The majority of the latter are indicated in Figure 1, but some have been omitted for clarity of presentation. Traverse stations are normally 50 m apart, but as close as 10 m in some cases. A LaCoste and Romberg geodetic gravimeter No. G-88 was used for all the observations, which were tied to a local gravity datum established by helicopter ties to the control stations of the national gravity net.

Stations were positioned along the grid by transit and slope-corrected chainage. Since there were no geodetic control monuments in the vicinity, the horizontal control survey was tied to a point (identified on NTS map-sheet 72G) with geographical coordinates — latitude 65°35.6' and longitude 107°54.2'. Elevations were obtained by spirit level using a local datum tied to a Department of National Defence spirit level line located some 30 km east of the survey area. This tie was obtained by repeated barometer readings; the elevations of the 10 regional stations were also obtained barometrically.

The adjusted observed gravity values for the traverse stations are relatively accurate to ±0.03 mgal, elevations to ±3 cm and horizontal positions to ±2 cm.

The gravity data were reduced to the common datum of sea level using a uniform density of 2.67 g/cm^3. Terrain corrections were not computed, but since the terrain is relatively flat any error from this source is considered negligible. The Bouguer anomalies shown in Figure 1 have an accuracy of ±0.1 mgal; the regional stations which lie outside the area of Figure 1 have an accuracy of ±1 mgal.

Geology and Rock Densities

Geology

A detailed geological account and map of the area is presented elsewhere (Cameron, preceding paper, Fig. 2). In summary, the rocks in the area of the gravity survey comprise a more or less vertically-dipping sequence of intermediate to acid volcanics striking north-northwest, which are believed to become younger towards the northeast (Cameron and Durham, 1974b). They have been metamorphosed to greenschist to low amphibolite facies, and as a result the original mineralogical composition and textural features have been altered, making microscopic identification extremely difficult (Turay, 1974). However, chemical identifications of the rocks indicate compositions ranging from andesitic through dacitic to rhyolitic (op. cit.).

The detailed geological map was incomplete at the time of analyzing the gravity anomalies and only a simplified picture of the geology was available through the descriptions of Cameron and Durham (1974a, b) and from selected rock samples collected by the Geological Survey of Canada in the summer 1974 work.

A simplified geological map based on 97 rock samples is superimposed on Figure 1; the locations of the samples are also indicated. On the basis of hand sample identification the majority (79) of the samples are classified into three main groups indicated as A, B and C on Figure 1. Another 9 samples (group D) appear to be a slightly more acidic variety of B. Brief descriptions of the three main rock-types based on macroscopic and microscopic (one thin section of a representative sample of each group was used) examination follow.

Group A. Dark grey, medium to fine grained in hand specimen. Contains approximately 80% hornblende, apparently of secondary origin. Tentatively identified as an AMPHIBOLITE, probably originally an intermediate to basic intrusion.

Group B. Medium to dark grey, fine grained in hand specimen. Contains abundant sericite, epidote, biotite, quartz and opaques. Feldspar is likely present but is indistinguishable from quartz. Ghost areas of differing texture suggest altered fragments or phenocrysts. Tentatively identified as a recrystallized VOLCANIC TUFF.

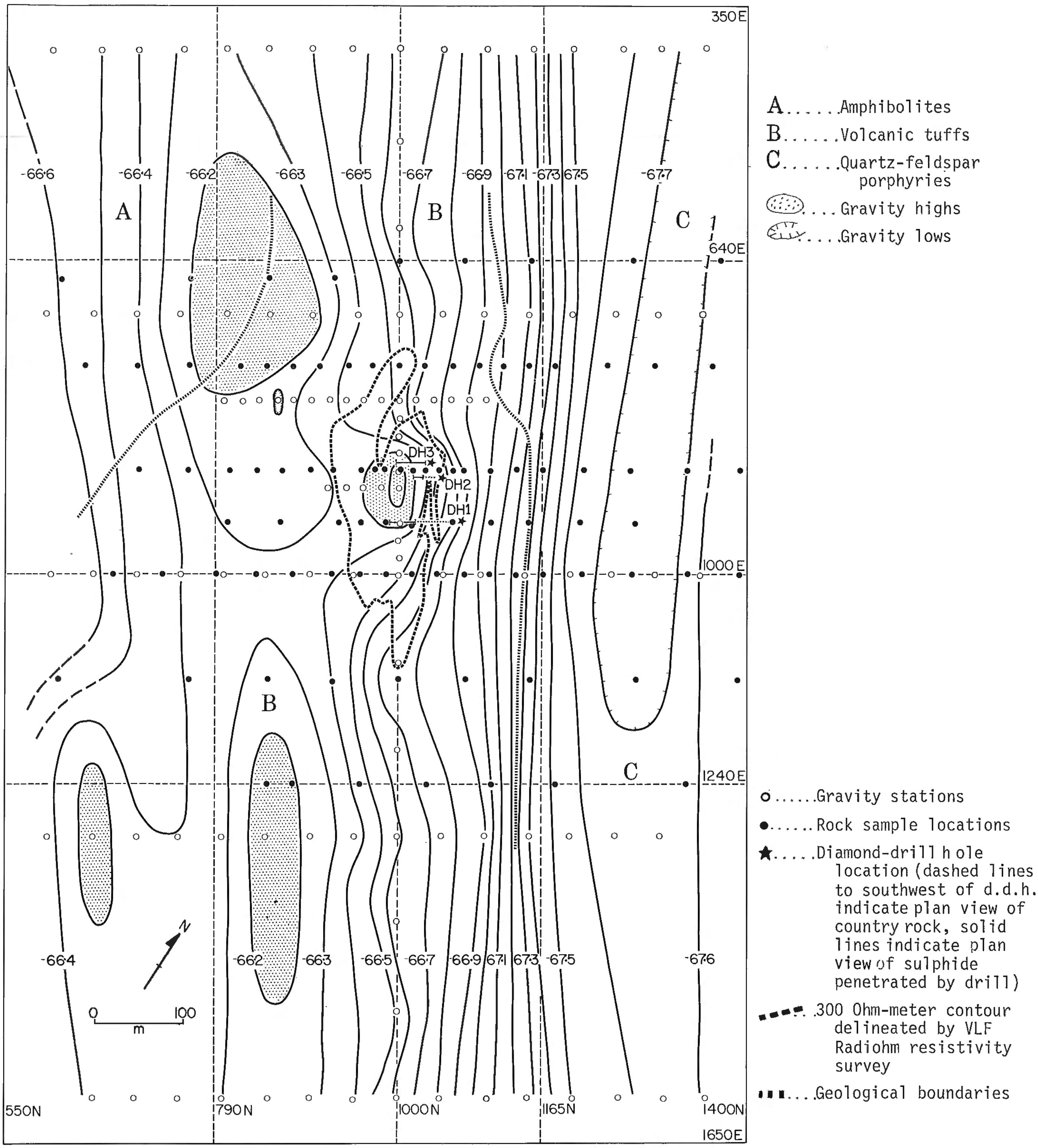

Figure 1. Bouguer anomaly map.

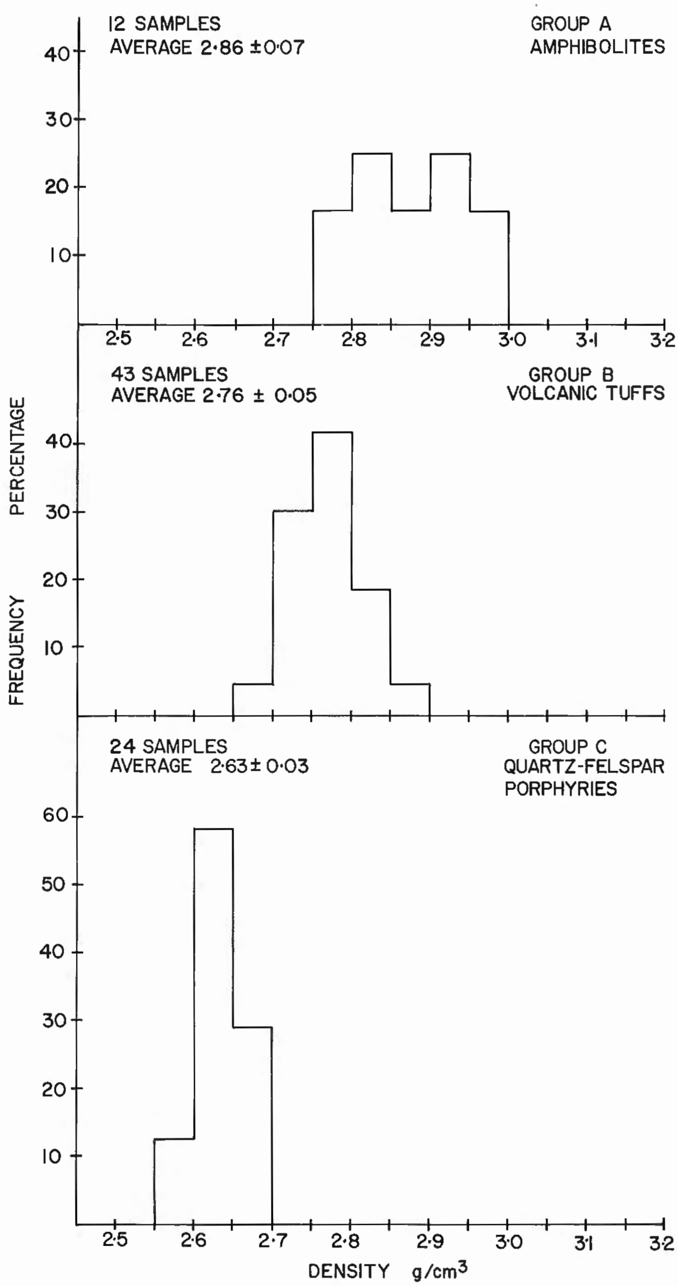

Figure 2. Histograms of rock densities. Average density and standard deviation of each group in g/cm^3 are indicated.

Group C. Light to medium grey, porphyritic texture in hand specimen. Quartz and plagioclase and probable K feldspar phenocrysts; feldspars are cloudy and sericitized. Identified as a QUARTZ-FELDSPAR PORPHYRY.

Rock Densities

A summary of rock density measurements on the samples of groups A, B, C and D, as well as of samples of mineralized material (sulphides) obtained from the Yava Syndicate's diamond drillhole No. 1 (DH1) (*see* Fig. 1 for position) is given in Table 1.

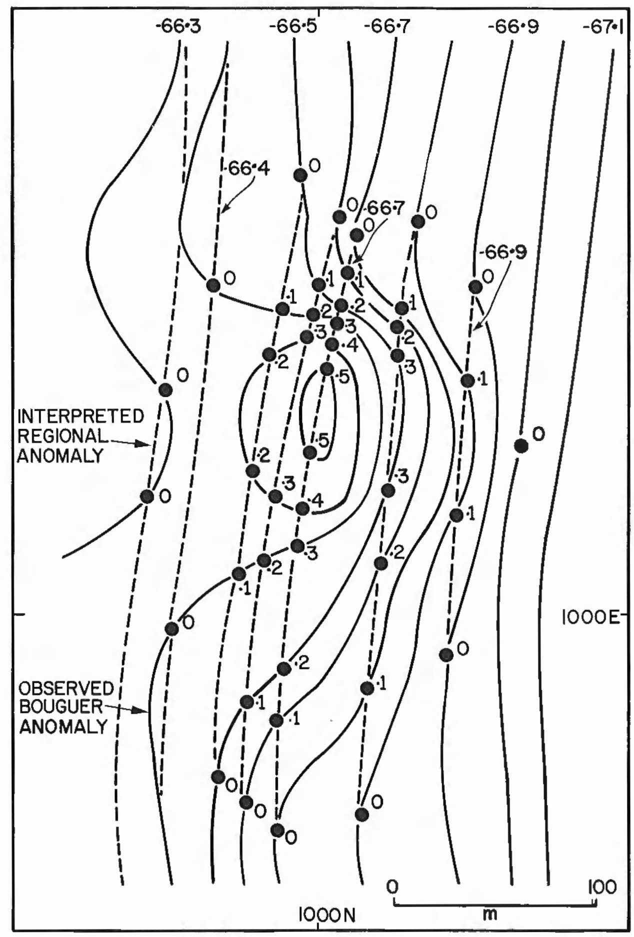

Figure 3. Observed gravity field and interpolated gravity field used to obtain residual gravity anomaly over sulphide body. Solid circles with values (in mgal) indicate point differences between the two gravity fields.

Histograms of densities for groups A, B and C are presented in Figure 2. The normal distributions and small standard deviations of B and C reflect the high degree of homogeneity of the densities of these rock types, and to a certain extent support the identifications and grouping. Certainly, as density groups for gravity interpretations they are well defined. The histogram for A is bimodal and this is believed to result in part from misidentification between the finer grained samples of group A and the samples of group B. The average densities of groups A, B and C are consistent with those expected for basic, intermediate and acidic volcanic rocks respectively. This consistency has been supported by microscopic studies for groups A and C; it seems likely, therefore, that group B is of intermediate composition.

Some mineralogical and density data pertaining to the sulphides are presented in Table 2. The percentages quoted in the table for the various minerals and host rock are based on macroscopic examination of very small (∿25 g) samples.

Table 1

Summary of rock density data

Lithology	No. of Samples	Average Density and Standard Deviation g/cm^3	Range of Densities g/cm^3
A	12	2.86 ± 0.07	2.75 - 2.96
B	43	2.76 ± 0.05	2.68 - 2.88
C	24	2.63 ± 0.03	2.56 - 2.69
D	9	2.69 ± 0.03	2.62 - 2.72
Mineralized Rock	7	3.45 ± 0.26	3.04 - 3.78

Table 2

Characteristics of mineralized rock from DH1

*Depth	Mineralogy	Density (g/cm^3)
72.5	Sp. 55%, Py. Trace, Ho. 45%	3.39
76.5	Sp. 10%, Py. 25%, Ho. 65%	3.45
79.6	Sp. 5%, Ch. 5%, Ho. 90%	3.14
81.2	Ph. 65%, Ho. 35%	3.78
86.9	Sp. 5%, Ho. 95%	3.04
87.8	Sp. 65%, Ch. Trace, Ho. 30%	3.64
114.3	Ph. 60%, Ho. 40%	3.72
	Average Density	3.45 ± 0.26

*Depths are in metres from surface along the length of the drill core which is inclined at 45°.
Ch. - Chalcopyrite, Ho. - Host rock, Ph. - Pyrrhotite, Py. - Pyrite, Sp. - Sphalerite.

Discussion of Gravity Anomalies

A Bouguer anomaly map of the area contoured at 0.1 mgal interval, is presented in Figure 1 superimposed on the simplified geological map based on the rock density samples. The anomalies do not vary by more than 1.5 mgal over the whole area. The gravity contours trend dominantly north-northwestwards reflecting the prevailing geological strike. The general pattern of anomalies is that of a broad gravity high overlying the southwestern two-thirds of the area separated by a narrow belt of steep gradients from a low amplitude gravity low lying along the northeastern margin of the area.

The belt of steep gradients correlates extremely well with the junction between the volcanic tuffs (B) and the quartz-feldspar porphyries (C) and may be directly attributable to the marked density contrast (0.13 g/cm^3) between the two groups; the quartz-feldspar porphyries being the lighter lithology are associated with the lower Bouguer anomalies. An explanation of the broad gravity high in terms of the mapped geology is not as readily apparent, either by comparison of the anomaly with the detailed geological map (Cameron, preceding paper) or the simplified map (Fig. 1). However, there are limited correlations between rock density, geology and gravity anomaly which suggest that amphibolitic rocks (average density 2.86 g/cm^3), possibly together with carbonate rocks, in contact with volcanic tuffs (average density 2.76 g/cm^3) are the main source of the anomaly.

A local gravity high is present within the vicinity of the mineralized zone, and is manifest in the bulging of the gravity contours towards the northeast and in a closure of the contours over the zone. This high corresponds in position with a prominent VLF Radiohm electrical resistivity anomaly (*see* Fig. 1). The results of the VLF Radiohm survey are described elsewhere (*see* Scott, this publication, report no. 64). It is important to note that the control for contouring the gravity field in the area immediately northeast of the zone is extremely poor, since gravity observations were not made northeast of grid line 1000N in this vicinity. Contour positions in this area were therefore obtained by interpolating between the -67.0 mgal contour line and the base line station value at the end of the shortest gravity profile.

Because the gravity high associated with the mineralized zone is superimposed on the flank of the

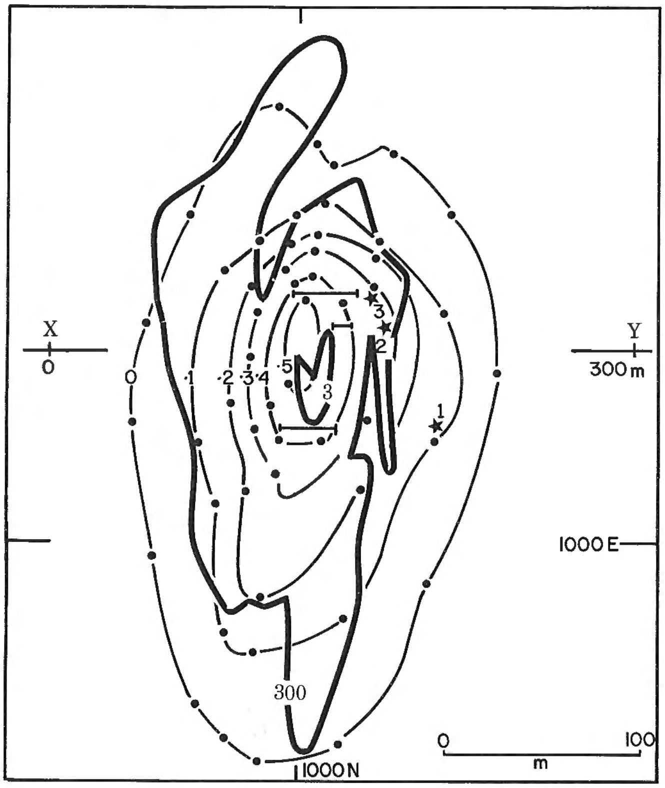

Figure 4. Residual gravity anomaly. Solid circles correspond to solid circles in Figure 3. Contour values are in mgal. Heavy lines represent VLF Radiohm resistivity contours. Stars indicate drill hole positions. Solid bars indicate plan views of sulphides as proved by drilling.

more extensive broad high attributed to amphibolitic rocks an estimation of its amplitude is somewhat difficult. It has been necessary, therefore, to remove a background anomaly, in order to portray more clearly the gravity effect of the mineralization.

A residual gravity anomaly was obtained by removing a background gravity field using a simple graphical method. The method, outlined below, is appropriate in the present case because the gravity contours to either side of the mineralized zone have similar gradients and are essentially linear and on strike with each other. Gravity contours interpolated from the linear belts on either side of the disturbed field were constructed (*see* Fig. 3) and the interpolated field was subtracted from the observed field at the points of mutual intersection of the fields. The point values obtained in this manner were then contoured to produce the positive residual gravity anomaly outlined in Figure 4.

The residual gravity anomaly is approximately elliptical in plan with axes of lengths 320 m and 180 m, and is symmetrical about the axis. The maximum values occur over the northwestern half of the anomaly where the 0.5 mgal anomaly defines the peak closure.

The close correlation in position between the gravity anomaly and the electrical resistivity anomaly indicated in Figure 1 is even more clearly demonstrated in Figure 4 where the 300 and 3 ohm-metre contours of the VLF Radiohm survey are outlined. The latter contours define respectively the perimeter and peak of the conductivity anomaly. There is a remarkable correlation between the lengths of the gravity and resistivity anomalies and in the positions of their peak values and axes.

The coincidental positions of the peaks of the anomalies suggest a number of possibilities; the mineralization is more concentrated in this location (gravity and resistivity indications); the mineralized zone is wider (resistivity); the mineralized zone is wider and/or deeper (gravity); or a combination of all these possibilities.

The close association between the gravity and resistivity anomalies taken together with the results from the other surveys (this section) and the drilling (Northern Miner, 1974) is a favourable indicator for the presence of a massive sulphide body. An idea of the minimum horizontal extent of this body may be obtained from the lengths of the anomalies themselves. Evaluation of the subsurface extent of the body may be accomplished by gravity modelling. It is intended to provide gravity model interpretations and estimates of the mass of the body in a future detailed presentation of the results.

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The authors wish to thank the following members of the Resource Geophysics and Geochemistry Division of the Geological Survey of Canada for the various forms of assistance they have rendered during the course of this study, S.B. Ballantyne, E.M. Cameron, C.C. Durham and I.R. Jonasson. A.J. Williams of the University of Windsor and E.W. Garrison of Carleton University are thanked for their contributions to the study.

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SOIL GEOCHEMISTRY OF THE AGRICOLA LAKE MASSIVE SULPHIDE PROSPECT

E.M. Cameron and C.C. Durham
Resource Geophysics and Geochemistry Division

The soil sample grid is centred over the "B" horizon massive sulphide prospect. Survey lines, normal to this horizon and to the strike of the volcanics, were established at 30-m intervals. Soil samples were collected at 15-m intervals along these lines. The main part of the soil grid extends from 640 E (metres) to 1240 E and from 790 N to 1165 N (Fig. 1). For the four lines 1060 N to 1150 E, the sampling was extended to 1390 N. This extension is over a stream draining the prospect; these additional soils were sampled to study dispersion along this drainage channel.

The geology of the soil study area is shown elsewhere (Cameron, this section, Fig. 2). It is situated in the upper part of the near vertical-dipping volcanic sequence. The 1165 N boundary is roughly coincident with the lower contact of the quartz porphyry sill. The "B" (exhalative) horizon (Cameron and Durham, 1974a, 1974b) runs parallel and close to the 1000 N base

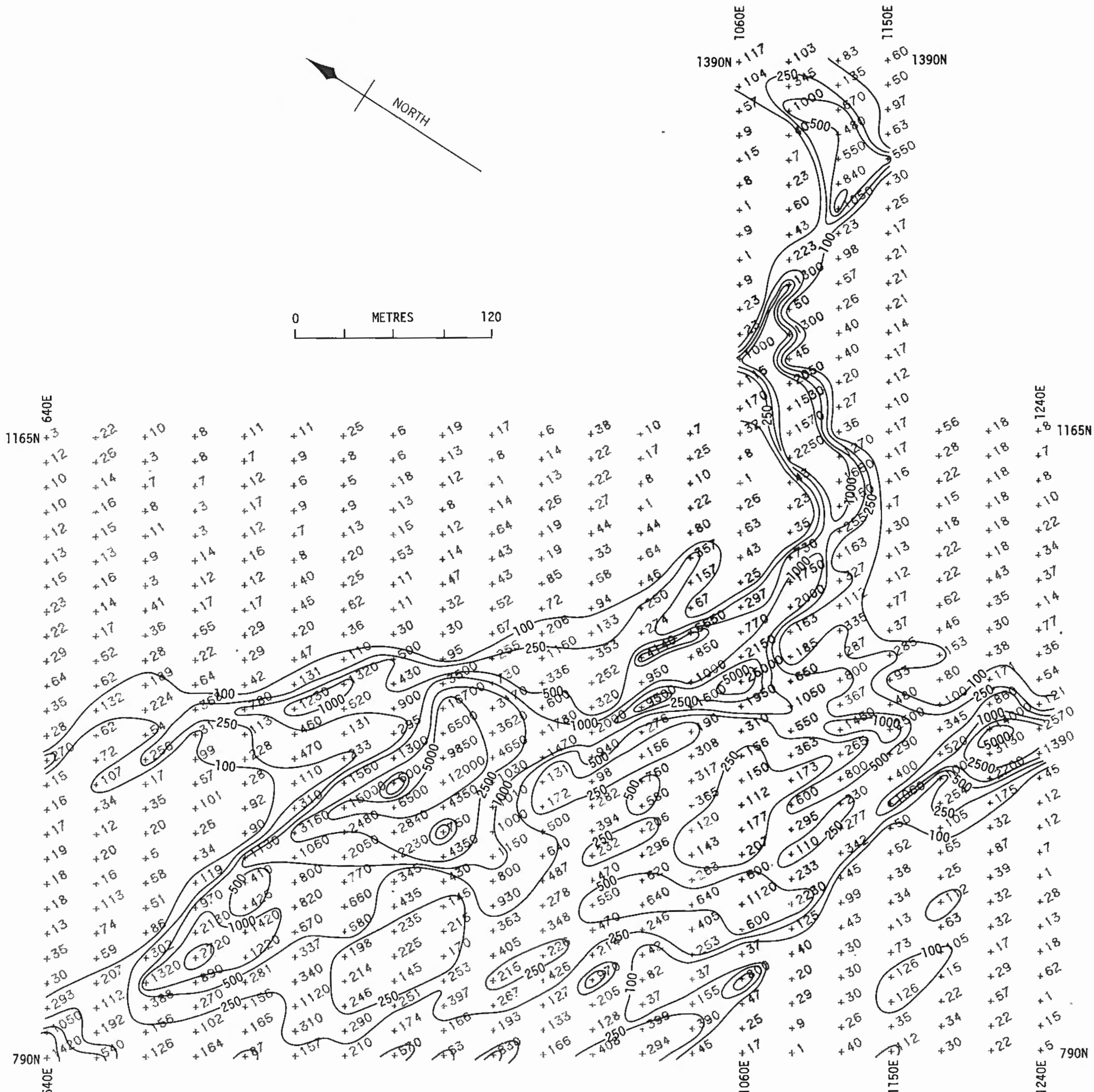

Figure 1. Distribution of lead (as ppm) in soils, Agricola Lake massive sulphide prospect, N.W.T.

line. The sampled area is roughly basin-shaped. The "B" horizon, the underlying hydrothermally altered rocks, and the shales form low, partly swampy ground with poor rock exposure. This is surrounded on all sides by better drained ground of greater relief, within which the rocks are well exposed. As noted above the basin drains (grid) north.

The soils in the central area of low ground are extensively dissected by frost boils. These soils tend to be stony and many are of a buff, gossanous colour. The hanging-wall volcanics are more resistant than the footwall volcanics or "B" horizon exhalite. This has caused the latter to be covered in many places by boulder fields derived from the hanging-wall volcanics.

The soils were sampled at a depth of 6-8 inches. Where possible, organic-rich soils were avoided, but in some places there was no alternative sample type. After drying, the soils were sieved, the minus 80-mesh fraction being used for analysis. Zn, Cu, Pb, and Ag were analyzed in the field by atomic absorption spectrometer. Extraction was with hot HNO_3-HCl. Samples below the detection limit of 2.5 ppm Pb were assigned a value of 1 ppm. Attempts were made in a number of places to sample the soil in profile. However, the highly thixotropic nature of the active layer, accentuated by a wet summer, rendered this impossible.

In Figures 1 and 2 we show the distribution of Pb and Cu in the soils. Figures 3 and 4 illustrate the frequency distribution of these elements in the sample population. We believe that there have been three important processes responsible for the transportation of Pb in the soil study area. This has been shown diagrammatically in Figure 5. Solifluction has dispersed the solid material relatively short distances downslope in the immediate vicinity of the sulphide body. Glaciation is believed to have produced a more extensive dis-

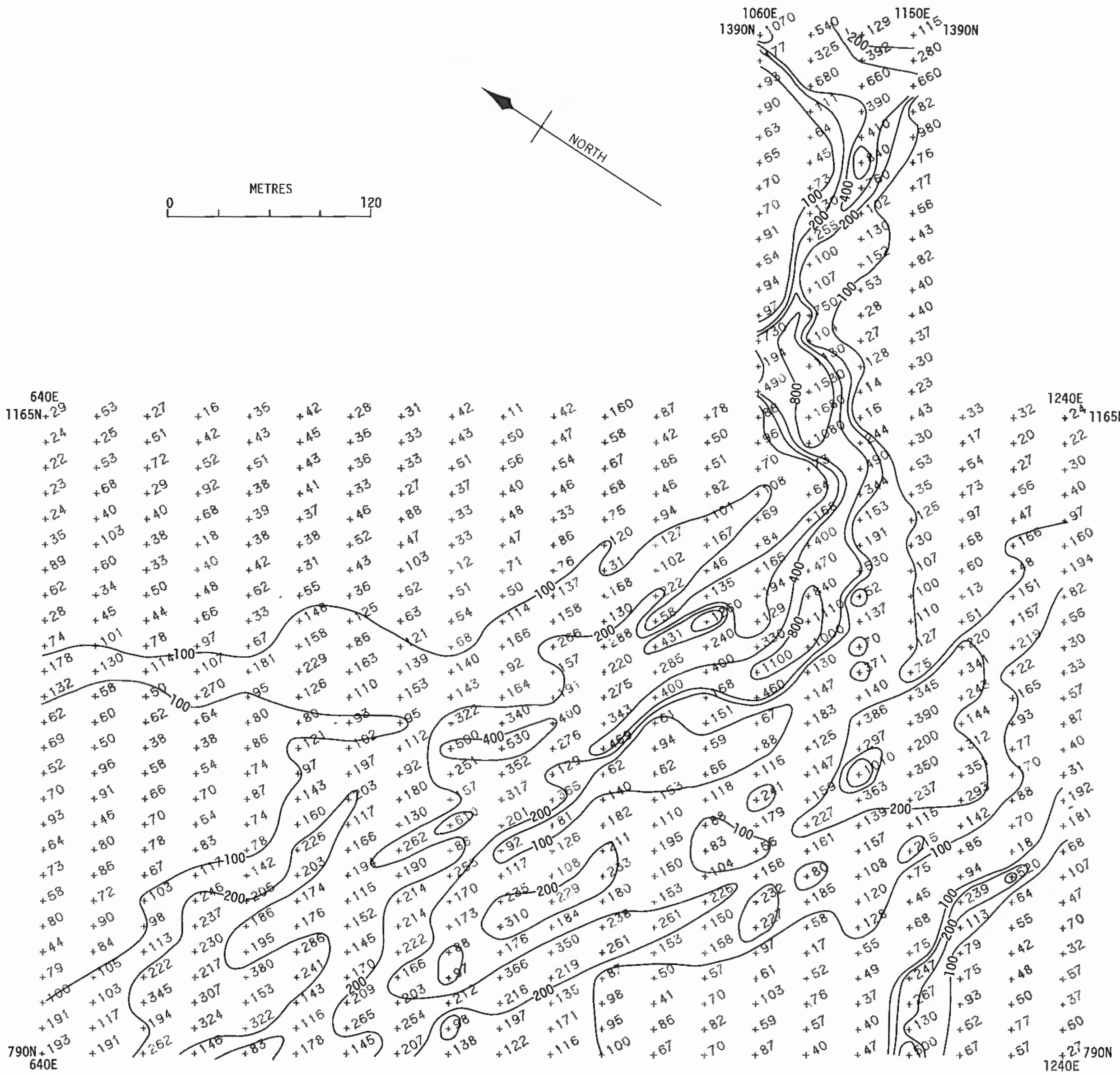

Figure 2. Distribution of copper (as ppm) in soils, Agricola Lake massive sulphide prospect, N.W.T.

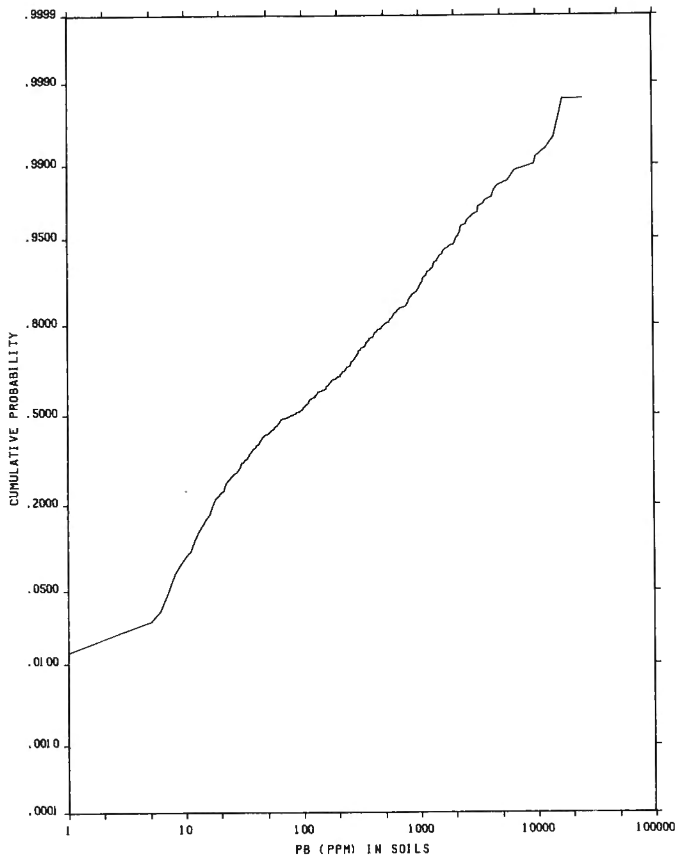

Figure 3. Frequency distribution of lead in soils, Agricola Lake massive sulphide prospect, N.W.T. (606 samples)

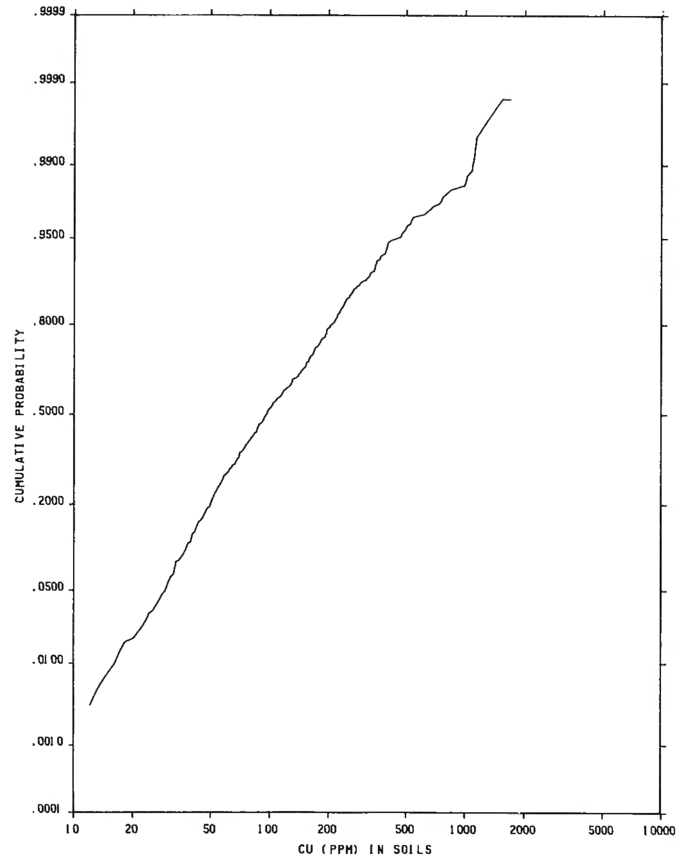

Figure 4. Frequency distribution of copper in soils, Agricola Lake massive sulphide prospect, N.W.T. (606 samples)

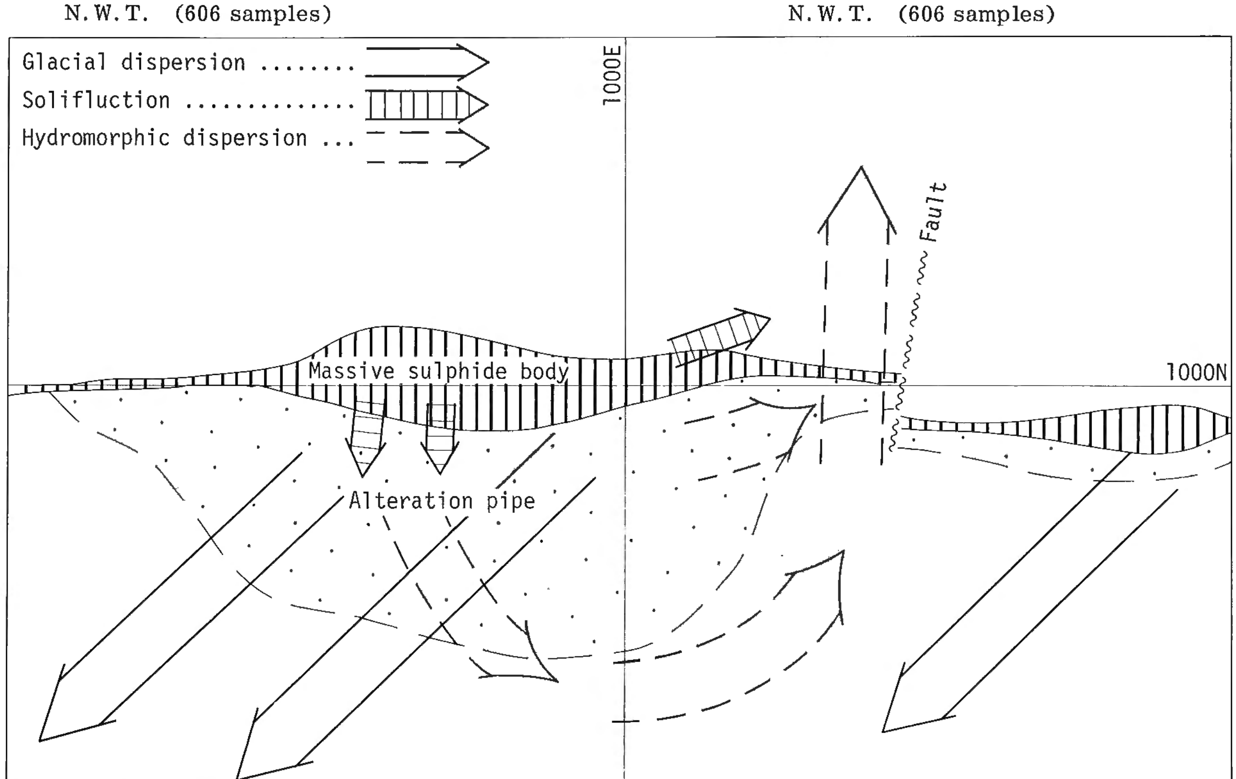

Figure 5. Patterns of secondary base metal dispersion, Agricola Lake massive sulphide prospect, N.W.T.

persion along a bearing of 290° true N from the body. Soils from the (grid) southeast corner of the area shown in Figure 1 contain fragments of shale and hydrothermally altered volcanics. Since no similar lithologies were detected in the bedrock in this area, it is believed that these fragments were transported from the central portion of the soil study area. The topographic gradient is upwards in this direction, so that glacial transport is the only feasible explanation. The indicated direction of transport is similar to the bearing of other glacial features in the region. An esker 5 miles to the west of the study area has a bearing of 320° true N. The third, important mechanism for transport of Pb is by solution. This is believed to have caused some movement of Pb across the central swampy portion of the site, and then out along the stream valley draining the area. The dispersion of Pb along the latter may be readily discerned in Figure 1. The concept of hydromorphic dispersion of Pb is substantiated by the data showing that this element is held in solution in the springs and streams around the prospect (*see* Cameron and Lynch, this section, following report). Lead is a relatively immobile element (Table 1) but it is dissolved in the highly acidic groundwaters in contact with the massive sulphide body. It is then precipitated in the upper reaches of the drainage system. Surface waters in the area are not conducive to the solution of Pb, as is evidenced by the high values for this element obtained by soil analysis. Many soil values close to 1% were obtained over the sulphide body. This is approximately the same abundance as was found in the drill core cutting the sulphide body (0.71% Pb for 134 feet, of which the upper 72 feet averaged 1.18% Pb; Northern Miner, August 15, 1974). Lead is present in the soils as the sulphates, anglesite and plumbojarosite (Cameron and Durham, 1974a).

In the case of Cu the same general pattern of dispersion resembles that for Pb (Fig. 2). There is, however, one striking difference from the Pb data. The soils from the central portion of the study area, above the sulphide body, are only weakly enhanced in Cu compared to background values (although the 134 feet of core noted above averages 1.09% Cu). The highest Cu values were obtained from the stream bed draining the area.

This distribution reflects the greater mobility of Cu. In the central, less well drained portion, underlain by sulphides and hydrothermally altered rock, soils and surface waters are rather acidic. Values for pH in the range 3 to 4 are most common. In the surrounding, better drained terrain the pH is greater, in the range 5 to 6. Cu has been largely removed from the central, more acidic, area to be dispersed in drainage waters. Outside this central area a greater proportion of the Cu derived from the rocks or transported overburden has been retained in the soils.

Table 1.

Solubilities of heavy metal sulphates

Sulphate	Solubility in g/100 ml
$ZnSO_4$	86.5 at 80°C
$ZnSO_4 \cdot 7H_2O$	96.5 at 20°C
$ZnSO_4 \cdot 6H_2O$	117.5 at 40°C
$CuSO_4$	14.3 at 0°C
$CuSO_4$	75.4 at 100°C
$CuSO_4 \cdot 5H_2O$	31.6 at 0°C
Ag_2SO_4	0.57 at 0°C
$AgSO_4$	1.41 at 100°C
$PbSO_4$	0.004 at 25°C

Since all three processes of surficial transport for Cu and Pb tend to disperse these elements across the hydrothermally altered zone, it is difficult to tell whether this zone is also enriched in base metals. In the opposite direction Pb and Cu values in soils overlying the hanging-wall are quite low.

For the other two elements determined, Ag mimics the distribution of Pb. Both are relatively immobile. Zn, on the other hand, shows the same trends as Cu, but more pronounced. As the most mobile element of the four, Zn shows an even greater depletion over the central area.

The soil anomaly in the area of the prospect is very extensive, as a result of glacial transport and hydromorphic dispersion. In a similar environment soils collected at a wider interval would give almost as much information as was obtained from this 30 m x 15 m grid. The distribution of base metals in the soils is largely determined by the individual chemical properties of these elements.

The writers wish to thank Mr. S.B. Ballantyne and Mr. J. Thomas for assistance in sampling; Mr. R. Horton, Miss E. Ruzgaitis and Miss S. Costaschuk for field analyses; Dr. R.G. Garrett for preparation of the cumulative frequency diagrams; and Mr. Denis Lefebvre for laying out the survey grid.

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HYDROGEOCHEMICAL STUDIES IN THE AGRICOLA LAKE AREA, 1974

E. M. Cameron and J. J. Lynch
Resource Geophysics and Geochemistry Division

In the 1973 field season extensive base metal anomalies were identified in the drainage systems of this area (Cameron and Durham, 1974a, 1974b). These anomalies have their origin in massive sulphide type mineralization in the volcanics of the area. It was apparent from these data that the most mobile elements (e. g. Zn) travelled several miles in the drainage system before being precipitated in lake sediments. The

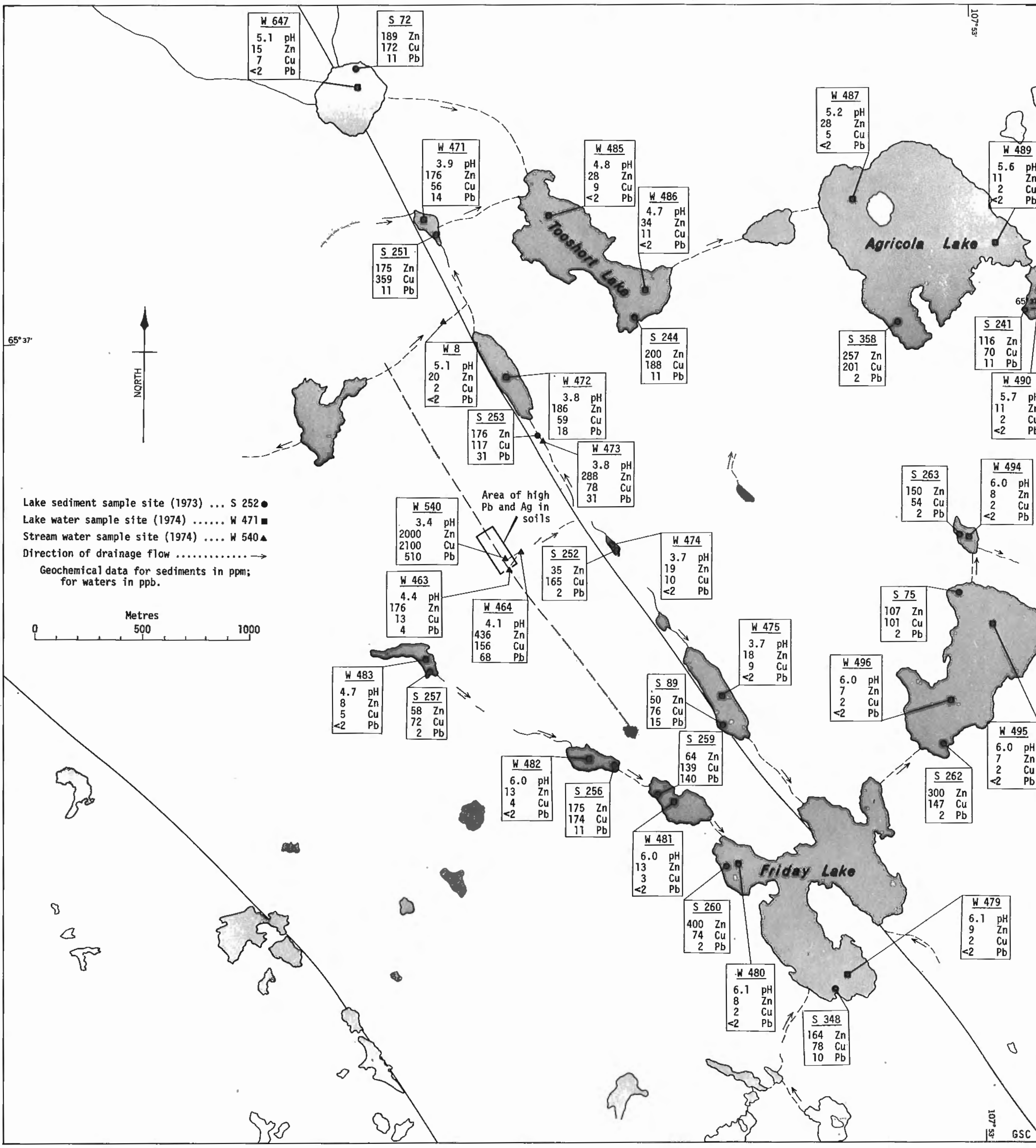

Figure 1. Selected analyses for Zn, Cu and Pb in lake waters and lake sediments, Agricola Lake area, N.W.T.

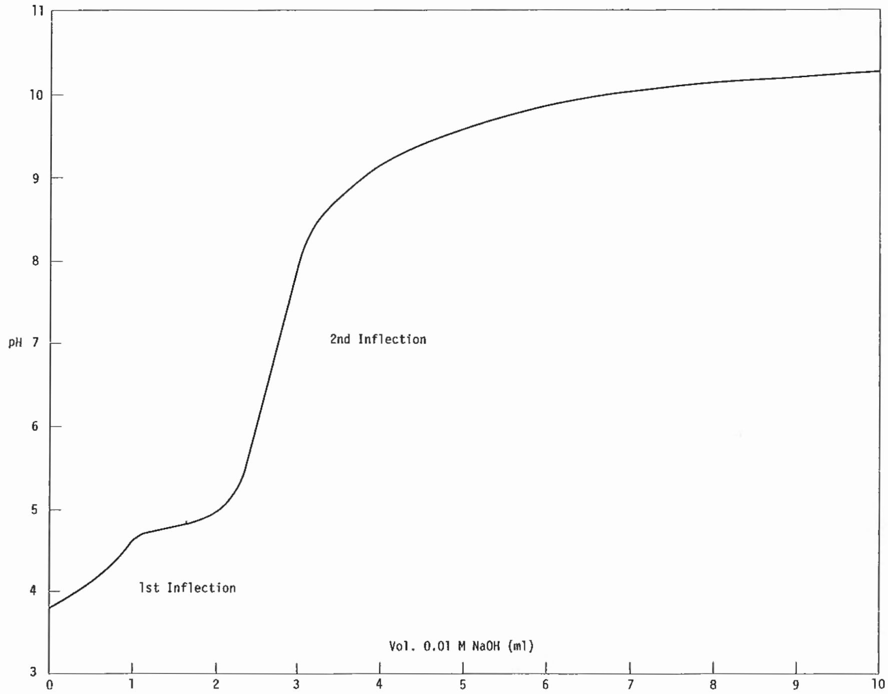

Figure 2.

Titration curve for sample 9 (50 ml sample).

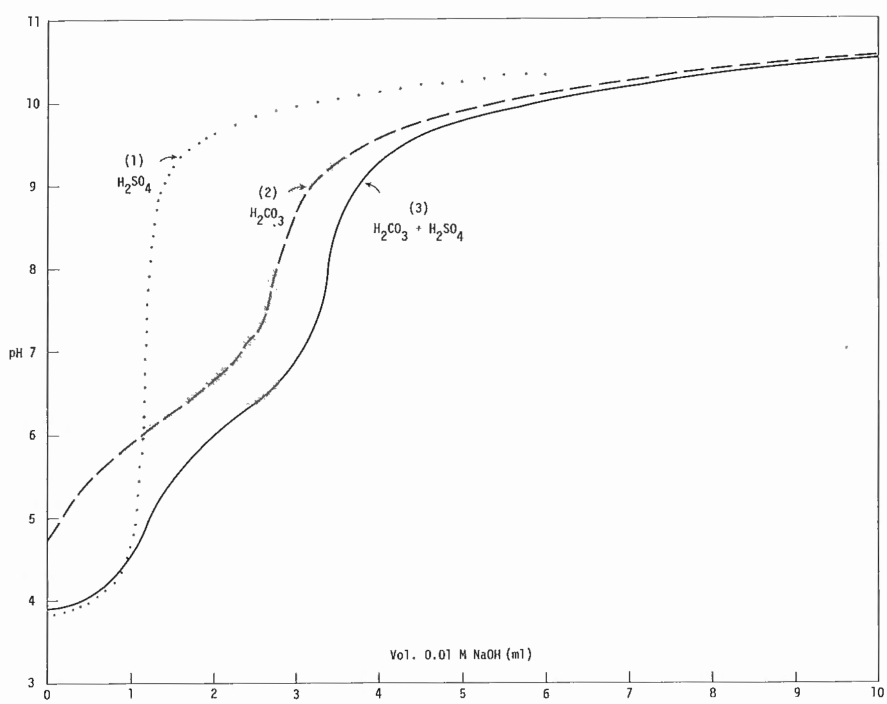

Figure 3.

Titration curves for (1) H_2SO_4, (2) H_2CO_3, (3) mixture of H_2SO_4 and H_2CO_3.

primary object of the 1974 hydrogeochemical studies was to more fully explain these processes of secondary dispersion. However, the results of the work, based on field analyses, were so favourable that the program was enlarged to consider the use of hydrogeochemical methods as a primary exploration method.

Boyle *et al.* (1971) have provided an excellent summary of the application of hydrogeochemical methods of exploration in the Canadian Shield. These methods have been infrequently used for a variety of reasons which they discuss. The features of the Shield that have discouraged such use include the relatively impermeable nature of Shield rocks, the low topographic relief, and the various effects of glaciation. In areas of permafrost, such as at Agricola Lake, the disadvantages may appear to be even more serious. Groundwater circulation and the oxidation of sulphides would, at first sight, appear to be severely restricted in this environment. Present-day oxidation is, of course, essential to any scheme of hydrogeochemical prospecting. Many geologists and geochemists have assumed that present-day oxidation is largely lacking in northern Canada and other permafrost areas. However, Boyle *et al.* (1971) have listed a number of examples of oxidized sulphide bodies in the Shield. While they suggest that this may be largely of Tertiary age, they feel that oxidation has continued in many places to the present. The most extensive work on this problem has been carried out in the Soviet Union. Here modern oxidation of sulphide bodies in permafrost areas has been demonstrated (Shvartsev and Lukin, 1965). Also, the migration of solutions along thin films of water at mineral/ice or ice/air interfaces has been demonstrated (Tyutynova, 1960, 1961). This work has been briefly reviewed by Cameron (1974).

Water samples were collected in 500 ml plastic bottles. They were analyzed in the field within two or three days of collection by procedures described elsewhere (*see* Horton and Lynch, this section). All samples were analyzed for Zn and Cu and some also for Pb. Almost without exception the samples were clear and colourless. They were not filtered prior to analyses. Several hundred samples were returned to Ottawa and analyzed for a more extensive suite of elements approximately two months after collection. No acid or other preservative was added prior to shipping. Contrary to the experience of other workers, there was no decrease in the Zn and Cu content of the waters as a result of this storage. This applied to waters of neutral as well as of acidic pH and of varying trace element composition. However, some samples gave higher Zn and Cu values by later laboratory analyses, compared to the field determinations. This is provisionally explained on the basis of the Zn and Cu of these waters being organically bonded. Organically bonded metals may extract less rapidly into M.I.B.K. when chelated with APDC than these metals in the ionic form. Field extractions were performed by hand shaking; in Ottawa shaking was done by mechanical means for a longer period of time. These various comparative data will be given in a later report.

In Figure 1 a selection of the water data are given for the Agricola Lake area. Sediment, soil and water analyses for the same area are shown in Cameron and Durham (1974b, Fig. 2). By far the highest concentrations of Zn, Cu and Pb are found in ponds, streams, and springs near the massive sulphide prospect (identified as the area of high soil Pb and Ag in Fig. 1). Several water samples were collected near the prospect with pH values in the 3.2 - 4.0 range and with Zn and/or Cu values near 1000 ppb and Pb values near 500 ppb. Samples collected before and after the start of drilling operations showed no marked differences in base metal content.

Downstream these waters are diluted as they mix with waters of lower trace element content. However, they remain noticeably anomalous as far as Agricola Lake. Approximately $1\frac{1}{2}$ miles to the east of Agricola Lake this drainage system enters a large unnamed lake. Here the mean value of three water samples was 3 ppb Zn, 2 ppb Cu and 2 ppb Pb. These may be considered as background values. It is of interest that in the Agricola Lake drainage system the most anomalous lake sediment samples for zinc are from Agricola Lake itself, several miles from the principal source of this metal. By contrast, the content of Zn in the waters of this lake is rather low, as a result of dilution and precipitation. These features will be discussed in detail in a later report, but the significance to geochemical reconnaissance of this observation should be noted. If anomalous levels of indicator elements can be detected at a greater distance from the source for lake sediments than for waters, then the former can be sampled at wider intervals.

The downstream dispersion of Zn, Cu and Pb in this drainage chain may be examined in more detail by reference to Table 1. Near the massive sulphide prospect there are a number of waters of varied metal ratios, reflecting perhaps metal zoning within the sulphide body and variable leaching conditions. Two such waters are samples 540 and 463. After mixing of these and other waters (sample 464) they travel mainly underground (at lease in summer) northeastwards to the main northwest-trending valley. Here they are mixed with waters of low pH and low trace element content (sample 474, Fig. 1). These valley waters may owe their low pH to the oxidation of the pyritic, carbonaceous slates underlying the valley. The changes in Zn/Pb and Cu/Pb between samples 464 and 471 indicate that Pb is fairly rapidly precipitated. The Zn/Cu ratio does not change substantially from samples 464 until Agricola Lake is reached. Zn is clearly the more mobile of the elements.

Table 1

Metal Ratios and pH values for selected waters from the Agricola Lake drainage chain

Sample	Zn/Cu	Zn/Pb	Cu/Pb	pH
540	0.95	3.9	4.1	3.4
463	13.5	19.0	3.2	4.4
464	2.8	6.4	2.3	4.1
473	3.7	9.3	2.5	3.8
472	3.2	10.3	3.3	3.8
471	3.1	12.6	4.0	3.9
485	3.1	>14	>4.5	4.8
486	3.1	>17	>5.5	4.7
487	5.6	>14	>2.5	5.2
489	5.5	-	-	5.6
490	5.5	-	-	5.7

The Friday Lake drainage chain (Fig. 1) presents an entirely different picture. These waters have only weakly anomalous levels of Zn and Cu and no detectable Pb. By contrast, many of the lake sediments of this drainage are noticeably anomalous with respect to

Table 2

Major and Trace Constituents of selected waters, Agricola Lake area

Sample (1)	2	9	6	14	19	M-52
Na, ppm	1.56	1.00	0.52	0.68	0.46	1.4
K, ppm	0.94	0.58	0.68	0.32	0.18	0.7
Mg, ppm	2.38	1.42	0.90	1.26	0.30	1.3
Ca, ppm	5.58	2.50	1.72	1.00	1.44	4.6
Fe, ppb	875	74	<10	80	58	10
Mn, ppb	92	76	25	41	< 5	< 1
Zn, ppb	1080	179	43	22	11	2
Cu, ppb	867	39	8	10	2	< 1
Pb, ppb	341	15	2	< 2	< 2	-
Cl, ppm	0.6	0.3	0.6	0.3	0.4	1.2
SO_4, ppm	76.7	40.6	13.6	41.5	7.3	2.4
Mineral Acidity as ppm $CaCO_3$	22.8	8.5	0.9	16.1	n.d.	-
Total Acidity as ppm $CaCO_3$	48.6	26.5	4.3	33.1	n.d.	-
pH	3.2	3.5	4.1	3.5	5.3	7.2
Conductivity as μ mhos/cm	230	112	31	155	15	<55

(1) Sample Locations: Sample 2 near 540 (Fig. 1); 9 near 472; 6 near 485; 14 near 474; 19 near 480; M-52, Yellowknife River, Reeder *et al.*, 1972.

n.d. = not determined

regional background (for background values *see* Cameron and Durham, 1974b). Our observations have revealed no large, actively oxidizing, base metal sulphide bodies along this chain, hence the low trace element content of the waters. In view of this, the anomalous nature of many of the sediments requires some explanation. Whatever the cause, it provides further evidence that anomalous base metal values are more widely distributed in the lake sediments of mineralized areas than in the waters.

For some other samples from the area the major constituents have been determined (Table 2). The waters shown in Table 2 are relatively pure. Only sulphate is notably abundant. In comparison with the sample from the Yellowknife River (also in the Slave Province), the samples are variably enriched in sulphate, base metals, Fe and Mn. Also these waters are markedly more acidic. It is the excess H ion that enhances the conductivity of the waters from the Agricola Lake drainage chain. The high sulphate, representing free sulphuric acid, is related to the oxidizing sulphides in the area. The source is sulphides enriched in base metals in the case of sample 2 and base metal-poor sulphides in the case of Sample 14. The low salt content of the waters allows the wide dispersion of H_2SO_4 before neutralization. This, in turn, facilitates the dispersion of base metals. The weak solutions of sulphuric acid associated with the massive sulphide body is a potent agent for the leaching of sulphides.

Samples 2, 9, 6 and 14 were titrated with 0.01 M NaOH. These samples showed a pronounced inflection in the titration curve between pH 4 and 5 caused by free sulphuric acid (Fig. 2). A second inflection, believed to be caused by weak acid(s) occurs between pH 7 and 8. Artificial mixtures of sulphuric and carbonic acids gave titration curves similar to Fig. 2 (Fig. 3). In order to determine whether the second (weak acid) was carbonic acid, samples were aerated with CO_2-free air and titrated. Aeration removes any free carbonic acid. In all cases, the aerated sample titration curves were slightly displaced to the left. However, the general shape of the second inflection was not changed, thus indicating the continued presence of a non-volatile weak acid or hydrolysis (e.g. Al).

To summarize the above data, the most significant finding is that the massive sulphide body and other sulphides in this area are undergoing active oxidation at the present day. Oxidation of the sulphides produces groundwater that is a weak solution of sulphuric acid which further leaches the body. The sulphuric acid solution is not quickly neutralized in the drainage system. This has obviously facilitated the wide dispersion of base metals, particularly Zn, in the drainage waters. Anomalous levels of base metals appear to be more broadly dispersed in lake sediments than in waters, with consequent advantages to their utilization in geochemical reconnaissance.

These favourable results for lake waters plus their ease of sampling and analysis suggested that they might be a very useful medium for semi-reconnaissance and detailed exploration in the northern Shield. To test this further, a 750-square-mile area around Agricola Lake was sampled at an approximate density of 1 sample per 3 square miles. An area of approximately 900 square miles was similarly sampled at High Lake, N.W.T. Most lakes in the Hackett River camp that contains a number of massive sulphide bodies were sampled. These data will be published in detail in a later report. The pH of waters from the latter two areas are approximately neutral, in contrast to the acidic waters of the Agricola Lake area. This undoubtedly reflects the abundance of exhalative-type limestones at High Lake and at Hackett River. Lead could not be detected at all in these neutral waters and it is possible that the mobility of Cu is reduced. Highly anomalous values for Zn were, however, found in lake waters from both areas near known massive sulphide mineralization. This very mobile element may be very useful for hydrogeochemical surveys in the northern Shield.

Mr. Bruce Ballantyne was responsible for most of the water sampling; both he and Mr. Robert Benson completed the High Lake regional sampling in the remarkably short time of 2 days. The skill and enthusiasm of our helicopter pilot, Mr. Bob Watson, contributed greatly to the efficiency of the water sampling. Mr. Ronald Horton, Miss Elizabeth Ruzgaitis and Miss Sue Costaschuk analyzed the water samples in the field, and Mr. Gilles Gauthier and Mr. W. Nelson carried out most of the determinations in Ottawa. We are most grateful to all these persons for their hard work and enthusiasm.

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SURFACE LAKE WATER URANIUM-RADON SURVEY OF THE LINEAMENT LAKE AREA, DISTRICT OF MACKENZIE

Project 720067

W. Dyck and E. M. Cameron
Resource Geophysics and Geochemistry Division

Using the facilities and helicopter support of the field camp at Friday Lake (lat. 65°36'N, long. 107°55'W) (*see* Cameron, this section), a uranium-radon survey of surface lake waters of the Lineament Lake area was carried out. The survey was prompted by the lake sediment uranium anomaly discovered during the geochemical reconnaissance in 1972 (Allan and Cameron, 1973). The anomaly is situated about 60 miles south-southeast from Friday Lake at lat. 64°50'N, long. 107°00'W.

The area is covered by massive granitic rocks composed mainly of biotite granite and quartz monzonite of Archean age (Wright, 1967).

Follow-up work in the form of ground scintillometry and rock collection in 1973 (Cameron and Durham,

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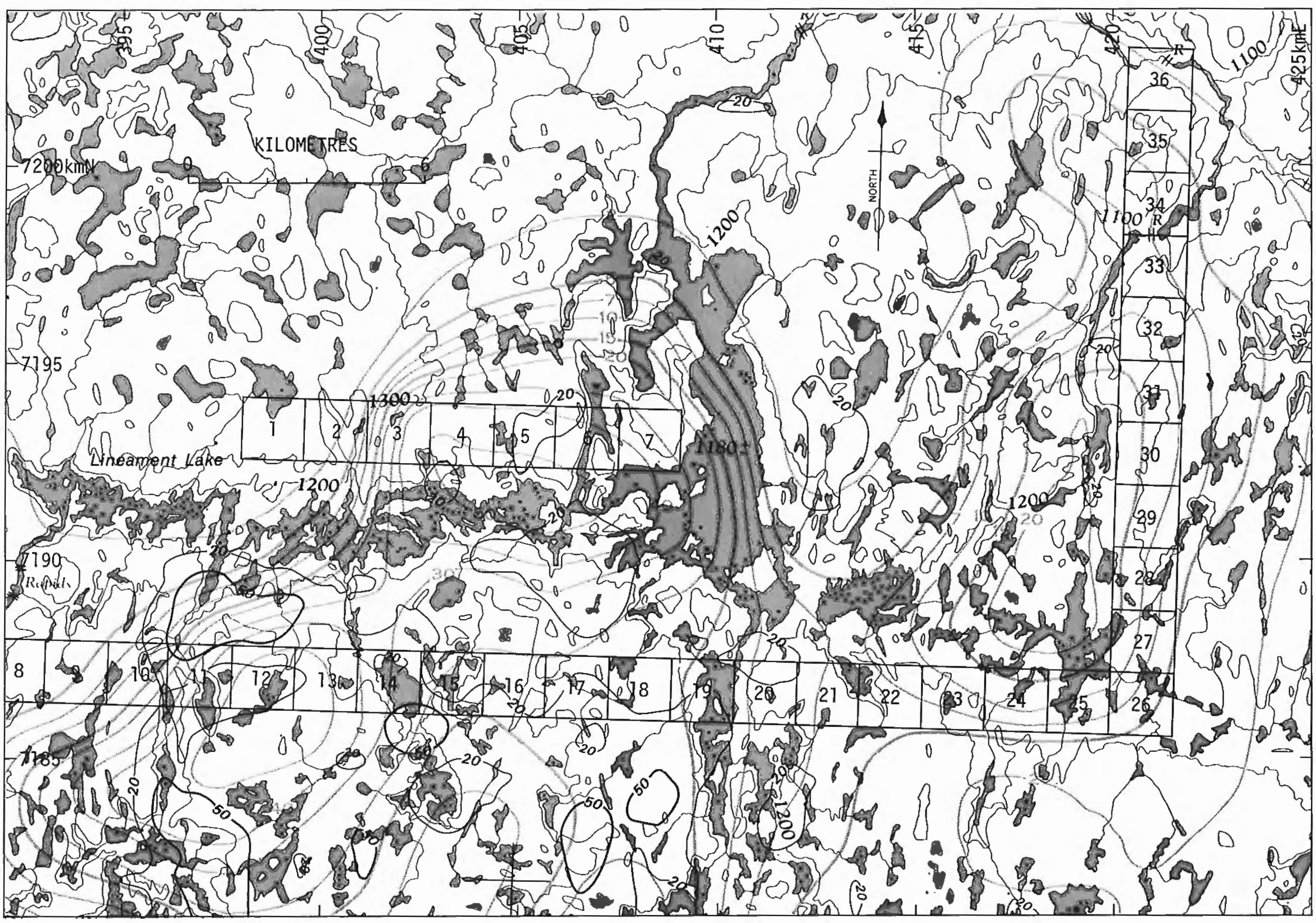


AIRBORNE GAMMA RAY SPECTROMETER COUNTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
346	389	387	383	453	474	465	488	511	484	520	570	516	512	473	637	552	527
38	49	43	64	48	60	50	46	36	59	74	85	97	75	73	73	58	49
75	72	43	52	80	105	174	120	134	120	137	173	246	274	193	182	163	186

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
712	643	666	665	676	578	408	410	541	447	378	365	435	401	342	382	544	454
49	21	38	24	21	15	28	24	50	39	8	33	30	41	15	51	58	51
127	136	115	114	165	113	53	58	77	80	47	35	32	71	18	72	145	114

Geometric mean + 3S/2 = 50pC/l 50
Geometric mean + S/2 = 20pC/l 20
Uranium in ppm in lake sediments (Map 9-1972 (Sheet 3)) ... 5
Study area ....

Figure 1. Radon in surface lake waters, Lineament Lake geochemical survey, 1974.

1974) confirmed the enrichment of uranium in the rocks in the anomalous area relative to rocks of Archean age outside the anomaly but revealed no uranium-rich minerals in the rocks.

The 1974 follow-up work consisted of (1) surface lake water sampling of about two thirds of the lake sediment anomaly, (2) airborne gamma-ray spectrometry and ground gamma-ray scintillometry of selected portions, and (3) rock collection from sites that gave highest radon and scintillometer readings.

A total of 307 lake water samples were collected, 257 samples for an initial semi-detailed coverage of the anomaly at a sampling density of 1 sample per 2.6 km^2 (1 sample per sq. mile) and 50 samples for more detailed follow-up in the most promising area as outlined by the radon content of the water samples from the semi-detailed survey. The samples were collected in 260 ml glass bottles at inflow or outflow bays of lakes within 5 m to 10 m from shore. Depth, temperature and conductivity of the water was measured at each site. Radon and pH was determined at the field camp using portable instruments. Uranium determinations were carried out in the Geochemical Laboratories of the Geological Survey of Canada, Ottawa (Smith and Lynch, 1969).

The radon and uranium results of the semi-detailed lake water survey are shown in Figures 1 and 2. The 1972 reconnaissance lake sediment uranium survey results are also shown in these figures. The coincidence of radon in water, uranium in water and uranium in sediments is quite striking but the semi-detailed results focus more sharply in an area just south of Lineament Lake. The slight displacement of the uranium in the sediments towards the north is probably due to its relatively greater mobility compared to radium (the immediate parent of radon) in the surface environment and the general direction of flow of the water system.

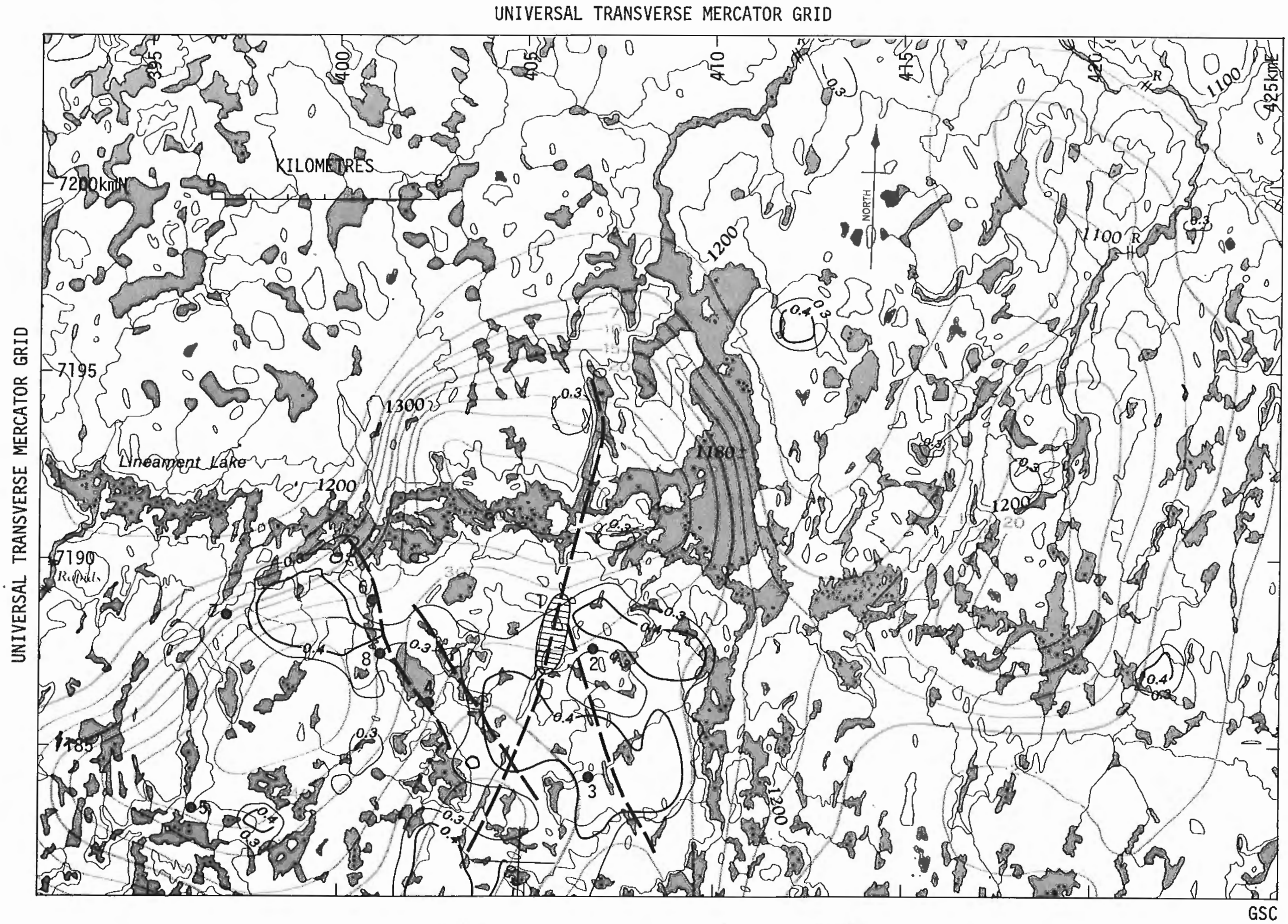
The highest radon and uranium values encountered were 366 pc/1 and 1.9 ppb with background levels (geometric means) of 7 pc/1 and 0.2 ppb, respectively. By comparison the Beaverlodge lake water survey in 1969 gave highs of 60 pc/1 and 2.7 ppb, and backgrounds of 1 pc/1 and 0.4 ppb respectively (Dyck *et al.*, 1971). Obviously environmental factors such as nature of rock, organic matter, size and depth of lakes, temperature variations etc. affect the mobility of these two elements. Hence an area comparison must take these into account. The lake waters in the area are exceptionally pure. This conclusion is based on the low average conductivity of 8 micromhos compared to 112 for Ottawa tap water and the pH measurements which were erratic and difficult to reproduce indicating poor buffering by ionic species. The negative correlation of lake area, depth, and temperatures with radon observed elsewhere in the Shield (Dyck, 1974) was barely significant in the Lineament Lake area probably as a result of general shallowness of lakes and permafrost in the ground. Incidentally, the mean lake area listed in Table 1 refers to an effective area taking into account the maximum range of approximately 1 km for radium and radon in the surficial environment.

To follow up in more detail on the radon highs, 50

TABLE I

GEOMETRIC MEANS, STANDARD DEVIATIONS, AND RANGES OF VARIABLES OF SAMPLES FROM LINEAMENT LAKE, N.W.T.

VARIABLES	SEMI-DETAILED SURVEY				DETAILED SURVEY			
	No. of Analyses	Mean	Log 10 Stand.Dev.	Range	No. of Samples	Mean	Log 10 Stand.Dev.	Range
Rn pc/l	257	7.0	0.585	0.2 - 165.0	50	37.6	0.480	0.2 - 366.0
U, ppb	256	0.2	0.235	0.0 - 1.0	50	0.3	0.336	0.0 - 1.9
pH	257	7.6	0.028	6.9 - 8.8	50	7.4	0.015	7.1 - 8.0
Temp, °C	257	13.8	0.035	11 - 16	50	15.2	0.043	11 - 16
Conductivity μ mhos	257	8.1	0.221	3.0 - 13.0	50	6.8	0.082	4.0 - 9.0
Depth, m	257	1.0	0.302	0.1 - 7.0	50	1.2	0.199	0.5 - 3.6
Area, km^2	257	9,2	0.642	0.01- 4.0	50	0.1	0.784	0.01- 2.50



GROUND SCINTILLOMETRY STATIONS AND READINGS
(granite - GRNT, pegmatitic - PGMT, general background - BKG)

1	2	3	4	5	6	7	8
GRNT 10-50 μR	GRNT 10-30 μR	GRNT 15-35 μR	GRNT 15-30 μR	GRNT 10-20 μR	GRNT 10-15 μR	GRNT 10-15 μR	GRNT 15-25 μR
PGMT 10-12 μR	PGMT 10-12 μR	PGMT 10-25 μR	PGMT 10-25 μR	PGMT 10 μR	BKG 10-12 μR	BKG 10-12 μR	BKG 5-20 μR
BKG 10 μR	BKG 10 μR	BKG 12-15 μR	BKG 12-15 μR	BKG 12-15 μR			

Geometric mean + 3S/2 = 0.4 ppb 0.4

Geometric mean + S = 0.3 ppb 0.3

Uranium in ppm in lake sediments (Map 9-1972 (Sheet 3)) ... 5

Detailed water sample site locations ....

Ground stations.......................

Figure 2. Uranium in surface lake waters, Lineament Lake geochemical survey, 1974.

lake water samples from trenches or faults in the anomalous zone were collected and analyzed. The location of these trenches is shown by the dashed lines in Figure 2. As the means in Table 1 indicate several samples contained more Rn and U than did the semidetailed samples but no values were high enough to suggest ore nearby.

The numbered squares in Figure 1 are the locations over which integral airborne gamma-ray spectrometry was carried out with the aid of a helicopter and a spectrometer system with a 15 cm by 10 cm crystal leased from Exploranium Corporation of Canada. The counts listed under Figure 1 are the net average of two one minute counts in the K, U and Th channels accumulated while flying in a circle inside a 1.6 km square at an elevation of 91 m, avoiding water as much as possible. Background counts were obtained over the largest part of Lineament Lake near the centre of the map-area.

The U and K counts were corrected for Compton Scattering using the following equations (Grasty and Darnley, 1971):

$$U_c = U_u - \alpha . Th$$

$$K_c = K_u - \beta . Th - \gamma . U_c$$

where the subscripts c and u are corrected and uncorrected respectively and $\alpha = 0.43$, $\beta = 0.62$, and $\gamma = 0.91$ for the 6-inch by 4-inch crystal used.

The counts indicate a rise in K, U and Th in the same area as the water Rn and U highs but fail to support ore grade concentrations of U in the surface rocks. Of interest may be the U/Th ratio counts. These are generally lower where the higher net counts occur. However, quantitative determinations of these ratios are required to confirm these field observations before conclusions may be drawn from them.

Groundstation scintillometry was carried out at 8 stations near sites of high R_n in water. These stations are shown in Figure 2 and the total gamma-ray counts of granites, pegmatites and general backgrounds listed in the legend. Total counts for granites ranged from 10 μR/hr to 50 μR/hr and for pegmatites from 10 μR/hr to 25 μR/hr. Background readings with the scintillometer slung over the shoulder were generally around 10 μR but values of 5 and 25 also were encountered. But as with the other tests, no counts were recorded high enough to suggest U mineralization. It should be noted that the pegmatitic rocks in any one area were always lower in total count activity than the adjacent granitic rocks and pegmatites with large mica flakes were more radioactive than those lacking in mica.

From the tests carried out this summer in the Lineament Lake area, one could conclude that the lake sediment U anomaly has resulted from the weathering of granites with above average U content. However, much more work and more detailed work is required to arrive at any firm conclusions on the uranium potential of the area.

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60. BEECHEY LAKE AREA: *IN* SEDIMENTOLOGICAL STUDIES OF THE YELLOWKNIFE SUPERGROUP IN THE SLAVE STRUCTURAL PROVINCE

Project 740018

John B. Henderson
Regional and Economic Geology Division

(*see* report 88 of this publication)

61.

A GEOCHEMICAL FIELD LABORATORY FOR THE DETERMINATION OF SOME TRACE ELEMENTS IN SOIL AND WATER SAMPLES

Project 580175

R. Horton and J.J. Lynch
Resource Geophysics and Geochemistry Division

From July 1 to August 2, 1974, a geochemical field laboratory was in operation at Friday Lake, N.W.T. The laboratory was set up to provide trace element analyses of soil and water samples for a field party headed by Dr. E.M. Cameron of the Geochemistry Section. Since the field area was a considerable distance from the nearest community, Yellowknife (483 km) it was essential that the laboratory operate at the base camp of the field party.

The fact that extremely low levels of Zn and Cu in water samples as well as low levels of Ag in soil samples were required to be determined, made it necessary to utilize atomic absorption spectroscopy as the main analytical tool rather than some of the simpler colorimetric methods used in previous field parties (e.g., Allan *et al.*, 1971).

The remoteness of the area where the laboratory was situated ruled out any technical assistance from service personnel; hence all pieces of equipment which could conceivably break down were duplicated, i.e. two atomic absorption spectrophotometers, two generators, two air compressors, etc. were shipped to the base camp.

All possible preparatory work was done in Ottawa. Standard solutions, buffer solutions and dilute acids were all prepared and purified (where necessary) at the Geological Survey laboratories. Analysts were trained in Ottawa and did test runs on analytical procedures to be used in the field. When all preparations were completed, the laboratory equipment was moved to Yellowknife and then flown from there by a Twin Otter to Friday Lake.

Two longhouse tents (12 by 14 feet each) were used to house the analytical laboratories. A third tent (10 by 12 feet) was used for sample drying and sieving. One longhouse tent contained the two atomic absorption spectrophotometers, balances and some office space. The other longhouse tent contained the apparatus for the hot acid decomposition of soils, separatory funnels for preconcentration of water samples, a water reservoir, demineralizers and a small stainless steel sink for the washing of glassware.

Utilizing both laboratory and field staff (total of seven) for two days the tents were put up, the major pieces of equipment were installed and made operational.

Electrical power was supplied by two 3000 watt generators equipped with gasoline engines. The power to the two atomic absorption spectrophotometers stabilized with a 500 watt voltage regulator. One generator was devoted entirely to running the air compressor.

A small electric pump was used to bring water from the lake to a 15 gallon storage vessel which in turn provided raw water for the sink and the demineralizing column by means of a siphon system.

The atomic absorption equipment consisted of two Perkin Elmer instruments, a model 300 and a model 303. The flue gases from these two instruments were vented through 4" aluminum drier ducting which lead to the outside of the tent. Draught was provided by two small electric squirrel cage fans.

The soil samples, in paper bags, were dried on a rack suspended above three catalytic heaters. When dried, approximately 100 grams were sized to -80 mesh using stainless steel sieves. The sieved sample was then stored in a plastic vial. The oversize fraction was discarded.

A 0.50 gram sample of the soil was weighted on a torsion balance and transferred to a 18 by 150 mm test tube. A 3 ml aliquot of an acid leach solution (4M HNO_3-1M HCl) was added and the sample heated in a hot water bath (aluminum roasting pan on a portable propane stove) for 2 hours in batches which usually

Table 1

Atomic Absorption Instrumental Parameters

Element	Lamp Current (mA)	Burner Length	Fuel	Oxidant	Wavelength (nm)	Slit-width (nm)
Zn	15 (a)	10 cm single slot (c)	C_2H_2 (d)	Air	213.8	0.7
Cu	15 (a)	10 cm single slot	C_2H_2 (d)	Air	324.7	0.7
Pb	8 (b)	10 cm single slot	C_2H_2	Air	283.3	0.7
Ag	12 (a)	10 cm single slot	C_2H_2	Air	328.0	0.7

(a) Perkin-Elmer lamp.
(b) Westinghouse lamp.
(c) Rotated to reduce sensitivity for the determination of Zn in soils.
(d) For the determination of Zn and Cu in water, the C_2H_2 flow was substantially reduced.

consisted of 60 samples. Metal-free water was then added to bring the final volume to 10 ml. The samples were mixed, allowed to settle and analyzed by atomic absorption for Zn, Cu, Pb and Ag. The instrumental parameters are listed in Table 1. Pb and Ag were determined on the model 303 which has a built in deuterium arc background corrector. Since Zn and Cu do not normally require background corrections, these two elements were done on the model 300. This instrument does not have background correction facilities.

The water samples were collected in 500 ml plastic bottles. For the determination of Zn and Cu a 50 ml aliquot was transferred to a 125 ml separatory funnel. The water sample was then buffered to pH 4.8 by the addition of 5 ml of a sodium acetate-acetic acid solution. A 1% solution (2.5 ml) of ammonium pyrrolidine dithiocarbamate (APDC) was then added to chelate Zn and Cu. The chelated metals were then extracted into 6 ml of methylisobutylketone (MIBK) by manually shaking the separatory funnels for a period of 1 minute. The solvent and aqueous layers were allowed to separate for 5-10 minutes; the aqueous layer was then drained and discarded; the solvent layer was transferred to a 16 by 100 mm test tube. The concentrations of Zn and Cu were then determined by spraying the MIBK solution into the burner of the model 300 atomic absorption spectrophotometer.

During the month of July, 4400 determinations were performed on 1400 soil and water samples.

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62. GROUND MAGNETOMETER SURVEY IN THE AGRICOLA LAKE AREA, DISTRICT OF MACKENZIE

Project 720080

L.J. Kornik
Resource Geophysics and Geochemistry Division

A ground magnetometer survey was carried out in August 1974 over the geochemical soil survey grid in the Beechey Lake belt of the N.W.T. (*see* Cameron, this section). This grid was positioned to cover the Agricola Lake massive sulphide prospect, and consists of 21 lines spaced 30 metres apart with sample sites every 15 metres along these lines. The sites were occupied with a McPhar GP-70 proton magnetometer.

The total field magnetometer survey results are presented in Figure 1. The contour interval is 10 gammas where the magnetic gradients are gentle and 100 gammas where the magnetic gradients are steeper. The magnetic field values have a range of 6,000 gammas from a low of approximately 57,000 gammas to a high of approximately 63,000 gammas, although most anomalies have less than a 1,500 gamma amplitude. The 10+00 E and 10+00 N lines are marked on the accompanying diagrams. Line 10+00 N was used as the base line to tie in all the lines for levelling with station 7+90 E/10+00 N used as the base station for correcting for diurnal fluctuations. During the survey a range of 325 gammas was recorded in the total magnetic field at the base station. The individual lines were levelled to the base line and the diurnal removed by repeatedly occupying the base station.

Figure 2 is the same contour map with a 100 gamma shading interval. The shading emphasizes the blocky nature of the magnetic anomalies and outlines some of the structural features of the area. The main sulphide body is not defined magnetically but occurs along the axis of a weak magnetic low along line 10+00 N between lines 8+50 E and 10+90 E. This is consistent with the fact that the mineralization consists of Zn-Cu-Pb sulphides and pyrite and apparently does not contain any significant amount of pyrrhotite.

Structural features are well defined magnetically and are shown in Figure 3. In this figure, magnetic discontinuities are depicted as zig-zag lines. These discontinuities in the magnetic anomalies probably represent faults. The trends of the axis of magnetic highs are shown as thick dotted lines. These magnetic trends probably represent the trends of the lithologic units. Structurally, the geology appears blocky with the lithologic units cut and displaced by faults. The mapped geology (*see* Cameron, this section) in general supports this interpretation although in some areas the interpretations conflict; a particularly striking example occurs in the (grid) southeast quarter of the map. In that area, a geological interpretation of the magnetic contours would favour a 30° change in the strike of the lithologic units as indicated in Figure 3, perhaps by fault block rotation. Also the area mapped geologically as shale should probably have a longer strike length on both sides of its mapped position if the area of lower magnetic relief on the magnetic map is related to this shale unit. An unmapped geological feature must also occur along line 10+00 E between 8+50 N and 9+70 N to produce the magnetic anomalies which are evident along this line.

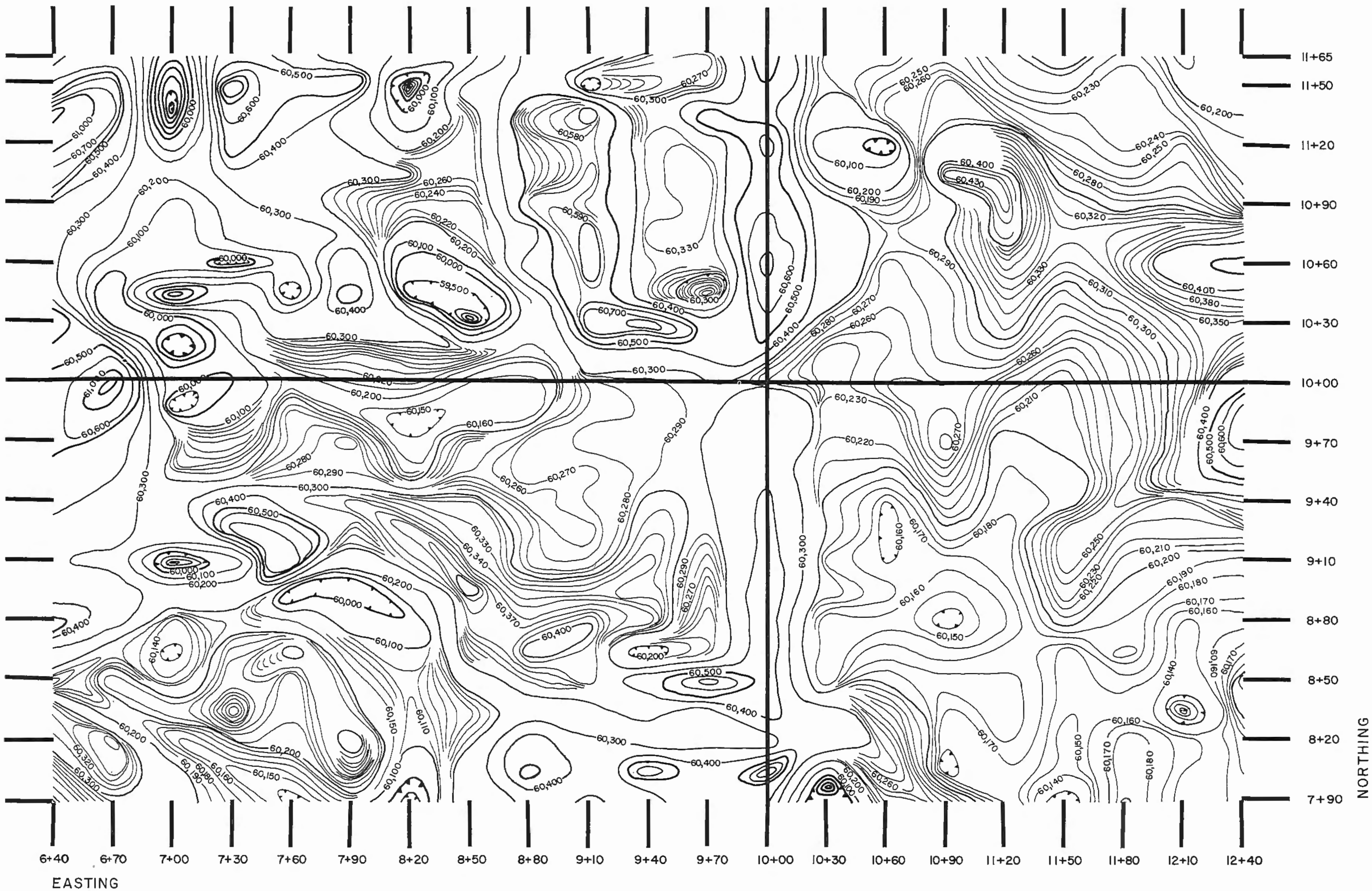

Figure 1. Total field map from ground magnetic survey, Agricola Lake massive sulphide prospect, N.W.T. Contour interval 10 gammas.

L. J. Kornik

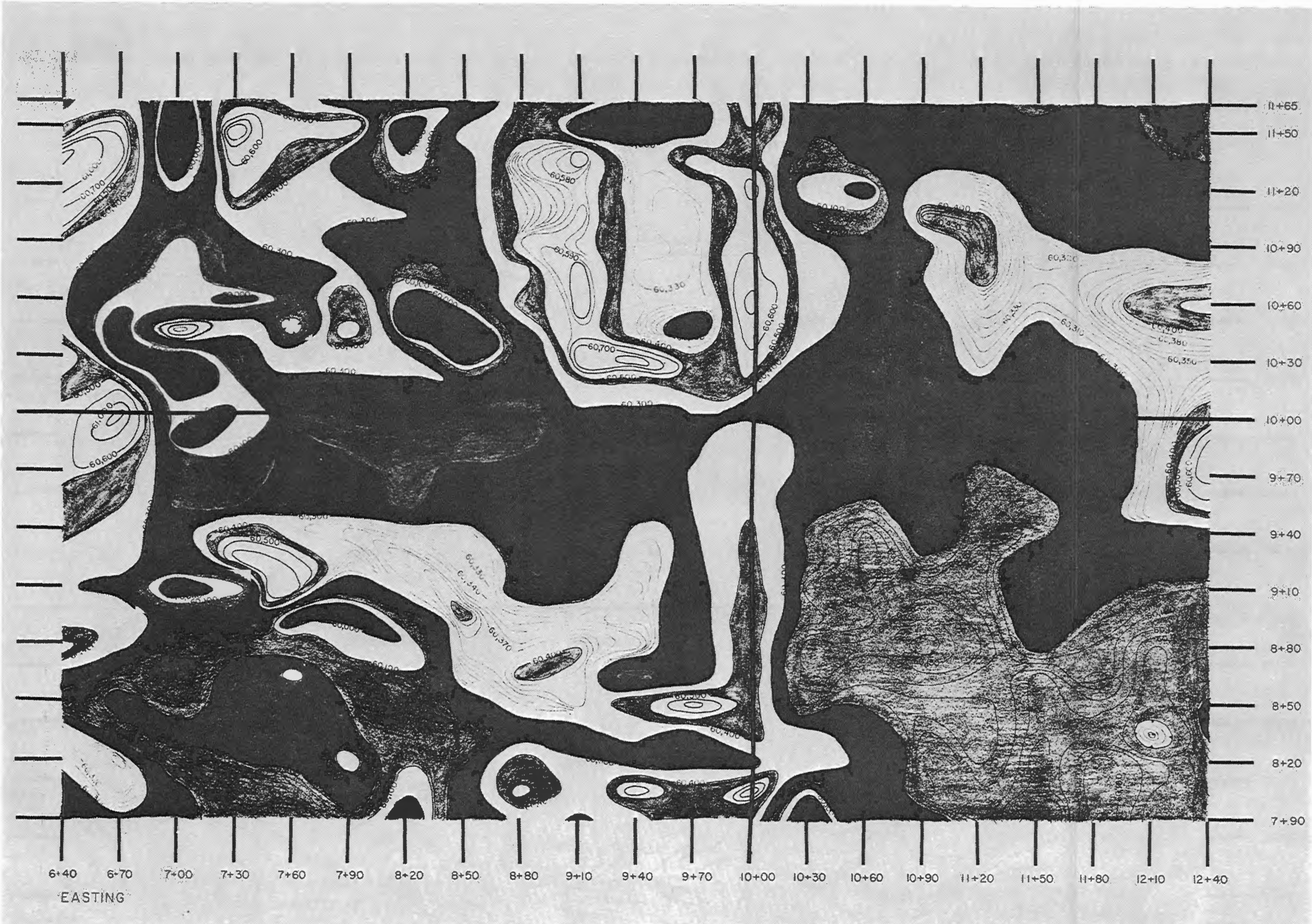

Figure 2. Total field map from ground magnetic survey, Agricola Lake massive sulphide prospect, N.W.T. Contour interval 100 gammas.
L. J. Kornik

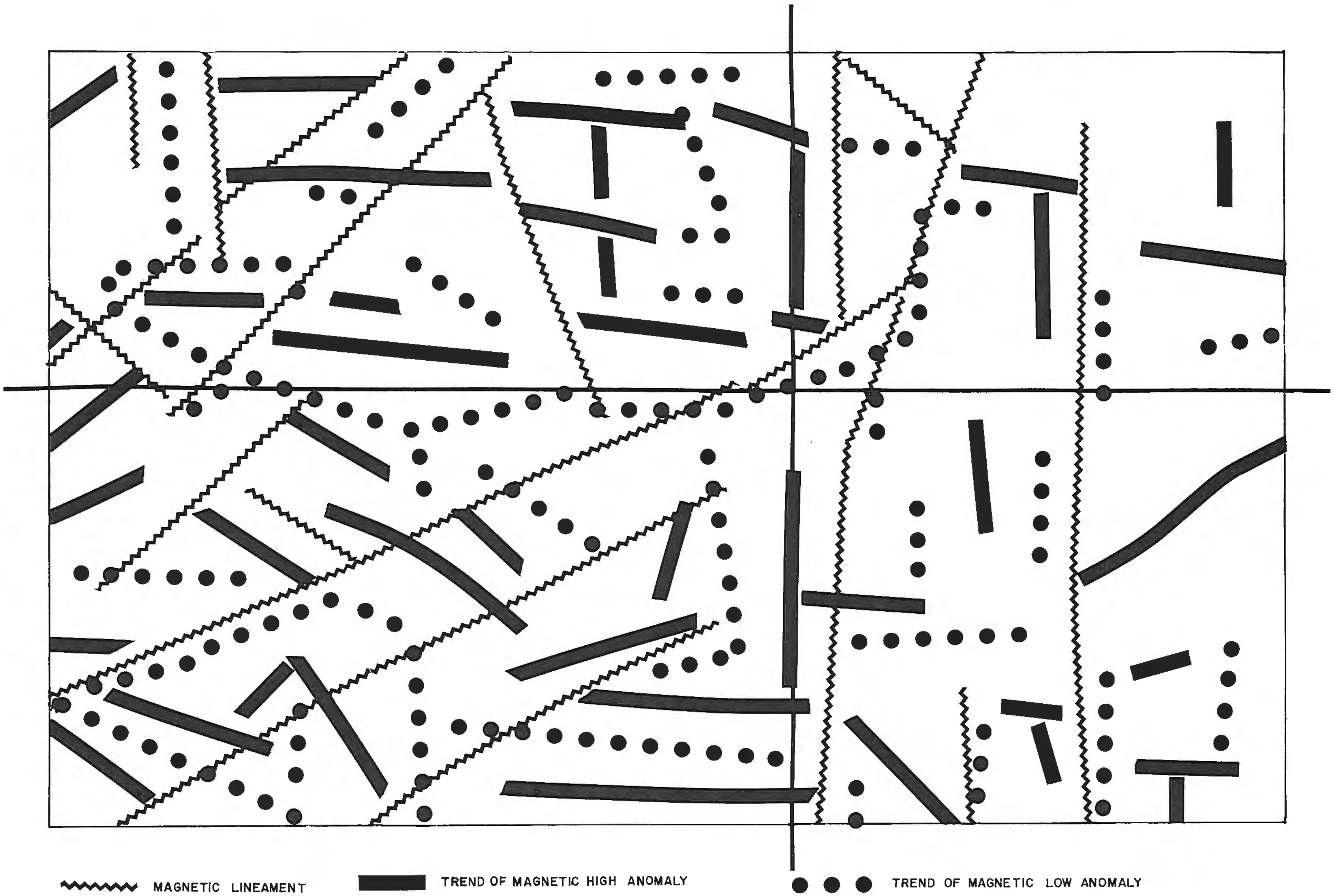

Figure 3. Structural features interpreted from ground magnetic data, Agricola Lake massive sulphide prospect, N.W.T.

L.J. Kornik

GEOLOGY OF THE AGRICOLA LAKE AREA, DISTRICT OF MACKENZIE

T.H. Pearce and Denis Lefebvre
(Queen's University, Kingston, Ontario)

Introduction

During the past years (1972 and 1973), the Geological Survey of Canada conducted an integrated program of geochemical reconnaissance and follow-up in the Bear and Slave Structural Provinces of the Canadian Shield (Allan *et al.*, 1973; Cameron and Durham, 1974; Cameron *et al.*, 1974). This program resulted in the discovery of several geochemical anomalies and especially in the discovery of one anomaly in copper, zinc, arsenic, lead, silver and gold in the Slave Structural Province. This anomaly, the Agricola Lake or "Y" anomaly, is located west of the Beechey Lake in the Northwest Territories, centred on the coordinates 65°36'N and 107°55'W.

The Agricola Lake anomaly is located in a new-found greenstone belt, near the contact of the volcanics and the sediments. This area was previously mapped as a metasedimentary belt (Fraser, 1964; Tremblay, 1971; Wright, 1967) but during the summer of 1973, several volcanic rock occurrences were observed (Cameron *et al.*, 1974).

Due to the lack of geological information on this specific area, mapping was initiated during the summer 1974 by Mr. D. Lefebvre, graduate student, under the supervision of Dr. T.H. Pearce. For this purpose, we benefited from the facilities and the equipment of the Geological Survey field camp. The field season, restricted to seven weeks, began in June and ended in the middle of August. In the field, we profited especially from the advice of Dr. E.M. Cameron (party chief) and C.C. Durham (assistant party chief). The help of Mr. A. Williams (senior assistant) and Mr. J. Spence (junior assistant) was greatly appreciated. Dr. S. Roscoe (Manager, Yava Syndicate) kindly facilitated work in the area.

General Geology

The geology of the Slave Province has been described by McGlynn and Henderson (1970), McGlynn and Fraser (1972) and by McGlynn (1970). The Slave Province underlies 195,000 sq. km of the northwestern part of the Canadian Shield. Mostly Archean in age, the rocks of this province consist also of Aphebian cover to the northwest, the northeast and the southeast. From a visual estimation, 50 per cent of the Archean rocks are sedimentary-volcanic and the rest mostly consist of granite, granodiorite and granitic gneiss. Up to date, around 20 greenstone belts trending north to northeast have been recognized in these Archean rocks and they form the Yellowknife Supergroup.

Commonly, in the Yellowknife Supergroup, a thin sequence of predominantly mafic volcanics, is followed by thick sedimentary series of greywacke and shale. The transition is locally marked by minor amounts of conglomerate, more mature sandstone, limestone and tuffaceous sediments. The volcanics of the Yellowknife Supergroup are generally restricted to the margins of the greenstone belts. Most of the contacts between the granitic rocks and the rocks of the Yellowknife Supergroup appear to be intrusive. However, some evidences of a granitic basement have been observed here and there in the Slave Province and have been described in the literature.

The volcanic rocks of the Yellowknife Supergroup form 5 per cent of the total area of the Slave Province. They mainly consist of mafic lavas with minor proportions of intermediate to acidic lavas and tuffaceous rocks. Sills, dykes and irregular shaped masses of gabbro, diorite and acid porphyry occur in the volcanic rocks and less commonly in the overlying sediments. The thickness of the volcanic piles usually varies between 1 and 3 km.

Among the sediments of the Yellowknife Supergroup, greywacke, mudstone and their metamorphic equivalents are the most abundant rocks. These are usually conformable with the volcanics, their contacts being gradational and consisting of a series of interbedded flows, tuffaceous beds, greywacke and mudstone. The thickness of the sediments average 1 to 5 km or more.

The rocks of the Yellowknife Supergroup have been folded, intruded by granitic bodies and metamorphosed during the Kenorean Orogeny. The metamorphism varies from low greenschist facies to amphibolite facies.

Description of the Work

Before the field season, D. Lefebvre worked at the Geological Survey in Ottawa, doing photo interpretation, literature research and petrographical work on the samples collected by the Dr. E.M. Cameron party during the previous summer.

For the photo interpretation, we used the two following aerial photographs of the Energy, Mines and Resources Department: A16317-102 and A16317-103. These are the usual black and white contacts of the vertical photographs at the scale 1: 6,000. The study area is very well exposed and on the aerial photographs, we could recognize several geological features:

- the general trend (northwest-southeast) of the greenstone belt;
- a relatively thin sequence (2000 m) of volcanic rocks, bedded and slightly folded;
- a thick sequence (over 7000 m) of sedimentary and metasedimentary rocks, more finely bedded but largely folded, located to the northeast of the volcanic rocks;
- granitic rocks, with rough topography and concurrent sets of fractures, located to the southwest of the volcanic rocks;

- folds, which cut the different units perpendicular to the general trend or with a 30-40 degrees angle (west-northwest).

A more detailed study under the stereoscope revealed, among the volcanics, the presence of volcanic tuffs, acid intrusive (locally at the contact of the volcanics and the sediments) and a zone of intense weathering and erosion around the massive sulphide prospect.

These features were checked out in the field and re-examined on the aerial photographs to extend their correlation.

The literature research and the photographical work are not original studies. They were done only to become familiar with the geology of the already known of the greenstone belts in the Slave Province and to be able to recognize more easily the several rock types. The papers of Fraser (1964), Tremblay (1971), Wright (1967), Cameron and Durham (1974) and Cameron *et al.* (1974) were mostly consulted.

In the main area of interest, the mapping was done using a grid of 10 lines, 120 or 240 m apart and 800 m long, set across the general strike of the rock units. Almost all outcrops were visited and each rock type was sampled on each line. The grid was centred on the massive sulphide prospect. The mapping was extended over an area of 6 by 6 km. Twelve traverses, from 300 to 800 m apart, were run in the volcanics and extra traverses were run in the more complex areas. Two short traverses in the granite and two short ones in the sediments were also run to check the uniformity of these rock types. Three intrusions in the sediments but outside the working area were sampled: a granitic plug, a stock of diorite, and a mafic dyke with a diabasic texture.

Geology of the Agricola Lake area

The Agricola Lake area is part of a greenstone belt of the Yellowknife Supergroup, nearly 40 km long and probably the same belt in which the Hackett River deposit (Cominco) has been found. This area is excellent for geological work on the Archean rocks of the Slave Province, the exposure being very good. The rocks are only slightly deformed and metamorphosed. The strike of the volcanics in this part of the belt is northwest-southeast, varying between 145^o and 160^o and the dip is sub-vertical, varying between 85^{o}NE to 85^{o}SW. The thickness of the volcanics is nearly 2 km but the thickness of the sedimentary rocks is much greater. To the northwest and the southeast of the area, the volcanics are more metamorphosed and more folded. It appears that the area surrounding the massive sulphide prospect has been preserved from high metamorphism and deformation, even if the rocks were tilted to the vertical.

Stratigraphy

Due to the subvertical dip of the rock units, a nearly complete stratigraphic section is exposed in the Agricola Lake area. Two kilometres of volcanics, locally intruded by mafic to felsic bodies are overlain conformably by more than 4 km of sediments. In the field, the contact is marked by a valley 10 m deep and 200 m wide caused by the erosion of the soft sediments (slate) in contact with the volcanics. This ridge may also be produced by a fault along the contact (J. B. Henderson, pers. comm., 1974). The volcanics are not folded, but several transverse faults cut the units perpendicular to their strike. In the field, the displacement is usually not considerable, due to the geometry of the faults and the strata. Near the contact with the volcanic rocks, the sediments are mainly composed of slate and greywacke. Commonly, these rock units are interstratified and the thicknesses of the slate and the greywacke beds vary between 1 to 5 cm and 2 to 10 cm respectively. These rocks are highly deformed in open, closed and isoclinal folds and the amplitude of the folds vary from less than 5 cm to several kilometres (visible on the aerial photographs). The metamorphism of the sediments increases away from the volcanics, from the low grade greenschist facies to the staurolite and sillimanite subfacies of the amphibolite facies.

The granite appears to have intruded the volcanics. Near the contact, several narrow dykes of granitic composition cut the intermediate volcanics. Locally, the volcanic outcrops show a pink weathered surface on their joint planes which probably correspond to the filling of the small fractures by the quartzo-feldspathic material derived from the granitic intrusion. Usually, near the contact between the granite and the volcanics, we found small bodies of granodiorite to diorite composition which represent probably a contamination of the granite by the intermediate volcanics. A few dykes of intermediate material, similar to the volcanics, have been observed locally in the granite, near the contact of the volcanics. Possibly, they represent the feeder of the intermediate intrusions in the volcanics.

The Volcanic Rocks and their Related Rocks

This group of rocks consists mainly of mafic and intermediate to felsic flows, tuffs and fragmental rocks. Moreover, the limestone beds, the gossan zones, and the alteration zones within these rocks are included in this category. Finally, the mafic and the acid intrusives found within the volcanic rocks will be described under this title.

The mafic and intermediate flows generally exhibit a massive structure and the contacts between the flows are hard to see. However, in the northwest part of the mapped area, we observe good flow contacts, locally less than 1 m apart. These contacts are continuous over several hundred metres. Other flows exhibit pillow structures. These are not well developed, recognizable only here and there and averaging 1 m in diameter. Great thicknesses of pillowed lavas were not observed in the field but the correlation from one line to another permit us to delimit major pillowed lava units.

The massive lavas and the pillowed lavas are greenish grey on weathered and fresh surface, fine to medium grained and locally showing a diabasic texture. Occasionally, they exhibit 2-5 mm black amygdules of chlorite and amphibole, rimmed by white feldspar. These amygdules are rounded or angular. Other flows show the presence of numerous amygdules of calcite, 1-5 mm or more of diameter. The weathered surface of these rocks is sponge-like. Locally, amygdules of quartz were found in the intermediate flows. These structures are usually less than 3 mm.

A calcite-rich flow lies on the northwest part of the central fault, which cut the main gossan of the massive sulphide prospect. The calcite occurs in a few amygdules, infilling of fractures, in dissemination through the rock, or in the matrix of the brecciated rock. This presence of calcite is not restricted to the flows and is probably due to a secondary effect.

The tuffs and the fragmental rocks are uncommonly well bedded. We think they are of a pyroclastic origin because of the rounded and elongated fragments they contain. These lapili vary in size from 1 to 3 cm. Occasionally, the fragments are more angular. The rock exhibits the same greenish colour on the weathered and the fresh surface and the grain size is similar to the mafic to intermediate flows. Northwest of the central fault, the tuffs present also the concentration in calcite as a dissemination through the rock, as a filling of fractures or as the matrix of local breccia.

Acid flows were not positively recognized. This name was given to a rock type according to the massiveness of its outcrops in the field, the homogeneity of the texture, the absence of bedding, banding, etc. Locally, we found some vacuoles in this thick unit, not very widely spread. This rock exhibits also a local brecciation corresponding possibly to a flow breccia. The rock is white on weathered surface. The light greyish fresh surface is glassy to fine grained, hard, siliceous, with conchoidal fractures and textureless. A few phenocrysts of feldspar, less than 1 mm, were locally observed.

The acid tuffs are the most interesting rocks of this area. Usually, they show fresh structures and textures like bedding, banding, crossbedding, graded bedding, flow-like texture, shards, fragment of pumice, microbreccia and agglomerate. The thickness of the individual beds is commonly less than 5 cm. The rock is white to greyish on weathered surface, greyish white on the fresh surface, glassy to fine grained, hard, siliceous, similar to the rock of the acid flow but differing by its bedding and by the presence of small fragments usually less than 1 cm. Agglomerates and microbreccias were locally observed but no widespread units were recognized.

The gossan zones are found mainly in the acid tuffs or at the contact of these rocks with the intermediate rocks. They are produced by the oxidation of the iron sulphide contained in the tuffs. These sulphides are probably derived from the exhalative activities of the volcanoes. In the field, these zones appear rusty and usually the host rock is deeply altered or weathered.

The alteration zone is located on either side of the central fault. In this zone, the rocks are altered to chloritic schist and to sericite schist, probably derived respectively from intermediate and acid rocks. Numerous gossan were found in the alteration zone. In the field, this zone is poorly covered by sheared outcrops. We used principally the material contained in the frost boils to map this area.

The limestone horizons are not extensive. Usually, they are less than 2 m thick and less than 200 m long. They consist of impure carbonate mixed with recrystallized chert. The weathered surface is typically rugged, deeply eroded and rusty brown in colour. The origin of these carbonate horizons is probably a chemical sedimentation of the exhalations of the volcanoes.

The mafic intrusions are a group of massive and structureless mafic rocks. Greenish grey on weathered and fresh surface, they are coarse grained, equidimensional, composed of hypidiomorphic feldspar and ferromagnesian minerals, locally containing blue quartz eyes up to 2 mm. These bodies are commonly conformable but they can end suddenly in the volcanics by faults or their spatial geometry. A few mafic dykes were observed in the mafic, granitic and acid rocks.

One of the most important features of the geology of the Agricola Lake area is the presence of a sill of quartz and feldspar porphyry near the top of the volcanic succession. This body is probably an intrusion due to the nature of its contact with the acid tuffs and the slate. Where the slate is in contact with the porphyry, the matrix of this latter is usually darker and contain angular inclusions of slate, less than 5 cm. The porphyry is massive and randomly jointed. The white weathered surface exhibit euhedral and zoned feldspar phenocrysts up to 3 mm and quartz eyes up to 5 mm. Under the microscope, the quartz phenocrysts appear to be corroded (irregularly shaped). The fresh surface is greyish white and shows a few biotite flakes. This rock is hard, siliceous and porphyritic, the grain size increasing toward the centre of the intrusion.

Small dykes of quartz and feldspar porphyry and small dykes of fine grained acid rock were also found and are probably related to the same period of intrusion.

The Sedimentary Rocks

Generally, the slate found in the valley at the contact between the volcanics and the sediments does not occur in outcrops. Due to its softness, the slate is eroded and the remnants are found in the rubble alongside the gully and in the frost boils. The slate is black, very fine grained, with at least two schistosities well developed and a very good cleavage.

The greywacke found over the thick sequence of slate is usually interbedded with thin layers of slate. The greywacke is well bedded, schistose, greyish green on fresh surface, fine grained and usually showing tiny fragments of quartz and/or feldspar crystals. The alternation of greywacke and slate is well observed due to the difference in hardness of these rocks. Moreover, the slate developed a perfect cleavage compared to the poor schistosity of the greywacke.

The Granitic Rocks

The granite is massive, randomly jointed and occurs as large rounded outcrops partly covered by granitic blocks. The rock is white to pink on the weathered surface. The fresh surface is usually pink, showing a granitic texture composed of an assemblage of quartz, potassium feldspar, plagioclase, muscovite, biotite, hornblende and locally epidote. The grain size increases from 1-3 mm, near the contact with the volcanics, to 3-5 mm, 500-1,000 m away from the contact.

Locally, the granite exhibits partly assimilated inclusions of the volcanic rocks as dark irregular patches of greenish material in the pink matrix. These features are commonly less than 1 cm. Near the contact of the granite with the volcanics, the composition of the granite looks slightly more mafic and usually, several local outcrops exhibit a fine grained rock with a granodioritic to quartz dioritic composition.

Structure and Metamorphism

Beside the transverse faults which cut the formation nearly perpendicular, several other transverse faults, parallel and forming an angle of 30 to 40 degrees with the strike of the rocks, were mapped. Also, a shear zone of the same orientation was found with the help of a resistivity survey in the vicinity of the main "B" horizon gossan (W.J. Scott, 1974, pers. comm.).

Commonly, the volcanic rocks in the central portion of the Agricola Lake area are metamorphosed to the greenschist facies and locally we could observe metamorphic biotite flakes in the intermediate rocks.

Conclusion

The result of this field work is a geological map of the Agricola Lake area, using a 100- by 100-cm base map which is the enlargement to the scale of 1:6,000 of the portion L to R, 4 to 10 of the aerial photograph A16317-103. On this map, the area covered by the volcanics is nearly 2 by 6 km.

The environment in the Agricola Lake area corresponds to the same type of environment found in the Archean volcanogenic massive sulphide deposits as described by Sangster (1972). The initial drillhole put down by the Yava Syndicate cut a section of 134.4 feet (40.99 m) assaying 3.70 per cent of zinc, 0.71 per cent of lead, 1.091 per cent of copper, 2.73 oz/ton of silver and 0.036 oz/ton of gold (Northern Miner, August 15, 1974). This hole was drilled to test the soil geochemical anomaly described by Cameron *et al.* (1974) and further defined by geophysical studies by the Yava Group. This gossan zone is located near the intersection of the shear zone and the central fault, in the middle of the alteration zone.

It is clear that from geological consideration, further mineral prospecting and drilling will be done in this area by the mining companies. It is clear also that, for a better understanding of Archean geology in the Slave Province, laboratory work on the samples and further field work need to be done in this area where the rocks are well exposed, undeformed and not highly metamorphosed. The writers plan to continue study of the petrology and chemistry of the rocks of this area to develop techniques which will be of use in resource evaluation.

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64. VLF RESISTIVITY (RADIOHM) SURVEY, AGRICOLA LAKE AREA, DISTRICT OF MACKENZIE

Project 670041

W. J. Scott
Resource Geophysics and Geochemistry Division

Introduction

During the last week of July 1974, a VLF resistivity survey was carried out over the Agricola Lake massive sulphide prospect. Measurements were made along the soil survey lines (Cameron, this publication, report 55, Fig. 1) using the Radiohm technique (Collett and Becker, 1968). In this technique, the apparent resistivity of the earth is determined by a magnetotelluric measurement of the radiated field from a remote radio transmitter.

The quantities measured are the horizontal components of the radial electric field (E_x) and the tangential magnetic field (H_y), and the phase difference between E_x and H_y. A value for apparent resistivity is derived from the approximate expression:

$$\rho a = \frac{1}{\mu \ \omega} \left| \frac{Ex}{Hy} \right|^2$$

ρa = the apparent resistivity in ohm-metres

where μ = the magnetic permeability of the medium (assumed = $4 \pi \times 10^{-7}$ Henrys per metre)

ω = the angular frequency of the signal $2\pi f$, where f is the frequency in h_z

The instrument used in this survey was a Geonics EM16R, which obtains H_y by means of an integral coil and E_x by means of two ground probes spaced 10 m apart. The measurement is made by orienting the instrument so that the coil is maximally coupled to H_y (determined from an audio signal) and inserting the two ground probes along the direction indicated by the

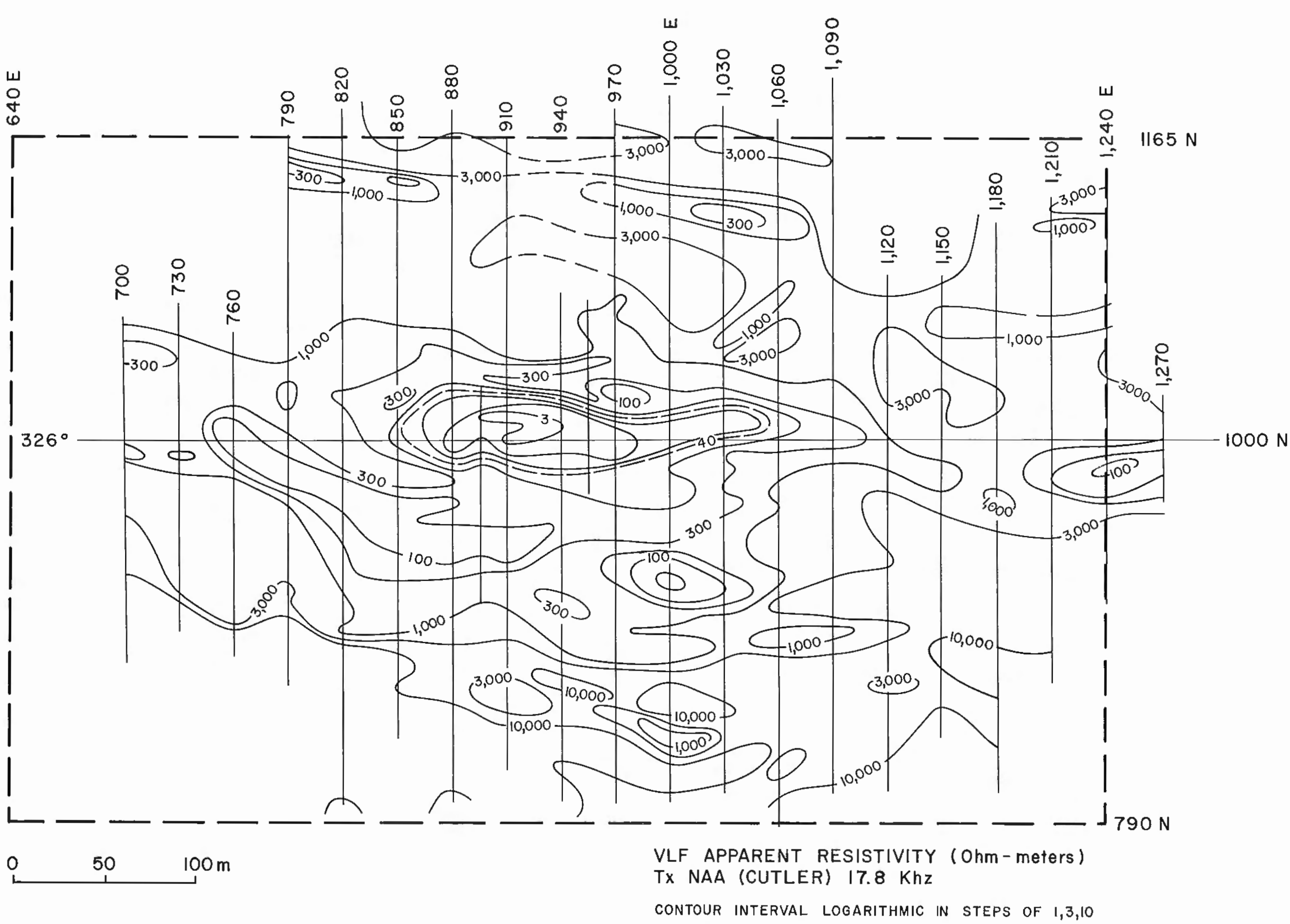

Figure 1. Contour map of VLF apparent resistivity, Agricola Lake massive sulphide prospect, N.W.T.

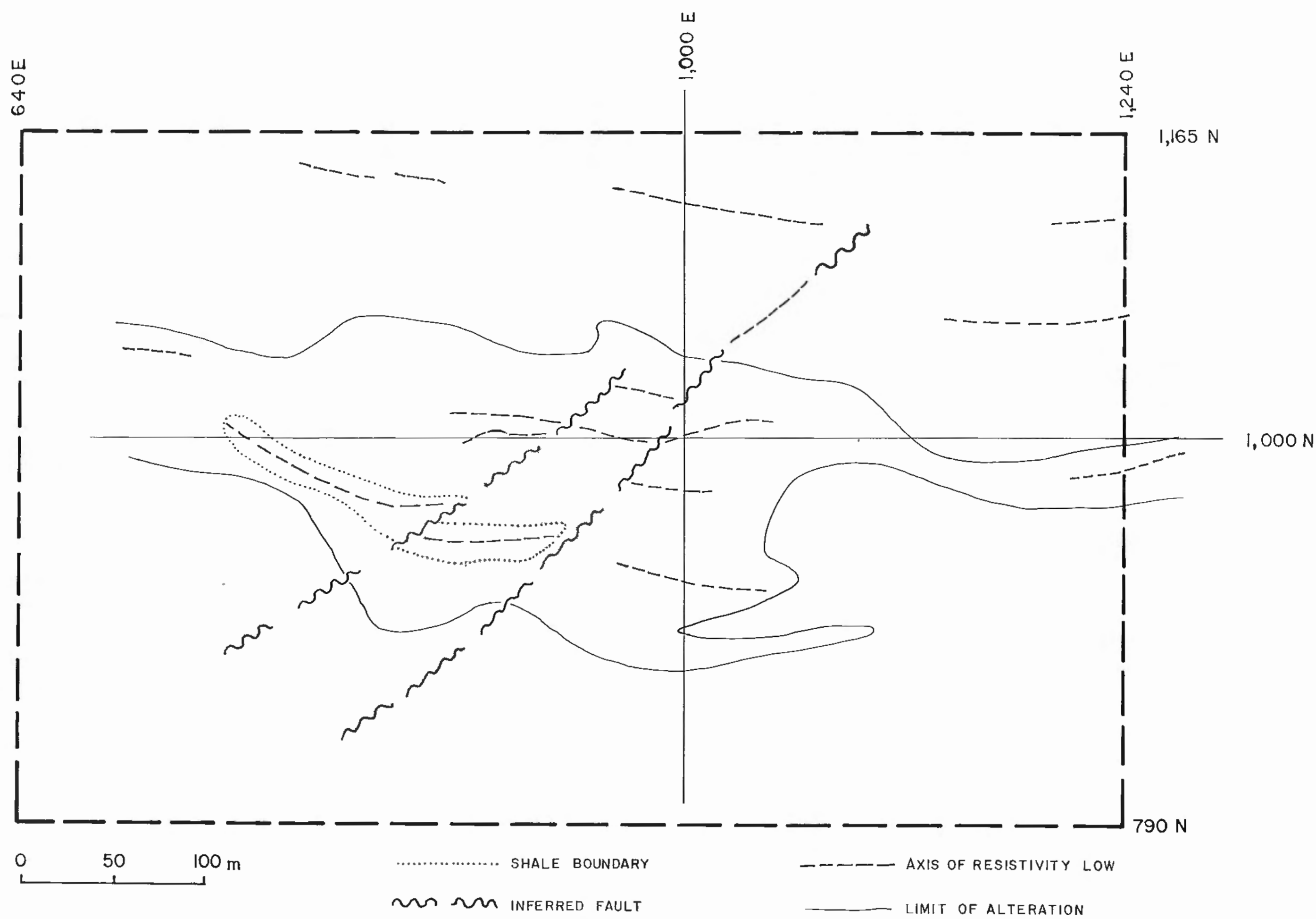

Figure 2. Geological interpretation of VLF apparent resistivity data, Agricola Lake massive sulphide prospect, N.W.T.

instrument orientation. After the audio signal is nulled by means of two controls, the phase angle and apparent resistivity values can be read directly from the instrument. The apparent transmitter azimuth may be determined from the orientation of the instrument.

For the present survey the signal utilized was from NAA, Cutler, Maine, at a frequency of 17.8 Kh_z. The transmitter azimuth was approximately parallel to the base line of the survey grid.

During four and a half field days some 900 measurements of resistivity, phase angle and transmitter azimuth were made by a crew of two, augmented at times by a third man to speed the work on rough ground. The readings were taken at intervals of 15 m on grid lines spaced at 30 m. When adjacent readings varied by a factor of 1.5 or more, intermediate readings were taken.

Results

Figure 1 shows a contour map of apparent resistivities obtained on the grid lines indicated; Figure 2 shows an interpretation based on these data. For purposes of clarity the grid lines are defined to run north-south, and the baseline east-west (true bearings notwithstanding). Directions referred to in this paper are understood to be grid directions.

The observed variation of apparent resistivities agrees in general with the preliminary geological interpretation of (*see* Cameron, op. cit., Fig. 2). In the northern part of the grid, apparent resistivities from 1000 to 4000 ohm-m reflect the presence of acid and intermediate volcanics, whose southern boundary agrees on the whole with the 1000 ohm-m contour.

Rather higher resistivities in the southern part of the grid correlate with a further sequence of acid and intermediate volcanics. In the south-central area, the 1000 ohm-m contour agrees with the northern limit of the volcanics. In the southeast, however, the resistivity data suggest that the unaltered volcanics may extend farther west beneath thin overburden, than indicated by the geological map.

The central area of low resistivity (less than 1000 ohm-m) in general coincides with the area mapped as hydrothermally altered volcanics. Within this zone are several prominent lows. Lying on the baseline from 850 E to 1060 E is a pronounced low, whose outline as shown by the dashed 40-ohm-m contour (Fig. 1) agrees with the part of the boundary of a massive sulphide zone indicated by diamond drilling by the

Yava Syndicate (Northern Miner, August 15, 1974). A small low at 990 N, 1240 E coincides with high metal values in the soil, and may be an extension of the main sulphide body.

The low trending southeast from 760 E on the baseline to 940 N, 940 E crosses a shale unit indicated by the presence of shale fragments in frost boils. In view of the lack of outcrop it is possible that the geology could be re-interpreted to place the shale member under this low as suggested in Figure 2. The results of a magnetic survey on the same grid (Kornik, this publication, report 62) support this interpretation. The low at 925 N, 1000 E appears from the magnetics not to be an extension of this feature, and may indicate a further concentration of sulphides.

The weak east-west low from 960 E to 1080 E at 1120 N coincides with rocks mapped as rusty-weathering intermediate volcanics; it is probable that the westward extension of the feature from 790 E to 870 E indicates the presence of more of this unit. A similar low from 1140 E to 1240 E at about 1060 N may also be associated with such a rock unit.

The traces of two faults trending northeast-southwest (Fig. 2) are picked on the basis of aberrations in the resistivity contours and offsets in the axes of low trends. Further faulting could probably be inferred as well, but would best be done on the basis of a combined interpretation of all the geophysical results. The two faults shown, however, are also indicated by the magnetic data (Kornik, op. cit.).

Discussion and Conclusion

Despite the fact that the area is well within the zone of continuous permafrost (Brown, 1967) there is a wide variation in apparent resistivities. For metallic sulphide mineralization this is to be expected, but it is less obvious that frozen rocks should exhibit such variation. Spot measurements on shale outcrops to the north of the grid give resistivities ranging from 10 to 200 ohm-m, while some measurements on outcrop within the zone of alteration yielded values of a few hundred ohm-m. It is reasonable to suppose that such low resistivities are the result of clay minerals in the rock, with the resultant retention of some pore water in the fluid phase, despite ground temperatures significantly below $0^{o}C$.

In the unaltered volcanics, however, particularly to the south, quite wide variations in resistivity did not appear to be related to known rock types, and subdivision of the volcanics on the basis of resistivity would at the present time appear unreliable. It is possible that further work, including laboratory measurements of resistivities at low temperatures, may clarify this problem.

The phase angle and azimuth data taken in this survey have not been shown, because they contain peculiarities which are difficult to interpret. Phase angles are theoretically limited to the range from 0 to 90 degrees, yet at a number of stations, particularly at the west end of the baseline, values much greater than 90 degrees were recorded. Strong variations were observed in the apparent azimuth of the transmitter, as indicated by the direction of H_y. It is probable that these variations are the result of the presence of a strong linear conductor in a region of generally high resistivity. It is hoped that further study will identify the cause of this variation.

The major disadvantage of VLF Radiohm measurements is the lack of penetration through any thickness of conductive overburden. In this study area, however, overburden was generally thin. There appeared to be no significant correlation of resistivity variation with the presence or absence of overburden.

The concept of Radiohm measurements, as embodied in the Geonics EM16R, is extremely useful, particularly in difficult conditions such as experienced at this site. Even in permafrost regions, there appears to be some utility in resistivity mapping as an aid to geological work.

Acknowledgments

The help of D. Eberle (Geological Survey of Germany), A. Williams (GSC), J. Williams (DOE) and Jim Thomas (GSC) in carrying out the field work is gratefully acknowledged.

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65. COLOUR PHOTOGRAPHY IN THE BEECHEY LAKE BELT, DISTRICT OF MACKENZIE

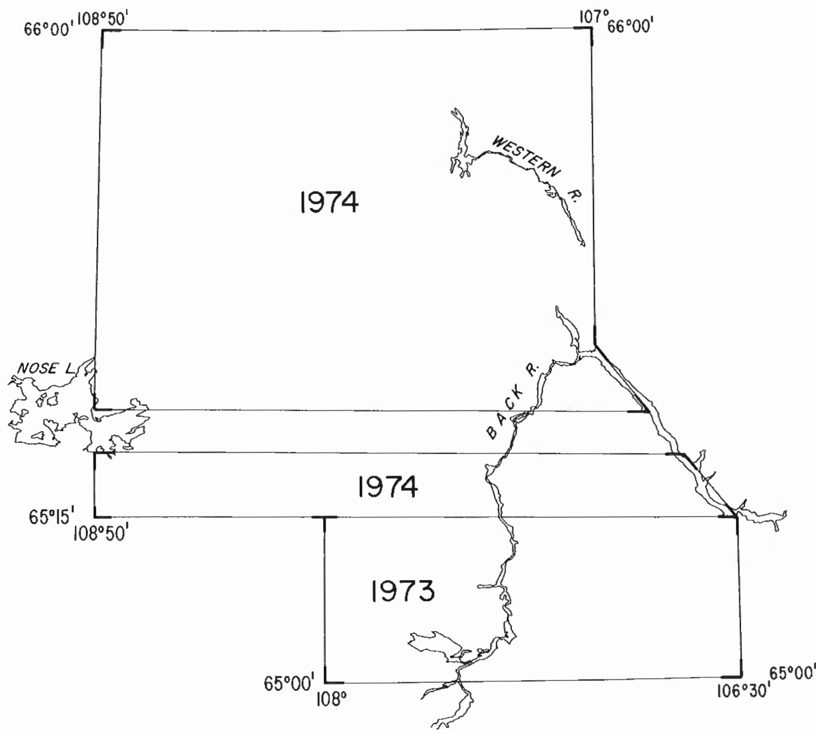
Project 630031

V.R. Slaney
Resource Geophysics and Geochemistry Division

A colour airphoto survey of the Beechey Lake belt was undertaken to provide photogeological support for the interpretation of geochemical data and to assist geological mapping of the volcanics of the Beechey Lake belt. An examination of the 1973 imagery has determined that many if not most of the gossans known to be present will be recognized on colour film.

Some 600 line miles of photography were flown in August 1973 before poor weather conditions halted the project. Flights were continued in July and August 1974, when the whole of the planned area was completed except for a gap 3 lines wide (3 miles) in the southern half of the area.

The area now flown is shown in Figure 1 and totals 3,400 square miles. There are 45 east-west lines spaced at 1.6 mile intervals. The average photoscale is 1:15,000. The negatives acquired in 1973 are held by the National Air Photo Library in Ottawa.



LIMNOLOGICAL INVESTIGATIONS IN THE AGRICOLA LAKE AREA

J.D.H. Williams
Lakes Research Division
Great Lakes Institute, Department of the Environment

The feasibility of using present equipment and techniques for locating and sampling sediments in Arctic lakes was investigated. These studies were carried out at the Geological Survey of Canada Friday Lake camp over the period July 18-29, 1974.

A Geological Survey member (Bruce Ballantyne) and I both had the same experience with the Ponar grab sampler - unless the sampling platform was stationary, the sampler rarely brought up any material. Presumably it toppled over on hitting the bottom if the platform was drifting appreciably. The Minishipek was not available for testing, but the sediment was such that I see no reason why it should not have been as effective on these sediments as it has been in the Great Lakes to date. I wonder, however, whether the Minishipek might be vulnerable to damage on striking boulders, due to its protruding knobs. Perhaps the knobs could be partially encased.

A Geological Survey sampler designed for collecting organic-rich samples from lakes in the southern Shield was also used. It is similar to the Phleger corer but slightly heavier. The valve system uses a ball. This corer failed on two drops out of three, and is probably inferior to the Minishipek as a grab sampler.

The Phleger corer in its present form is not a suitable coring instrument for sampling soft sediments. Problems encountered were:

(1) many cores were often far shorter than the depth of immersion of the corer (generally to the fins). Presumably the valve mechanism was closed on entering the sediment, either because the valve was not properly freed before lowering the corer into the water, or because the valve closed as the corer descended.

(2) the liners are open at both ends and, as soon as the barrel was unscrewed, the sediment started sliding out. Attempts to remove the cores by immersing the corer under water were usually not successful, though the job may have been easier with two persons (shoulder length rubber gloves might have helped too). Under these conditions, it was very tricky to slip the present type of cap onto the liners. The problem was not much alleviated by filing the outside edges of the ends of the liners.

(3) some of the liners were too tight to slide out of the barrel easily. While trying to free them, the core was invariably lost.

(4) the cutting edge had to be removed with a vise grip on one occasion.

Owing to the clear water, the descent of the Phleger in free fall could be watched. It kept a good vertical orientation. On impact the disturbed sediment spread out for about 0.5-1 m around the corer, but did not billow up into the water which remained clear.

It looks as if we need another lightweight system for recovering sediment cores for helicopter sampling. Possibilities are a type of box corer such as the one developed at Brock University. Another possibility is to develop a miniaturized version of the Sphincter corer. Yet another is the Brown and Livingstone corers. It might be possible to convert the Phleger corer into a useful instrument by:

(1) having constructed valves similar to the new Benthos valves which could be taped to the top of the liners. The stop inside the core barrel would then have to be moved upwards.

(2) filling the outside edges of the ends of the liners OR redesigning the caps.

Even then, the narrow barrel of the Phleger means that a disproportionate amount of uppermost 2 cm or so of the sediment column is smeared down the sides of the barrel. This objection may apply to the Brown and Livingstone corers also.

Because of the shallowness and clearness of many Arctic lakes, it might be advantageous to record at each sampling station the Secchi disc reading and/or whether the bottom was visible by viewing tube.

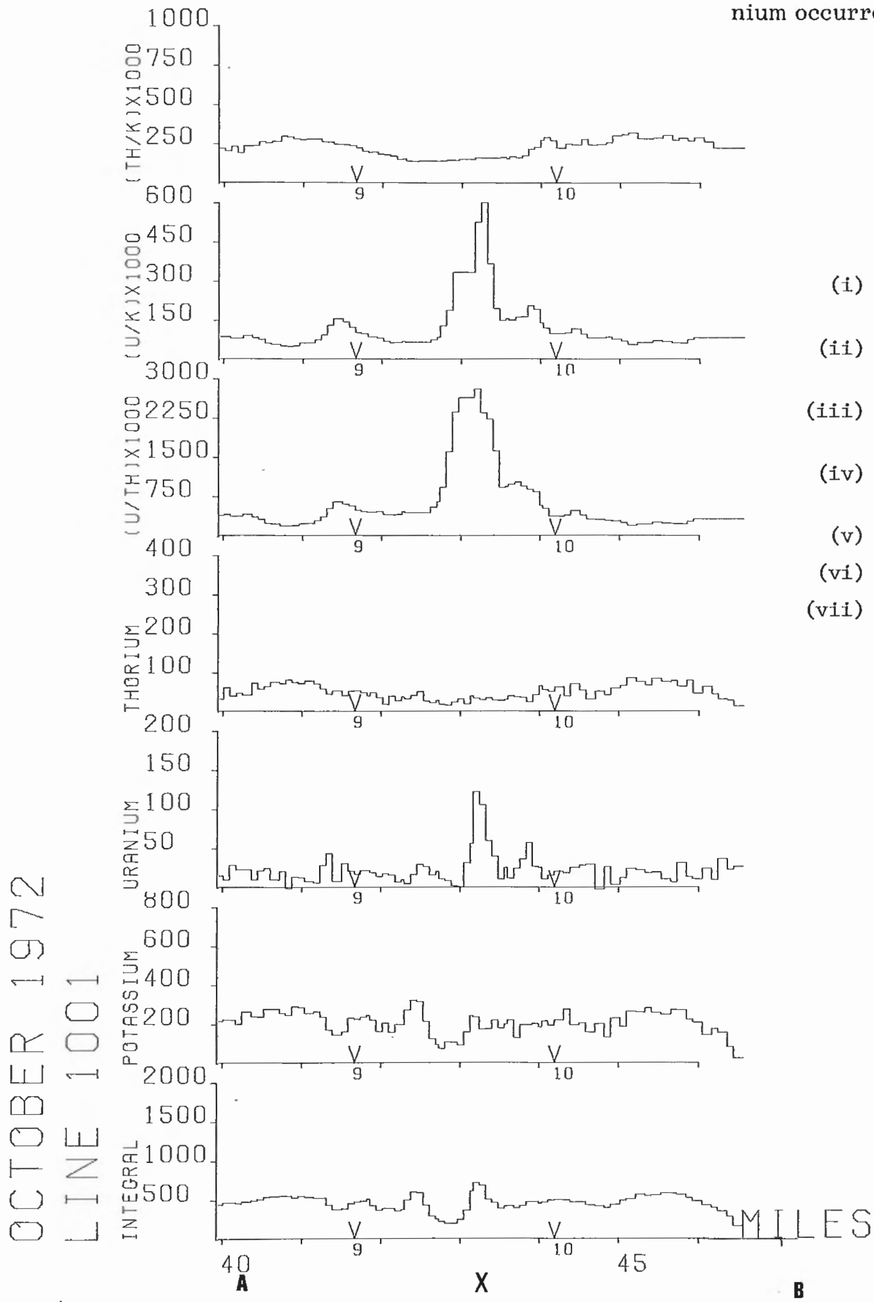
The lakes which I visited all seemed to have rocky "nearshore" areas (occupying at least half the lake) and central depressions partly filled with sediment, with little or no transition. The Kelvin-Hughes MS 39 echo sounder, had no difficulty in differentiating rock from sediment-filled areas. The sediments recovered by Geological Survey sampler were very varied in colour, including light brown, light grey, bright red and dark brown materials with sandy, silty and "soily" appearances. In Friday Lake two distinctive types of sediment were seen, and could be distinguished by the echo sounder. Type I, giving a very "soft" reflection, consisted of a reddish uppermost layer, about 1 cm thick, overlying soupy brownish material down to a depth of at least 30 cm (the maximum length of core recovered by the Phleger corer). The other type, Type II, giving a "harder" reflection, consisted of bright reddish surface material overlying brownish material over bluish-grey sediment. The last material readily oxidized in the core liners on standing after only a couple of days to a deep black material, inducing the speculation that the bluish material contains $Fe(OH)_2$ which readily oxidizes to material of the approximate composition $Fe_4(OH)_{10}$ with possibly serious consequences for paleomagnetic measurements.

In conclusion, Arctic lake sediments are fascinating materials, and should give abundant scope for process studies. There is evidence that the post-depositional changes in these sediments are very different from what we are familiar with in the Great Lakes. The development of adequate dating techniques for these probably pollen-free lakes could lead to studies of the dispersal of man-made pollutants (including radionuclides and exotic organic compounds) in high latitudes.

67. CU-U MINERALIZATION IN THE MARCH FORMATION PALEOZOIC ROCKS OF THE OTTAWA-ST. LAWRENCE LOWLANDS

B.W. Charbonneau, I.R. Jonasson and K.L. Ford[1]
Resource Geophysics and Geochemistry Division

Certain aspects of the geology, mineralogy and geochemistry of an area of copper-uranium mineralization in the March Formation Paleozoic sedimentary rocks of the Ottawa-St. Lawrence Lowlands have been described in three previous papers (Grasty *et al.*, 1973; Jonasson and Dyck, 1974; Steacy *et al.*, 1973). The airborne radioactivity anomaly which led to the original discovery of the mineralization described is shown in Figure 1; the geology and the location of the mineralization is shown in Figure 2 by an X along the airborne profile, A-B. By virtue of its proximity to Ottawa, this area has proved convenient as a training ground for students and foreign visitors, as well as having considerable geological novelty insofar as Canadian uranium occurrences are concerned.



(i) Integral counts per 0.5 sec (0.41 to 2.81 MeV)

(ii) Potassium counts per 2.5 secs (1.37 to 1.57 MeV); 1% K ≃150 counts

(iii) Uranium counts per 2.5 secs (1.66 to 1.86 MeV); 1 ppm eU ≃24 counts

(iv) Thorium counts per 2.5 secs (2.41 to 2.81 MeV); 1 ppm eTh ≃9 counts

(v) Uranium/thorium counts

(vi) Uranium/potassium counts

(vii) Thorium/potassium counts

Figure 1.
Original airborne γ-ray spectrometry profile A-B over South March Cu-U occurrence.

[1]Carleton University.

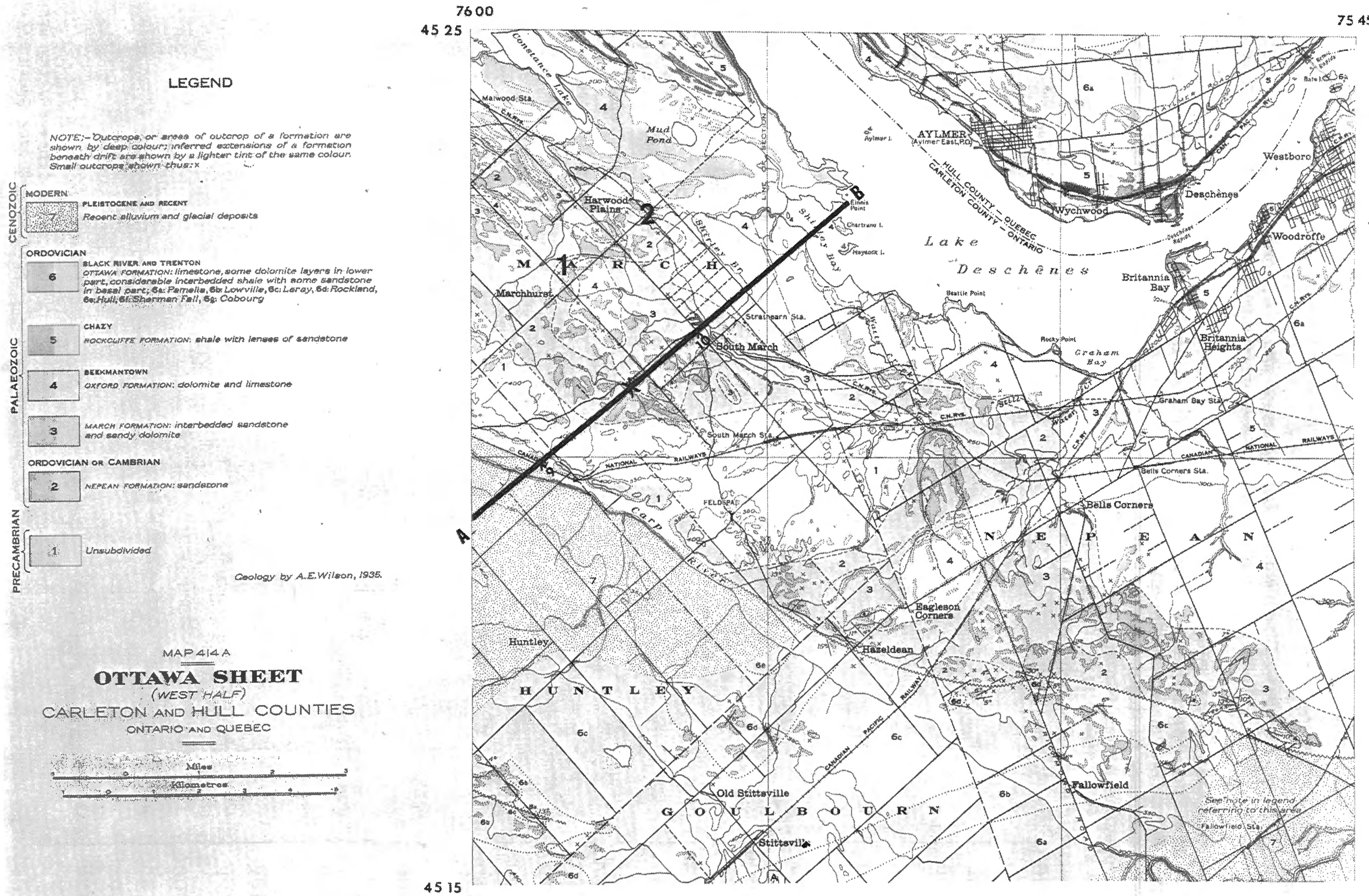


Figure 2. Geology of the area around South March showing the position of the original airborne γ-ray spectrometry profile A-B and the South March occurrence X and two new occurrences; 1. Marchhurst, 2. Shirley's Bay.

Figure 3

Total count (ratemeter) map of the South March anomaly area.

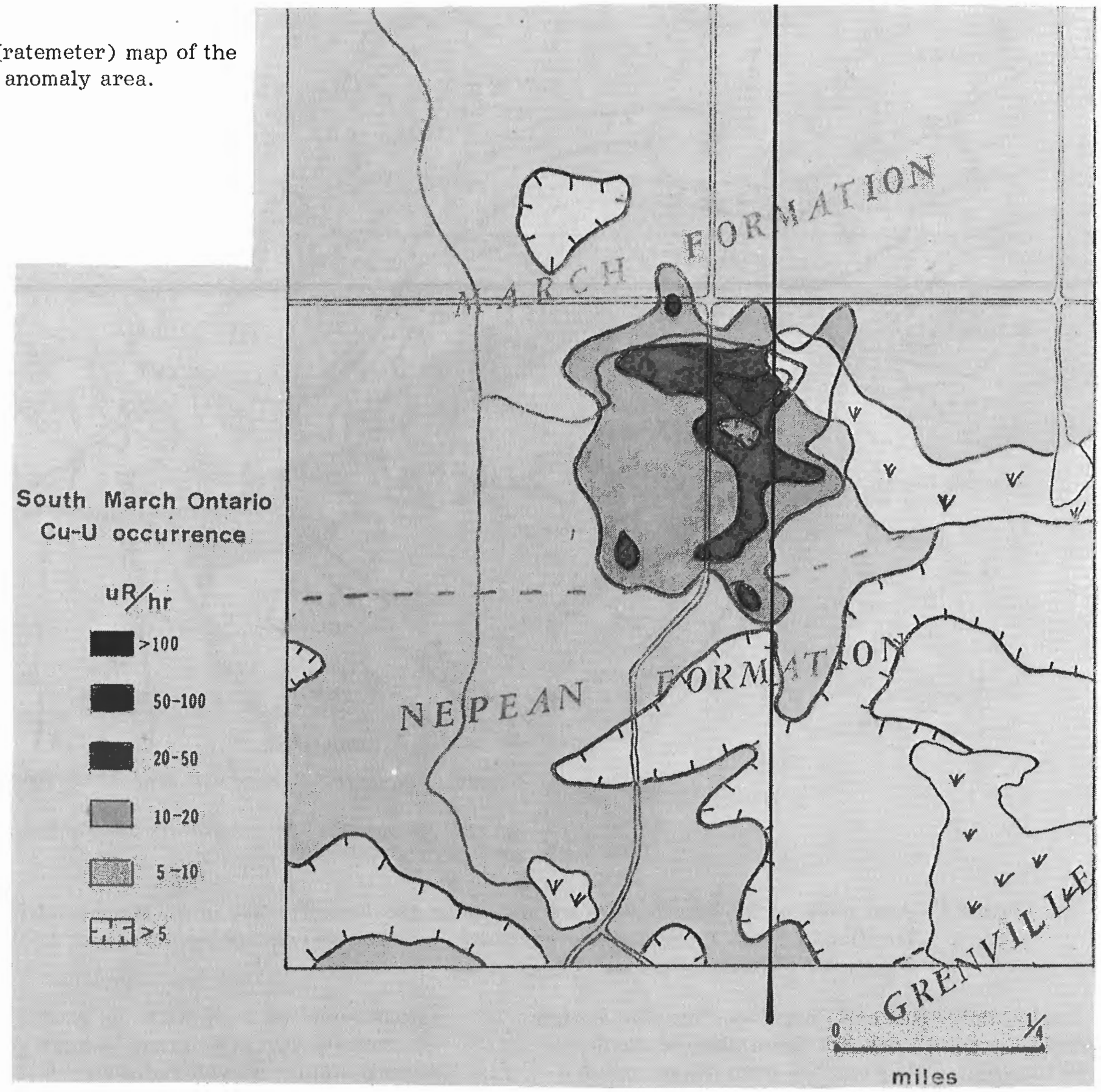


Figure 4

Photograph of a piece of drill core and of a hand specimen showing chalcopyrite (bright patches) and thucolite (black specks) in a particularly rich sample.

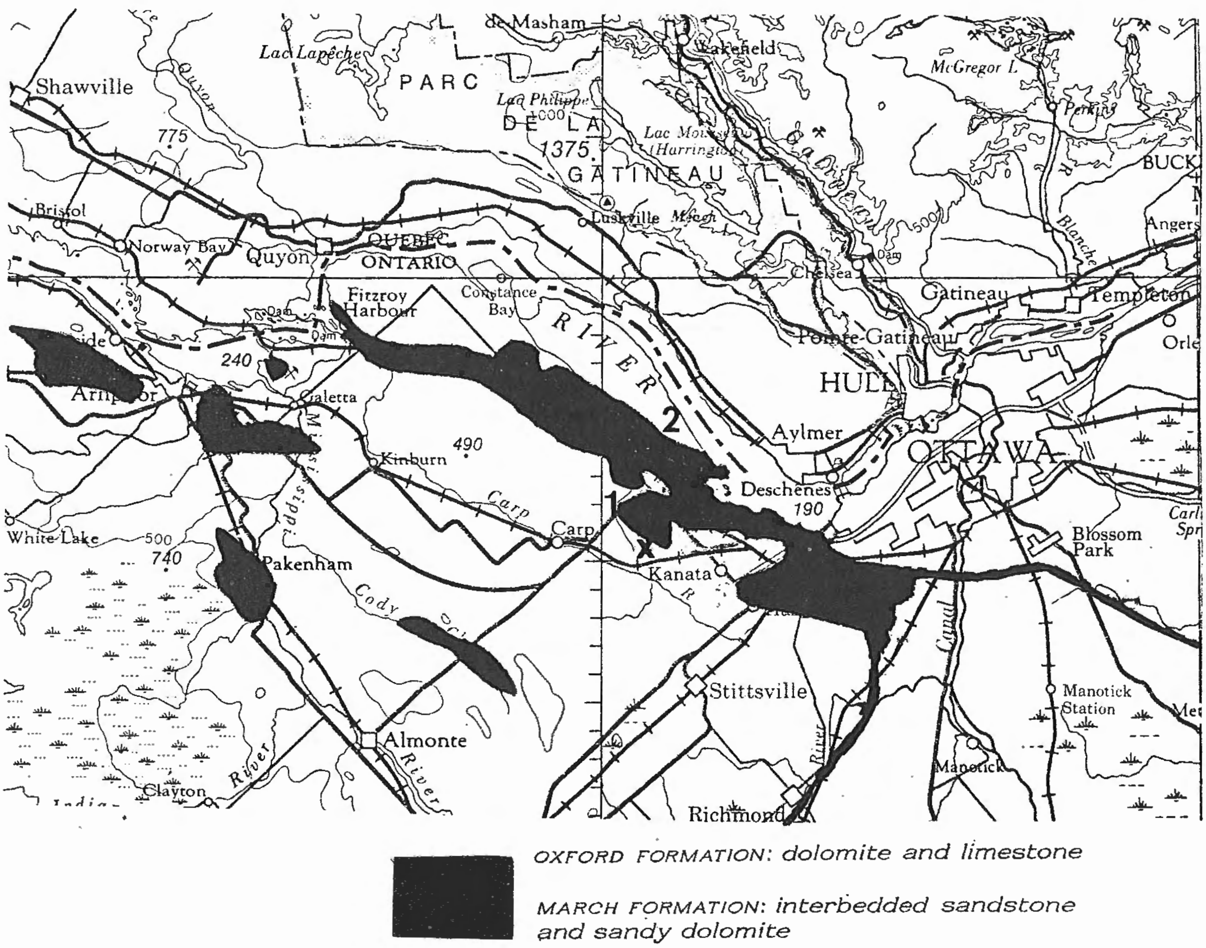


Figure 5. Area covered by stream sediment and water geochemistry late in the summer of 1974. Location of South March Cu-U occurrence X as well as two new occurrences; 1. Marchhurst, 2. Shirley's Bay.

During the summer of 1974 a considerable amount of detailed ground work has taken place at the South March locality. This work has been organized on a grid with 100-yard station spacing and 50-yard spacing in the vicinity of the anomaly, covering a total area of approximately one square mile. In total some 360 stations were occupied. Scintillometer (ratemeter) readings were taken at each station along with field γ-ray spectrometer readings which enabled the production of ratemeter (total count), K, U, Th, U/Th, U/K, Th/K maps. In addition soil samples were taken, nominally from the "C" horizon, at an approximate depth of one foot for U, Cu, Pb, Zn analyses. The detailed nature of the anomaly is illustrated by the ratemeter (total count) map, Figure 3 along with the position of the original γ-ray profile A-B. As described previously (Grasty *et al.*, 1973) the radioactive zone trends some 2,000 feet perpendicular to the geological strike, is about 500 feet in width and lies entirely within the March Formation. The maximum values in the core of the anomaly, 200 μR/hr, are some 40 times greater than local background radioactivity. All these values are on overburden rather than bedrock, and the bedrock values would be expected to be greater. The centre of the anomaly covers an area some 150 yards by 100 yards. Slightly higher overall radioactivity is noted in the March Formation than in the underlying Nepean Formation, Figure 3. The γ-ray spectrometry at ground level revealed that the radioactivity is mainly from uranium with negligible contribution from thorium. This is consistent with the airborne profile (Fig. 1).

Some shallow drill sampling of bedrock (6 to 12 inches), under about 1 foot of soil cover within the centre of the anomaly, has been completed. The rocks are sandy dolomites with up to 4% chalcopyrite (visual estimate) and .05% U_3O_8 (calculated from field readings) in the form of thucolite. The average concentrations are much lower than this and could not be estimated without deeper systematic drilling. The mineralized zone may strike to the north under barren rock. Figure 4 is a photograph of a piece of drill core and of a hand specimen showing chalcopyrite and thucolite in a particularly rich sample. The Cu-U mineralization is emplaced in sandy lenses within the dolomite. The age of the mineralization has not yet been established. The mineralization may have been emplaced by fluids during or shortly after diagenesis or at a much later date (Grasty *et al.*, 1973; Steacy *et al.*, 1973).

Further examination has taken place along the March Formation and two additional zones of Cu-U enrichment (chalcopyrite and thucolite) have been located. These approximate positions are shown on Figures 2 and 5 as localities 1, 2 along with South March X. Further work is planned in these areas. While apparently not as strong as the concentration at South March, these additional localities are significant in that they imply a regional nature to the distribution of the mineralization.

Figure 5 shows as well an area investigated by stream sediment and water geochemistry and by radon sampling of water wells to outline further zones of Cu-U mineralization. These data have not been fully assessed but it appears that some zones of increased Cu-U have been outlined for follow-up. The radon investigations were carried out under the direction of W. Dyck of the Geological Survey. The outlining of this type of mineralization by geochemistry has already been illustrated (Jonasson and Dyck, 1974). Additional airborne γ-spectrometry is planned over the Ottawa-St. Lawrence Lowlands to investigate the regional concept of the mineralization in the March formation.

The above work will be described and evaluated as it becomes available, but it would certainly seem likely that additional Cu-U targets will be outlined for investigation within the March formation. The combination of the Cu with U makes this type of mineralization doubly interesting economically and it also facilitates its detection by airborne geophysics. The possibility that the concentration of Cu may not always be coincident with U should be kept in mind.

In conclusion, work to date suggests that the March Formation constitutes a definite focus of interest for an unusual type of Cu-U mineralization.

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NEW RADIOACTIVE OCCURRENCES IN THE PRECAMBRIAN WEST OF OTTAWA

Project 670029

V. Ruzicka[1] and H. R. Steacy[2]

Field investigations carried out by the senior author on the uranium mineralization in lower Paleozoic dolomitic sandstone near South March, Ontario (Grasty *et al.*, 1972) have centred on two metallogenic features, namely: (a) regularities in the distribution of uranium mineralization in the Paleozoic sediments and (b) distribution of radioactive elements in adjacent source areas.

With regard to distribution in the Paleozoic sediments, recent examination of selected areas containing impure psammites in the Ottawa Embayment have shown that anomalous contents of uranium are confined to certain stratigraphic and lithologic horizons of the lower Paleozoic adding further evidence to the postulation by Grasty *et al.* (op. cit.) of a potential distribution of uranium in the Ottawa-St. Lawrence basin.

The source of the Paleozoic sediments is Precambrian rocks, which in this region comprise (a) metasedimentary rocks, mainly greywacke, quartzite, conglomerate, paragneiss, amphibolite, and pyroxenite, (b) felsic igneous rocks, mainly granite and syenite and their metamorphic derivatives, (c) crystalline limestone and dolomite, and (d) metavolcanics, mainly chlorite schist and amphibolite.

This Precambrian source area has been known for many years to contain at least one uranium occurrence, namely a uraninite-bearing pegmatite on lot 6, conc. 11, March Twp. (Lang *et al.*, 1952). A new occurrence of radioactive mineralization may now be reported. The locality is 1.5 miles southwest of Dunrobin, where radioactivity was detected, and radioactive minerals identified, in two systems of disjunctive structures in gneiss.

The older structural system is represented by nearly vertical fractures, several were partly filled with quartz, only one of which contained a lightweight, black, appreciably-radioactive 'thucolitic' material. The radioactive material was a few inches wide exposed for a few feet vertically but not along strike. Laboratory examination of the black radioactive material revealed it to be a mixture of hydrocarbon and coffinite, carrying disseminated microscopic grains of thorite. On ignition a representative portion lost approximately 80 per cent of its weight and, by X-ray fluorescence, the residue showed a uranium-to-thorium ratio of 2 to 1. In polished section, the hydrocarbon is seen to be of two generations, the older constituting the groundmass and the younger filling syneresis cracks and other voids. The coffinite is apparently thoriferous. Coffinite and thorite are isostructural and the literature indicates that a complete series extends between them. If further work confirms that the mineral is thorian coffinite, it would be the first occurrence in Canada.

The younger structural system is represented by a gently dipping vein-dyke, approximately 5 inches wide, consisting of apatite, calcite and reddish dolomite with some pyrite and lepidolite. Both the apatite and dolomite contain small grains of thorite. The vein-dyke dislocates the steeply dipping mineralized fracture of the first system.

All the above-mentioned occurrences are near the Precambrian/Phanerozoic unconformity.

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[1]Regional and Economic Geology Division.

[2]Central Laboratories and Administrative Services Division.

Project 650056

D.F. Sangster
Regional and Economic Geology Division

Plate Tectonics and Mineral Deposits

In May, the author was a participating member of the NATO-sponsored Advanced Study Institute on Metallogeny and Plate Tectonics held in conjunction with the G.A.C./M.A.C. Annual Meeting in St. John's, Newfoundland. Under the able direction of Dr. D.F. Strong of Memorial University, a Symposium and a succeeding 12-day field trip across the island were devoted to a study of the relationship between plate tectonics concepts and current metallogenic theories.

The Canadian Appalachians, and Newfoundland in particular, have been one of the focal points of plate tectonic theory in the past years and Dr. Strong has been a strong advocate of its application to Appalachian metallogeny. In spite of this, however, and in spite of the fact that the Institute included several luminaries of international reputation in the general area of plate tectonics and metallogeny, the author was left with the impression that, with the possible exception of volcanogenic massive sulphide deposits, plate tectonic theory contributes little to our understanding of the genesis of mineral deposits; rather, it appeared that plate tectonics concerns itself more with the host rocks to certain types of deposits e.g. porphyry coppers, than to the deposits themselves. Subduction of ocean plates, followed by anatexis and diapir-like rise of sialic melts, may clarify why granites appear where (and when) they do relative to, say, island arcs but contribute little as to why the porphyry mineralization is only Cu and not (say) Cu-Zn, or why some intrusions carry Cu, some Cu-Mo and others Mo only. Whereas the position of a subduction zone in Newfoundland was recognized by most participants, there was no agreement on the direction of dip of the subduction zone so that, in this instance, plate tectonics could not be used as a predictive tool to suggest which side of the suture line should be prospected for porphyry coppers. Plate tectonics offered no explanation as to why the Ordovician has produced Mississippi Valley type zinc deposits on one side of the island and Clinton-type iron deposits on the other, both in a quiet water, shelf type of environment.

Regarding metallogeny in Newfoundland in general, the author was struck by the profound lack of information on critical age relationships, particularly in the Central Mobile belt. Metallogeny in any area, whether or not it is related to plate tectonics, must rely on a sound chronological base; without this, correlations are speculative and metallogenic interpretations are impossible. For example, the author, in conjunction with Dr. D. Strong, identified the following problems as crucial to the metallogeny of central Newfoundland: 1. The age of the Rambler deposits. 2. The age of Buchans, Pilley's Island and Gull Pond deposits. 3. Age of New Bay Pond deposits. Anyone familiar with the mineral deposits of Newfoundland will recognize these areas as containing the most important metal deposits on the island and yet their exact metallogenic position is uncertain because the age of their host rocks is not known.

The foregoing remarks are not to be construed as a criticism of Dr. Strong and his associates for the decision to hold a Symposium and field trip on the general topic of metallogeny and plate tectonics. Indeed, both functions could be readily considered a success in that they did focus attention on the problem, but to this writer at least, the impression was left that, while plate tectonics may have revolutionized our concepts of earth history, it has not yet attained this stature in metallogenic studies. In fact Bilibin's (1955) empirical observation on the orderly succession of metallogenic provinces and epochs has probably contributed more to metallogeny than plate tectonic theories have to date. The role of plate tectonics in metallogeny may have been accurately forecast recently by de Corvalho (1972, p. 308): "His (Bilibin's) work is older than the plate tectonic theory but neither the sequence of events nor the associated mineralization types will change greatly. The big difference is that now there is a much more accurate interpretation of the mechanisms of folding, metamorphism, and eruptive activity".

The Significance of Smithsonite in Northern Cordillera

Interest in the Northern Cordillera, particularly eastern Selwyn Basin, was generated in late 1970 by the discovery of significant lead-zinc mineralization in Middle Devonian carbonate rocks in the Robb Lake area of northern British Columbia (56°55'N; 123° 45'W). This interest has been sustained since then and has extended well into the Yukon-N.W.T. by virtue of several factors: 1. the steady reports of continued lead-zinc discoveries in lower Paleozoic rocks to the north; 2. the release by the Geological Survey of Canada of several high-quality four mile to one inch geological maps in the areas of interest; 3. the widespread use of a rapid spray-type field test for zinc, and 4. the present political climate for mineral exploration in British Columbia which has resulted in many companies concentrating their attention north of the B.C.-Yukon border.

Most of the significant new lead-zinc discoveries in the eastern Selwyn Basin area (*see* Dawson, K.M. this publication, report 70) were examined by the author during the 1974 field season. With the exception of the Summit Lake (Howard Pass) deposit, all occur in carbonate rocks, most of which are considered to be of Lower Cambrian age. The nature of this lead-zinc mineralization, the bulk of which appears to be stratabound, will be the subject of a future report; the present note deals with the significance of smithsonite ($ZnCO_3$) at many of the localities visited.

Although several carbonate-hosted lead-zinc deposits occur in Canada, none, with the possible exception of the Eclipse and Polaris deposits on Little Cornwallis Island, contain smithsonite in more than mineralogical or academic curiosity amounts. Recent zinc discoveries, however, in the Godlin Lakes (63°45'N; 129°15'W), Goz Creek (64°26'N; 132°31'W), and in the Snake River (64°59'N; 132°18'W) areas have included substantial amounts of zinc carbonate in addition to the conventional sphalerite. For example, Barrier Reef Resources reported intersections of up to 141 feet of "carbonate zone" (i. e. zinc in carbonate rather than sulphide) in the first ten holes drilled on its Goz Creek property (Northern Miner, Aug. 22, 1974). At the time of writing of this report, drill results indicating the full extent of smithsonite in the Godlin Lakes and Snake River areas have not been reported but surface exposures examined by the writer suggest that the smithsonite is much more abundant than for similar deposits elsewhere in Canada.

The abundance of smithsonite in the Northern Cordillera in contrast to its virtual absence in carbonate-hosted lead-zinc deposits in the rest of the country, suggested to the writer that possibly the smithsonite was not simply a product of post-glacial weathering of primary sphalerite. Although the stability field for smithsonite permits it to co-precipitate with calcite (Schmitt, 1962), the nature of the Cordilleran occurrences also precluded an origin by syngenetic precipitation with the host carbonate. Furthermore, the best and most abundant smithsonite is found on the peaks, ridges, and high plateaus of the mountains and seldom occurs, to the same extent at least, in the valleys. This suggested to the writer that perhaps smithsonite was a product of pre-glacial weathering and was preserved on mountain-tops that remained above ice-level as nunataks.

A glance at the Glacial Map of Canada (Geol. Surv. Can. Map 1253A) reveals that the area in question lies well within a unique part of Canada which has been only partly glaciated. Furthermore it lies well west of the westward limit of Wisconsin (or classical) glaciation. In more detail, examination of Map 6-1968 (Hughes *et al.*, 1969) and Map 1319A (Hughes, 1970) and discussions with Dr. N. Rutter (formerly Terrain Sciences Division, Geol. Surv. Can.), shows that the smithsonite occurrences lie in an area in which only certain cirques and/or deep valleys were glaciated. The discovery of deep soil profiles in the same area also suggests that glaciation was minimal and local in its distribution. It would therefore appear that the "sudden" appearance of smithsonite in association with carbonate-hosted lead-zinc deposits in the northeastern Cordillera north of 60° latitude (Mackenzie Fold Belt) can perhaps be attributed to the preservation of the pre-glacial weathering products of a sphalerite-bearing deposit.

The exact age of formation of the smithsonite is

Table 1

A list of selected secondary lead and zinc minerals and certain of their parameters

Mineral	Composition	Metal content (%)	Colour	H	S. G.	Remarks
Smithsonite	$ZnCO_3$	52	Grey, buff, white	4-4½	4-4. 4	Rarely crystalline, usually botryoidal, compact, massive earthy, friable
Cerussite	$PbCO_3$	77	Colourless, white, grey	3-3½	6. 5	Granular, dense
Hydrozincite	$Zn_5(OH)_6(CO_3)_2$	59	White to grey	2	3. 5-3. 8	Usually occurs as white powder. Fluoresces pale blue in ultraviolet light
Minium	Pb_3O_4	91	Scarlet red	2½	8. 9-9. 2	Massive, earthy
Massicot	PbO	93	Yellow	2	9. 6	Massive, earthy
Anglesite	$PbSO_4$	68	White, grey	2½	6. 4	Tabular crystals or stalactitic growth. Massive, may fluoresce yellow in ultraviolet light
Goslarite	$ZnSO_4 \cdot 7H_2O$	23	White	2	1. 9	Dehydrates to a dull white powder

unknown but it must be post-Laramide (Upper Cretaceous - early Tertiary) because this was the time during which much of the present mountain topography was created. Erosion in the Cordilleran Region was dominant during the mid-Tertiary and it is possible that much of the smithsonite formed at this time. The absence of extensive glaciation in the area suggests a dry climate, ideal for the supergene weathering of sphalerite and for the production and preservation of smithsonite. It is interesting to note that the Robb Lake deposit, in contrast to those in the northeastern Cordillera, occurs in an area which was extensively glaciated during Wisconsin time and does not, to the author's knowledge, contain any significant amount of smithsonite. In all of Canada, the Mackenzie Fold Belt, western Yukon, and most of Banks Island are unique in the extent to which they remained unglaciated. In the author's opinion, the "sudden" appearance of smithsonite, a recognized weathering product of carbonate-hosted sphalerite, in this unique area is no accident.

If the origin of substantial amounts of smithsonite in the Mackenzie Fold Belt can be attributed to ancient weathering of pre-existing stratabound lead-zinc deposits in lower Paleozoic carbonate rocks, then several significant factors emerge:

1. The potential for more smithsonite occurrences will increase to the west and north along the Mackenzie Fold Belt and into the Richardson Mountains as the favourable host rocks enter areas of the Yukon which escaped glaciation completely or were only lightly affected (Map 1253A). It therefore behooves the wise prospector to bone up on the physical properties of secondary zinc and lead minerals (*see* Table 1), a factor hitherto considered unimportant in Canada.

2. The extensive, albeit low-grade, zinc carbonate deposits at Goz Creek, together with the increased potential for similar deposits to the northwest, suggests that perhaps techniques for the concentration and/or other ore dressing procedures for smithsonite be examined by Canadian mining companies. Until now, the extraction of zinc and lead from secondary minerals has not been of concern to Canadian metallurgists.

3. The existence of probable secondary zinc deposits in this unglaciated "window" of Canada raises the possibility of secondary deposits of other commodities e.g. bauxite, laterite (both nickeliferous and ferruginous varieties), malachite-azurite, etc.

In the belief that recognition of secondary zinc and lead minerals will be of importance to future prospecting for lead and zinc in this part of Canada, a selected list of secondary minerals with some of their chemical and physical properties are given in Table 1.

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K.M. Dawson
Regional and Economic Geology Division

The accompanying map shows the distribution of significant recent discoveries of zinc and lead in the Mackenzie Mountains, some two dozen of which were examined in the initial phase of a continuing metallogenic study of the northern Cordillera. All occurrences are in strata older than Upper Devonian, and the majority of significant deposits has been found in dolomites of Lower Cambrian age. The strong affinity of base metal deposits for Lower Cambrian rocks elsewhere in the northern Cordillera was noted by Gabrielse (1969) some three years prior to these discoveries in the Mackenzie Fold Belt.

The base metal deposits, most of which appear to be of classic Mississippi Valley type, bear no apparent spatial or genetic relationship to igneous rocks. In fact, none is less than 20 miles east of a line of Cretaceous plutons peripheral to eastern Selwyn Basin (Fig. 1). Zinc, as pale sphalerite, commonly predominates over lead by about 10:1. Silver and iron content of the deposits are low. Pyrite and pyrobitumen are minor constituents, and gangue minerals include sparry dolomite, calcite, quartz and barite. Secondary Zn-Pb minerals, notably smithsonite, are developed in higher ridge-top occurrences that apparently escaped glaciation (*see* Sangster, this publication, report 69).

The deposits follow the trend of Lower Paleozoic strata for 225 miles along the Mackenzie Fold Belt, but may be considered as constituting three "camps": Godlin Lakes, discovered in 1972; Bonnet Plume River in 1973, and an arcuate belt of deposits in the northern Mackenzies discovered mainly in 1974.

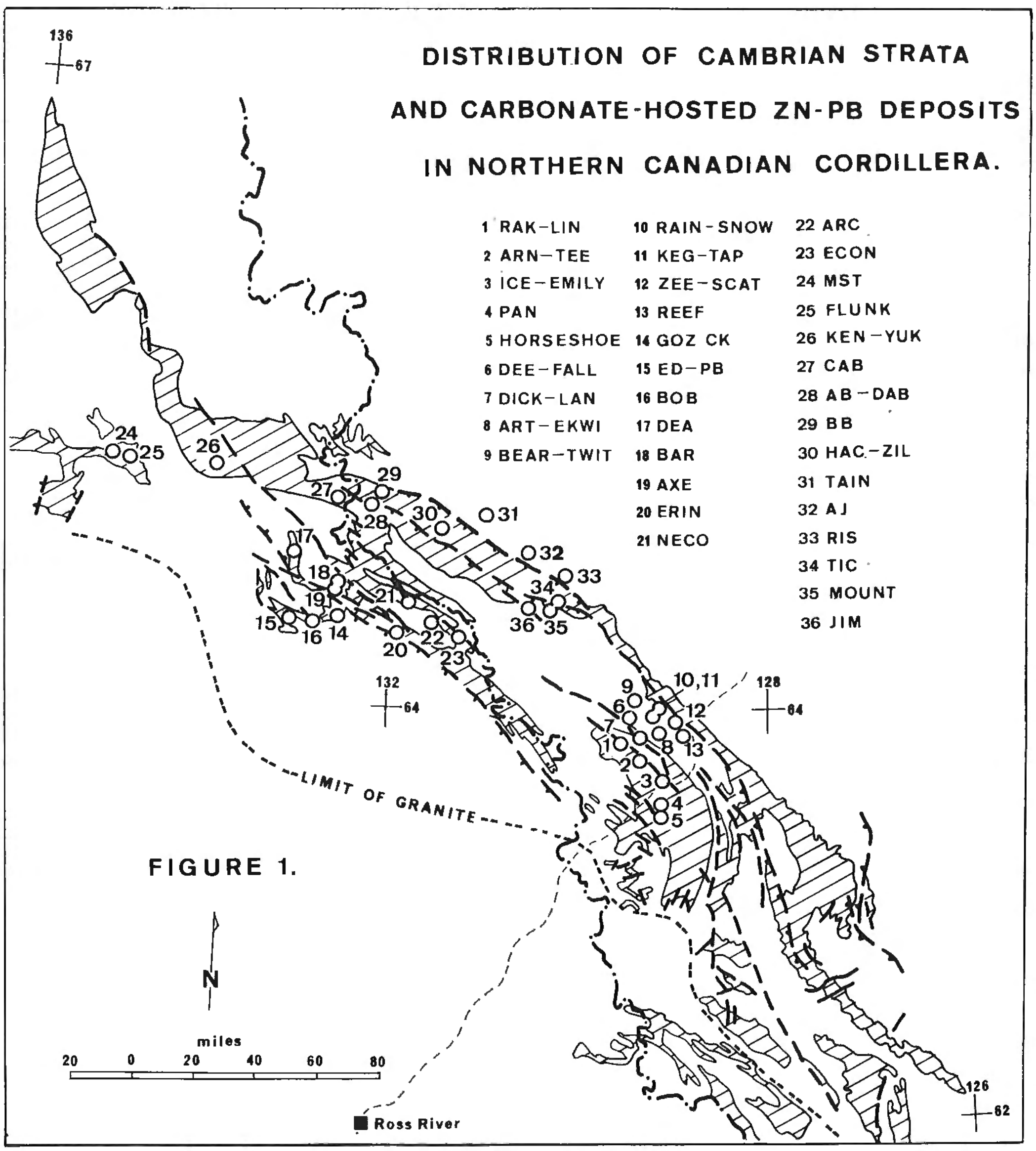

FIGURE 1.

Godlin Lakes

The Godlin deposits are clustered in the Sekwi Mountain map-area (Blusson, 1971) 200 miles northeast of Ross River along the North Canol road. The camp includes 20 zinc-lead prospects that were discovered and/or acquired by Welcome North Mines in 1972-73, and subsequently optioned to other mining companies.

The Sekwi Formation (Handfield, 1968), a porous, orange-weathering Lower Cambrian dolomite, hosts an almost continuous array of stratiform deposits running northwestward from the ICE and EMILY claims of Geomont ($63^{\circ}40'$N, $129^{\circ}05'$W) for 16 miles along strike through to the ARN and TEE claims of Bethlehem ($63^{\circ}44'$N, $129^{\circ}15'$W). A resistant orthoquartzite bed overlain by red and green shale beds serves as a marker horizon about 1500 feet above the base of the Sekwi Formation. Yellow sphalerite, coarse-grained galena and white dolomite fill open spaces in a very porous, 6-mile-long horizon about 100 feet above the quartzite on the ARN-TEE claims, whereas similar, if not more continuous deposits occur 60 feet below the marker horizon on the ICE-EMILY ground.

On the KEG (Dynasty) and TAP (AMAX) claims (63°58'N, 129°13'W) northwest of Godlin Lakes, Upper Cambrian to Silurian dolomites of the Sunblood, Road River and Whittaker formations contain zinc-lead deposits of several forms. Pale yellow sphalerite with galena and pyrite occurs as disseminations and pore fillings throughout permeable horizons in the three units, particularly as interstitial fillings of solution and collapse breccias with white dolomite, and as vug and fracture fillings in reefal Whittaker dolomite.

On the BEAR-TWIT property of Cominco on the Twitya River (64°02'N, 129°25'W), zinc-lead-copper deposits occur mainly in brecciated dolomites of the Upper Silurian to Lower Devonian Whittaker, Delorme and Camsell formations. A window in a southwestward-dipping thrust plate involving the three formations exposes the most intense mineralization in the Delorme Formation. Low-grade stratiform disseminations of fine-grained sphalerite and galena are remobilized and upgraded locally in crackle breccias and fracture zones adjacent to the thrust fault. Fracture-fillings of coarse-grained galena, yellow-green sphalerite, and lesser quartz, calcite, barite and tetrahedrite are irregular in length, width and spacing, but yield highest-grade intersections. Finer-grained (and lower grade) Zn-Pb mineralization, with quartz and calcite, fills the matrix of crackle breccia.

The RAIN-SNOW (63°58'N, 129°16'W) property of Welcome North is a similar deposit in younger rocks that occurs on strike 5 miles southeast of the BEAR showings. Beds of intraformational breccia within black dolomite of the Middle Devonian Arnica Formation contain interstitial sparry white dolomite and yellow sphalerite (Brock, 1973).

The ART-EKWI (63°51'N, 129°12'W) property of Atled Explorations contains secondary Zn-Pb minerals in a fault zone subparallel to steeply-dipping, northwesterly-trending dolomites of the Middle Devonian Arnica and Landry formations. Three showings occur along a strike 1000 feet long, the northernmost of which contains the highest grade zinc deposits. Spectacular smithsonite "dry bone ore" occurs with barite, cerussite and hydrozincite where the fault zone crosses an unglaciated ridge at 6500 feet above sea level (*see* Sangster, this publication, report 96).

Bonnet Plume River area

Following the Godlin discoveries, significant base metal deposits of the same type were discovered 120 miles northwest at Goz Creek by personnel of Barrier Reef Resources in early 1973. Subsequent exploration activity by numerous companies and individuals continued through 1973 and 1974, resulting in the staking of at least 8 important Zn-Pb deposits.

The Goz Creek claims of Barrier Reef (64°26'N, 132°31'W) cover a number of zinc deposits extending more than 2 miles along an east-trending strike of a Lower Cambrian dolomite. The grey, thick-bedded, porous, partly pisolitic and sandy dolostone unit is about 2500 feet thick at Goz Creek, and is overlain by Sekwi dolomite one mile to the east. The principal "A" and "B" zones are characterized by high-grade sphalerite deposits that show both stratigraphic and tectonic controls, within pervasively silicified dolomite. Zinc deposits were controlled initially by primary and secondary porosity; then upgraded by tectonic brecciation along north and northeast-trending faults with concomitant remobilization, and finally modified by supergene alteration.

The striking mineralized breccias at Goz Creek contain sphalerite that varies from white (cleiophane) through pale yellow ("turkey-fat ore") to honey brown and red (ruby zinc). Pyrite and galena are less abundant, and boulangerite ($Pb_5Sb_4S_{11}$), occurs in "B" zone only. Massive smithsonite is common, and cerussite and hydrozincite also occur in the oxidized zone.

Similar Zn-Pb deposits occur on the ED-PB claims of Cypress Resources at 64°26'N, 132°55'W, 15 miles west of Goz Creek on the Bonnet Plume River. About 12 individual deposits occur for 3.5 miles along an east-trending strike of a dolomite unit, immediately below a northerly-dipping contact with overlying brown shale.

The host dolomite resembles that at Goz Creek in most respects, but was considered to be stratigraphically lower by Blusson (1974), and of possible Hadrynian age. Trilobites collected by Blusson and the writer in 1974 from the shale unit on Cypress' claims (G.S.C. Loc. 91689) have been tentatively assigned to the Bonnia-Olenellus zone (Lower Cambrian) by W.H. Fritz (1974, pers. comm.), indicating that the Cypress dolomite may be equivalent in age to the upper, reefoid part of the Sekwi Formation further west (Unit 14A on Sekwi Mountain Map-area, Map 1333A, Blusson, 1971).

Sphalerite deposits occur along an essentially continuous permeable horizon, as disseminations, vug and breccia fillings, and as discordant veins. Pale sphalerite is associated with framboidal pyrite, coarse-grained galena, quartz, sparry dolomite, calcite, barite and pyrobitumen. As at Goz Creek, highest grade deposits of sphalerite-quartz are the result of remobilization within transgressive crackle breccias localized where north- to northeast-trending faults cross the favourable dolomite horizon.

The BOB claims of Barrier Reef Resources (64°24'N, 132°50'W) are located on Harrison Creek, at the eastern end of Cypress' ground. Disseminated pyrite-sphalerite in dolomite extends westward to the ED-PB claims, where it occupies a horizon several hundred feet below the other showings.

Other significant deposits in the area of similar mineralogy, and within rocks of similar age that were not visited by the writer include the DEA claims of Cominco on Corn Creek (64°45'N, 133°00'W) and the ECON claims of Noranda (64°20'N, 131°15'W) 20 miles east of Bonnet Plume Lake.

On the ERIN claims of Clyde Smith (64°23'N, 131°55'W) 5 miles north of Bonnet Plume Lake, base metal deposits occur at the top of an Ordovician carbonate unit that overlies the Sekwi Formation, and is overlain by Devono-Mississippian Besa River shale. The carbonate is brecciated, dolomitized and silicified for thicknessess up to 100 feet below the shale contact, and is impregnated with sphalerite, galena and traces of pyrite.

Interesting Zn-Pb deposits in Siluro-Devonian limestones occur on the AXE claims of Welcome North (64°35'N, 132°31'W) and BAR claims of Andy Harman (64°37'N, 132°29'W) 6 miles west of Goz Lake. Colloform sphalerite with galena and pyrite fills vugs and breccias, in textures reminiscent of Pine Point ore.

Northern Mackenzie Mountains

The last camp visited during 1974 was the belt of deposits extending from Mountain River on the southeast for 175 miles through the Mackenzie Mountains to the Wind River in the Wernecke Mountains on the west.

At the west end of the belt, the FLUNK (65°06'N, 134°47'W) and MST (65°06'N, 135°03'W) claims of Archer-Cathro are located 18 miles southwest of Margaret Lake. The mineralized Lower Cambrian carbonate on the FLUNK claims resembles the Sekwi dolomite, but lacks the orthoquartzite marker bed. It is a white, thick-bedded micritic reefal dolomite that contains a horizon of disseminations and pore fillings of sparry dolomite, pale sphalerite, clear quartz and coarse-grained galena. Clastic content increases above the mineralized horizon, whereas underlying beds are a grey algal dolomite containing large pisolites and Lower Cambrian trilobites. Like the Bonnet Plume River deposits, the best zinc concentrations occur in two transgressive crackle breccia bodies apparently localized along a cross-cutting northwest-trending fault.

A different type of deposit occurs in rocks of the same age five miles west of FLUNK claims on the MST claims. A coarse clastic, partly conglomeratic member of a grit unit that dips 20 degrees south is impregnated with galena, pyrite and sphalerite along a strike several hundred feet long. An underlying reddish-purple shale contains Olinellid trilobites of mid-Lower Cambrian age (Blusson, pers. comm.).

The AB (64°49'N, 132°17'W) and CAB (65°00'N, 132°35'W) claims of Welcome North Mines are located near Gildersleeve Lake at the headwaters of both the Arctic Red and Snake rivers. The same host rock, grey, wispy-banded dolomite of the Sekwi Formation (Blusson, 1974) hosts similar Zn-Pb deposits at the two localities. On the AB claims, breccias that appear to be of both collapse and tectonic origin contain yellow sphalerite, framboidal pyrite, galena, secondary dolomite and barite. The CAB claims cover 7 or 8 deposits extending 10 miles along the strike of a porous horizon in the Sekwi. As elsewhere pale sphalerite occurs both as stratiform pore fillings and as remobilized breccia and fracture fillings.

Other significant Zn-Pb discoveries in this belt that were not visited include the ZIL-HACK (64°50'N, 131°30'W) and TIC (64°30'N, 130°07'W) claims of Serem Ltd., and the BB of Welcome North (65°02'N, 132°10'W) in the Sekwi Formation; as well as the JIM (64°29'N, 130°28'W), AJ (64°46'N, 130°29'W) and RIS (64°36'N, 130°06'W) of Welcome North in Silurian and Devonian carbonate rocks.

Summary

1. A major new zinc province has been discovered in the Mackenzie Fold Belt of the northern Canadian Cordillera.

2. Numerous deposits of Mississippi Valley type are hosted in Lower Paleozoic rocks, mainly Lower Cambrian carbonates.

3. Low-grade, stratiform sphalerite-galena deposits in porous dolomites are remobilized and upgraded locally mainly by tectonic means.

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THE GEOLOGY OF MOLYBDENUM AND COPPER DEPOSITS IN CANADA

A.E. Soregaroli
Regional and Economic Geology Division

The Molybdenum-Uranium Association

During the investigation of Canadian molybdenum deposits it has become increasingly apparent that the association of molybdenum with uranium may be of economic importance. This association has been reported in a wide variety of deposit-types which includes: pegmatites, base metal veins, skarns, pyroxenitic metamorphic rocks, Colorado Plateau uranium deposits, and porphyry deposits. In most reported occurrences, either molybdenum or uranium is the dominant metal with the other element occurring in trace or very minor amounts. However, some deposits contain potentially recoverable quantities of both metals and these require special recognition.

1. Makkovik Area, Labrador (British Newfoundland Company, Limited)

Geology of the Makkovik area has been described by Gandhi *et al.* (1969), Clark (1971), and Taylor (1972). Molybdenum mineralization, which is generally, but not always, accompanied by variable amounts of uranium, occurs in highly metamorphosed, massive to foliated, acidic volcanic derivatives of the Precambrian Aillik Group. Some molybdenite is found as disseminations in granitic rocks in the area.

At the Cape Makkovik and Sunil showings molybdenite is restricted to tabular, pyrite-rich zones which generally parallel the stratigraphy of the enclosing metavolcanic rocks. For the most part molybdenite flakes and seams parallel the internal foliation of the rocks, but some larger pyrite-molybdenite veins up to one centimetre wide cut the foliation at an angle of about 20 degrees. Dark purple fluorite occurs as disseminations and in veins which cut the foliation nearly at right angles.

Uranium minerals were not observed in hand specimen, but locally are of economic interest. There appears to be a general spatial relationship between fluorite and uranium. All uranium does not occur with molybdenite. Several uranium deposits, in which molybdenite has not been observed, are known in the Makkovik area (Gandhi, 1969). For this reason Gandhi (pers. comm.) feels the molybdenum and uranium mineralization is genetically unrelated. Although the author spent a very short period of time examining the deposits, he feels the spatial relationship between molybdenum and uranium suggest a genetic kinship which requires further definition.

2. Thelon-Kazan Area, Northwest Territories (Dynamic Mining Exploration Ltd. and Pan Ocean Oil Limited)

Little has been reported on the geological relationships of the uranium and molybdenum deposits of the Thelon-Kazan area. The following information was released by Dynamic Mining Exploration Ltd. (Northern Miner, August 8, 1974, p. 17):

"Prospect 68-1 has been drilled .... A mineralized volume containing 160,000 lb. U_3O_8 and 150,000 lb. MoS_2 has been estimated."

Prospect 68-2 .... "Estimates run to a maximum of one million pounds of U_3O_8 and 2,000,000 lb. MoS_2 in the mineralized body."

From these data it is obvious that molybdenum-uranium mineralization with apparent genetic relationship is being explored.

3. Rexspar Property, British Columbia (Consolidated Rexspar Minerals and Chemicals Ltd. and Denison Mines Ltd.)

Uranium and fluorite mineralization have been known for many years at the Rexspar property. Mineralization occurs in several zones in pyritic schists and phyllites and in a crosscutting feldspar porphyry dyke (McCammon, 1954). Consolidated Rexspar Minerals and Chemicals Ltd. report reserves of 1,561,000 tons grading 1.76 lb. U_3O_8 per ton and 1,500,000 tons of fluorite (Canadian Mines Handbook; 1974/75, p. 93). Molybdenite in potentially recoverable amounts accompanies purple fluorite in zones which are concordant with enclosing rocks.

4. Carmi Property, British Columbia (Vestor Explorations Ltd. and Kennco Explorations (Canada) Ltd.)

Molybdenite has been found disseminated through a breccia composed of gneissic granodiorite fragments in a matrix of quartz and comminuted rock, in sericite-rich alteration envelopes on quartz veins, and as rosettes in crosscutting quartz-biotite porphyry dykes. Uraninite has been found in drill core and in trenches as fine, discrete grains up to 3 mm in diameter. Purple fluorite is also present. One section of drill core assayed 0.05% U_3O_8 and 0.34% MoS_2 over a 35-foot length (A. Rich, President, Vestor Exploration Ltd., pers. comm.). Uranium does not accompany all molybdenite zones.

The presence of disseminated rosettes of molybdenite in quartz-biotite porphyry dykes which cut the breccia suggests a genetic relationship between the dykes and the molybdenite. A genetic relationship between molybdenum and uranium has not been established.

Conclusions

The molybdenum-uranium association may become economically significant in Canada. The general fine grain-size and black colour of the uranium minerals could make recognition difficult and cause them to be overlooked. Because the molybdenum-uranium association has been recognized in such diverse classes of deposits, it is suggested that all molybdenum deposits should be tested for the presence of uranium.

Copper and Molybdenum Deposits of the Okanagan Area, British Columbia

A study of copper and molybdenum deposits in the Okanagan area of British Columbia was initiated as a National Research Council project (grant A8850) while the author was at the University of British Columbia and is continuing as part of a study of Canadian copper and molybdenum deposits by the Geological Survey of Canada.

Many copper and/or molybdenum deposits are known in the Okanagan area. Most of these, with the notable exception of the Brenda Mine, are sub-economic or remain incompletely tested but are of interest because of their association with intrusive igneous rocks of widely divergent compositions. In an effort to establish genetic relationships and ages, eleven deposits were selected for detailed studies. One of the deposits, Brenda Mine, is the only one that has been studied in detail (Carr, 1967; Soregaroli, 1968, 1974; Oriel, 1972) and is used as a basis for comparison with other deposits.

Preliminary studies suggest two broad categories of deposits:

1. Molybdenum and copper-molybdenum deposits related to calc-alkaline intrusive rocks (quartz monzonite-granodiorite-quartz diorite e.g. Brenda, Susap, Carmi).
2. Copper deposits related to alkaline intrusive rocks (syenite-syenomonzonite-alkalic peridotite e.g. Lynx, Olalla, Whiterocks).

These two categories of deposits probably were formed during separate metallogenic epochs. Preliminary K/Ar dating of samples from the Brenda deposit by White *et al.* (1968) suggest an age of 148 m.y. for the mineralization. The interpretation of these ages is subject to some controversy and more samples have been submitted for K/Ar dating to more clearly define the age of the Brenda deposit.

Radiometric dating of intrusive rocks in the area by other workers (Roddick *et al.*, 1973; Peto, 1973) generally have centred around non-mineralized intrusive rocks. As part of the present study, fresh and hydrothermally altered (biotite/sericite) intrusive rocks, as well as biotitized wall-rocks (hornfels), where available, have been submitted for K/Ar dating.

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A STUDY OF COPPER MINERALIZATION IN MISSISSIPPIAN ROCKS OF THE ATLANTIC PROVINCES

Project 700059

W.P. Binney[1] and R.V. Kirkham
Regional and Economic Geology Division

Introduction

In 1973 a program was initiated to study the distribution of copper in basal Windsor limestone and immediately underlying clastic rocks, mostly of the Horton Group (Binney and Kirkham, 1974). These Lower Carboniferous sedimentary strata were chosen for study because copper minerals had been noted along their contact at several localities by previous workers, including Fletcher (1884), Williams (1914), Smith (1956) and Oldale (1967), and because the second author thought the mineralization might be analogous to that found in the Kupferschiefer of Europe (Kirkham, 1971). The 1973 field program dealt with Carboniferous sedimentary basins in Cape Breton Island and northern mainland Nova Scotia; whereas, the 1974 field program dealt with Carboniferous sedimentary basins in New Brunswick and Newfoundland as well as Nova Scotia.

Ten weeks were spent by the first author and two weeks by the second in the Atlantic Provinces documenting and sampling the strata for geochemical, mineralogical and petrographic studies. Of this time, one week was used by the first author for follow-up sampling near the Kaiser celestite mine at Lake Enon to clarify trends indicated by laboratory work on 1973 samples.

Stratigraphy and Sulphide Occurrence

The principal concern of this study is the contact of the basal Windsor limestone (A_1 or Macumber in Nova Scotia, Ship Cove in Newfoundland) and the underlying clastic sedimentary rocks (Horton Group or Grantmire Formation of the Windsor Group in Nova Scotia, Anguille Group in Newfoundland, Moncton Group in New Brunswick).

In northern mainland Nova Scotia and Cape Breton Island the basal limestone is typically dark grey to black, laminated, micritic, and carbonaceous. In the Windsor type area of Nova Scotia this limestone, however, is pale to medium grey, has a reddish tint, is crystalline, and is not carbonaceous. Limestone of this latter type was also noted at many localities in New Brunswick, except at Upham and near Hillsborough where dark, laminated limestone was observed. In Newfoundland, the basal or Ship Cove limestone, in general, closely resembles the A_1 on Cape Breton Island, except that in some areas it has a reddish cast.

A variety of stratigraphic relationships have been established between the limestone and the underlying rocks:

1. The basal limestone overlies, apparently conformably, a thick sequence of clastic rocks (commonly conglomerate). Typically these clastic rocks are red beds with one to twenty feet of green beds at their top. Examples of this type of contact are numerous and include Big Marsh (*see* Fig. 1), Rights River, Whycocomagh, and East Bay, in Nova Scotia, and Upham and Hillsborough in New Brunswick. At some localities (e.g. Steep Creek, Nova Scotia and the Codroy type area, Newfoundland) very thick green-grey sections with few or no red beds underlie the limestone.

2. The basal limestone lies with angular unconformity on red clastic sediments. The most striking example of this configuration is at Finlay Point, Nova Scotia where typical A_1 limestone and a four-inch-thick cobble conglomerate unconformably overlie relatively well indurated sandy, red pebble conglomerate.

3. The basal limestone conformably overlies a thin (about five-foot) bed of green-grey cobble-pebble conglomerate which in turn unconformably overlies

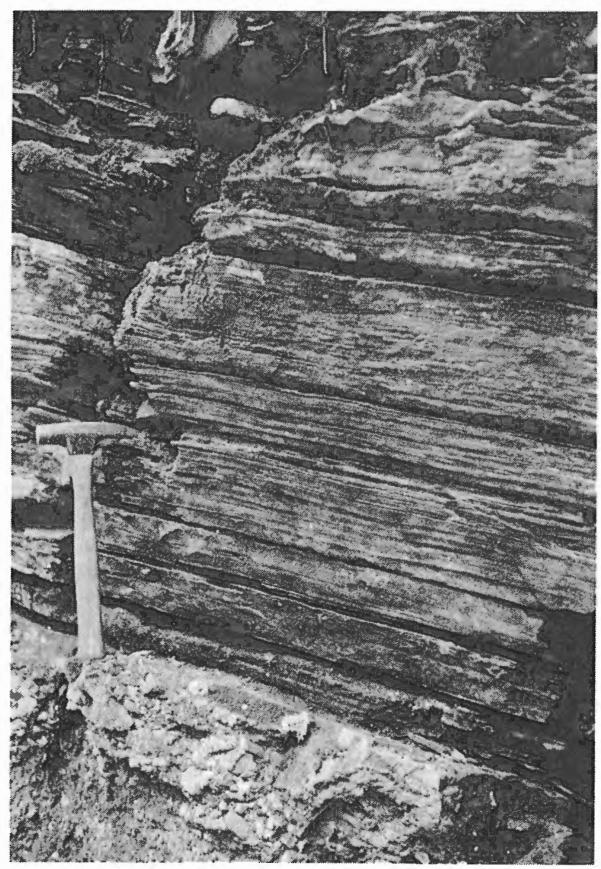

Figure 1. Typical basal Windsor limestone (A_1) overlying green pebble conglomerate of Horton Group, Big Marsh, N.S.

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[1]Queen's University, Kingston.

red and white sandstones. This type of contact has been observed north of Antigonish, Nova Scotia at McIsaac Point and Lakevale. It is believed that a similar contact may exist near Soldiers Cove on Cape Breton Island, but deformation and minor overburden at this locality have obscured the contact relationships.

4. The basal limestone directly overlies crystalline basement rocks such as at Albert Mines, New Brunswick, and at Lake Enon and Springville, Nova Scotia.

Although minor copper mineralization has been found at the basal limestone contact in each configuration, the most common and consistently mineralized contacts are Type I i.e. those where the basal limestone conformably overlies a thick sequence of red clastic sediments, with a green zone directly beneath the limestone.

In all configurations the copper sulphides, although characteristically very sparse, are relatively most abundant in the extreme base of the limestone and where present, the uppermost green portion of the underlying clastic units. Other sulphides, particularly galena and sphalerite, have also been observed in polished sections of the limestone.

Regional Copper Distribution

In the Antigonish-Strait of Canso area sparse chalcocite or chalcopyrite can be found at most exposed Windsor-Horton contacts. Chalcopyrite has also been found at Springville and south of Truro, near Brookfield. The limestone farther to the southwest, around Windsor, is red-pigmented and contains no visible sulphides. In drill core from the Gays River area scattered chalcopyrite has been found in discontinuous beds of dark, laminated, basal Windsor limestone which could be A_1 or Macumber limestone.

In east-central Cape Breton Island most observed contacts have sparse chalcopyrite along them. But to the west and northwest only pyrite has been noted.

Very limited success was achieved in extending the zone of copper occurrences into New Brunswick. In general, most basal limestone is white or red, crystalline, and contains no visible sulphides. Only two copper occurrences were seen, these being at Goshen and near Hillsborough. At Goshen, abundant malachite occurs in green conglomerate of the Moncton Group (Hawkins, 1958) at an unknown distance below the basal limestone; near Hillsborough very sparse malachite and chalcopyrite occur in green conglomerate underlying a basal grey, laminated limestone. At Upham, New Brunswick, medium grey, laminated limestone with sparse pyrite overlies green and red conglomerate and is very similar to many copper-bearing localities in Nova Scotia; however, even with considerable searching, no copper was found at this locality.

At Ship Cove in Newfoundland, minor chalcocite occurs in veins in basal pyritic Windsor limestone directly above reddish, hematitic limestone. In the Codroy type area thick sections of green-grey, pyritic arkosic sandstone without red beds underlie the Ship Cove limestone. These sections without red beds, although pyritic, typically do not contain visible copper minerals.

Work to date indicates that sparse copper mineralization is present throughout east-central Cape Breton Island and northern mainland Nova Scotia. However, it is not present in the Windsor type area, and only occurs in scattered localities in New Brunswick and Newfoundland.

The copper characteristically occurs where dark, anoxic, fine-grained, laminated limestone overlies red clastic sediments with a bleached green zone near their top. It does not occur where typical basal Windsor limestone rests on a thick section of anoxic, green-grey clastic sediments. These localities tend to be pyritic. The copper also does not characterize the more oxygenic, reddish, hematitic limestone areas. However, some of these hematitic areas might be analogous to the "Rote Fäule" facies of the Kupferschiefer and, as such, might be expected to have copper along their margins or stratigraphically above the hematitic facies (Rentzsch, 1974).

Selected Copper Localities

A few of the more significant copper localities as well as a new occurrence discovered by the first author are described below:

Coxheath, N.S.

Musgrave Showing

lat. 46°07'48" long. 60°20'30"

McMullin Showing

lat. 46°06'14" long. 60°23'05"

Several small showings occur along the northwest side of the Coxheath Hills, six miles southwest of Sydney, Nova Scotia. Two of the most accessible of these showings occur near the Frenchvale road; the Musgrave showing, in a small borrow pit beside the road, and the McMullin showing on Frenchvale Brook just southeast of McLeanville (Bell and Goranson, 1938).

At these showings a thin section of dark laminated limestone overlies green and red conglomerate of the upper Grantmire Formation. Minor chalcopyrite is disseminated in the basal few inches of the limestone, and malachite occurs throughout the upper two to four feet of the green conglomerate.

This area was drilled by Mariner Mines in 1967 and Cerro Mining Company of Canada in 1970. This work established that about 0.2 to 0.3% copper over 3 to 4 feet is continuous for more than three miles along strike.

Rights River, N.S.

lat. 45°38'00" long. 62°01'13"

This showing is on South Rights River about 1.5 miles northwest of Antigonish. At low water, the basal part of the A_1 limestone is exposed about two

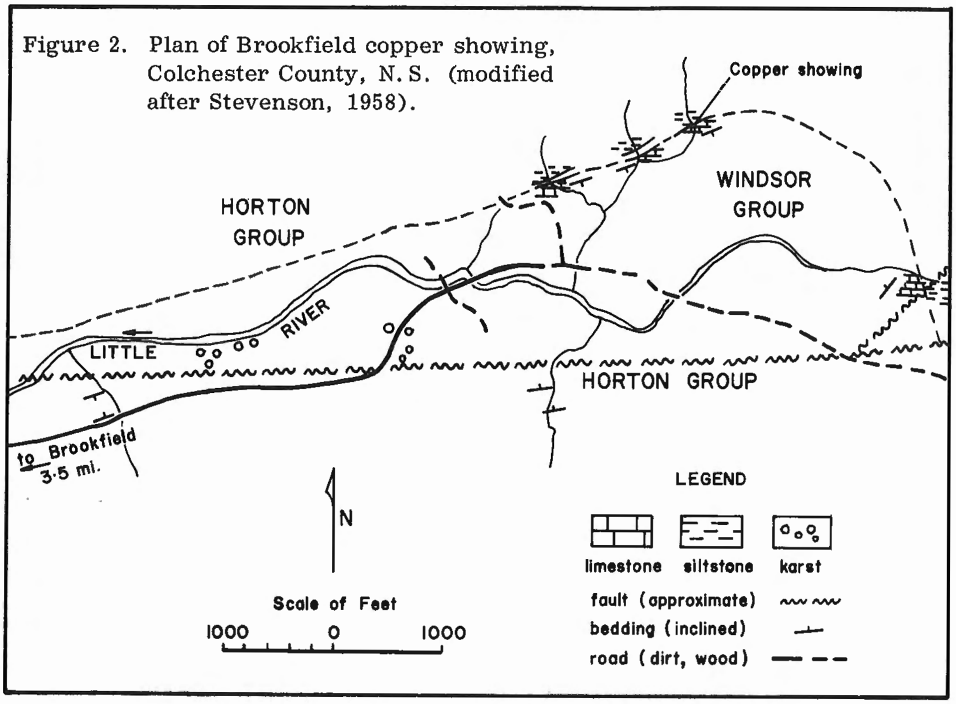

Figure 2. Plan of Brookfield copper showing, Colchester County, N.S. (modified after Stevenson, 1958).

hundred feet upstream from where the Antigonish to North Grant road crosses the river (Benson, 1970). Eighteen inches of typical dark grey, laminated limestone underlain by five feet of green conglomerate and a thick section of red conglomerate occur in the bed of the river.

Visible chalcocite and malachite occur in both the green conglomerate and limestone. In the limestone chalcocite occurs erratically disseminated along the bedding laminae with minor chalcocite and trace amounts of chalcopyrite occurring in small carbonate veins. Analyses of this limestone showed that there is about 0.4 to 0.6% copper over approximately eighteen inches.

During 1973 Imperial Oil drilled two holes about 1,000 feet east and 2,000 feet southeast, respectively, of this showing. Assays of these cores indicated only very low copper values along this contact.

Brookfield, N.S.

lat. $45^{o}16'32''$ long. $63^{o}13'07''$

The copper showing is located four miles northeast of Brookfield and 1.8 miles east of the Brookfield barite deposit (Stevenson, 1958). Access to the area is by a dirt road that branches off the Brookfield to Middle Stewiacke highway a mile east of Brookfield.

Basal Windsor limestone and underlying Horton clastic rocks outcrop along all three tributaries of a stream which crosses the main bush road (*see* Fig. 2). However, only on the easternmost tributary could the contact be exposed by digging in the valley wall.

At the base of the stratigraphic section is an unknown thickness of red siltstones and fine-grained sandstones. These red beds are overlain by about ten feet of green-grey, fine-grained sandstone. Above this is twenty-five feet of typical dark, fine-grained, laminated, carbonaceous Macumber limestone.

On the easternmost tributary, the basal foot of limestone is very carbonaceous and contains abundant disseminated chalcopyrite. Analyses indicate that it contains about 0.2% copper but negligible amounts of lead, zinc and silver. Specks of chalcopyrite were also seen in the lowermost exposed limestone in the middle tributary, suggesting that the mineralization is continuous from one outcrop to the next and could possibly be exposed in the middle and west tributaries by trenching.

At the time of the first author's visit (June 2, 1974) there was no evidence to indicate that this copper occurrence had been exposed or sampled previously.

Conclusions

Field and laboratory studies have substantiated that copper is widely but sparsely distributed along the basal Windsor limestone contact in parts of the Atlantic Provinces. However, the results of this work have not been encouraging for the discovery of economic deposits; nevertheless, much of this contact still has not been explored and there remains a possibility that significant copper deposits may occur somewhere along it.

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PRELIMINARY ASSESSMENT OF PORPHYRY DEPOSITS IN THE CANADIAN APPALACHIANS

Project 700059

R. V. Kirkham and A. E. Soregaroli
Regional and Economic Geology Division

Introduction

Despite the fact that the majority of porphyry deposits being mined are Mesozoic or younger and occur in one of the world's two young mobile belts, the Tethyan or Circum-Pacific, there is considerable interest in the possible occurrence of porphyry deposits in old mobile belts. In the Canadian Appalachians porphyry deposits have been sought for at least 10 years, but with only limited success. Although porphyry deposits have been found in the Canadian Appalachians, with perhaps the exception of Gaspé Copper, which is mainly a skarn deposit, no large well-mineralized "porphyry systems" have been discovered.

As part of continuing studies of copper and molybdenum deposits in Canada the authors have examined briefly a number of deposits in the Canadian Appalachians that have been called porphyry deposits or might be somewhat similar to typical young porphyry deposits. Such examinations will continue but this paper is a brief statement of impressions formed to date.

In this paper a porphyry deposit is considered as "...a large, low to medium grade deposit in which the hypogene sulphides are primarily structurally controlled and which is spatially and genetically related to felsic or intermediate porphyritic intrusions" (Kirkham, 1972). This short definition is meant to include most traditional porphyry deposits (except skarns) but is also meant to give enough latitude to accommodate significant variations that occur within the group. When used in this paper the term is meant to convey a strong analogy with well accepted porphyry deposits of the Cordilleran System. Cordilleran System

A separate class of deposits with "porphyry affinities" is used to refer to deposits that are either too limited in extent to justify classification as porphyry deposits, or where there are insufficient data available on the occurrence to be certain of its overall nature, or where the deposit has significant differences from, as well as similarities to, typical porphyry deposits. By using this class of deposits we hope to avoid any possible confusion with major economic porphyry deposits, yet still be able to draw attention to occurrences that have some similarities to typical porphyry deposits.

With the exception of Rencontre East, Figure 1 shows the distribution of only those porphyry deposits and deposits with "porphyry affinities" that have been examined by one or both of the authors.

Porphyry Deposits

The Catheart Mountain deposit in Maine is included because it is perhaps the best example of a porphyry deposit known in the Appalachian System (Schmidt,

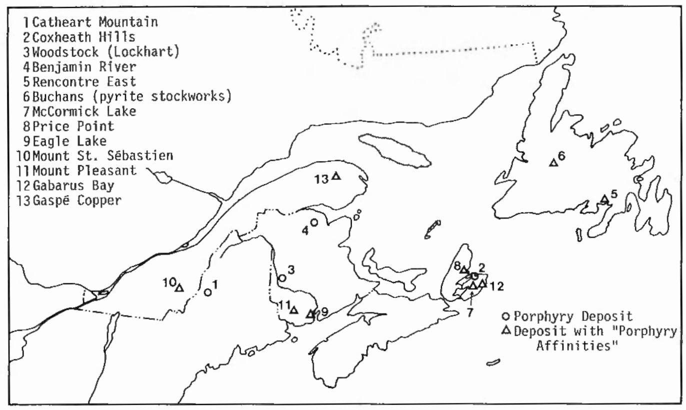

Figure 1. Location map.

1974). Although subeconomic at present, it has been extensively explored and contains a well developed copper and molybdenum zone as well as associated intense alteration.

The Coxheath Hills deposit on Cape Breton Island has a Central Zone (*see* Oldale, 1967, Fig. 2, p. 316) containing widely distributed but sparse chalcopyrite, molybdenite, and bornite along fractures and in erratic sets of quartz veins with associated potash feldspar alteration. The main host rock is a fine- to medium-grained quartz diorite(?). Mineralization is similar to that of some Cordilleran porphyry deposits with abnormally low pyrite content being particularly analogous to the Highland Valley and Brenda deposits in British Columbia. This deposit, however, has been somewhat deformed and contains local areas of folded quartz veins (Fig. 2). Cormier (1972) indicated that intrusive rocks in the area are about 580±70 m.y. old or near the Cambrian-Precambrian boundary.

The main Woodstock (Lockhart) deposit (anomaly number one) occurs immediately north of the Kilmarnock road about three miles east of Woodstock, New Brunswick. Pyrrhotite, pyrite and lesser chalcopyrite with trace amounts of molybdenite occur along fractures and disseminated in propylitically altered metasediments and irregular masses of medium-grained granodiorite or quartz diorite. Exploration by Falconbridge Nickel Mines Limited in 1970 (Lockhart, 1971) and Bethlehem Copper Corporation Ltd. and United Siscoe Mines Ltd. in 1974 has indicated a large tonnage of very low grade copper mineralization in the number one anomaly area as well as other mineralized zones on the property. Anderson (1968, p. 34) indicated that granitic rocks in the area are of Devonian age.

The Benjamin River deposit is located along South Benjamin River about 11 miles by road west of New

Mills, New Brunswick. It was discovered by Soquem and Umex in 1968 during the course of a regional geochemical survey. Exploration, which included greater than 15,000 feet of diamond drilling by Soquem and Umex between 1970 and 1973, demonstrated the presence of scattered subeconomic porphyry copper mineralization in the area (personal communication and New Brunswick assessment files). Sparse pyrite, chalcopyrite, and trace amounts of molybdenite with some biotite occur along fractures and disseminated in quartz monzonite dykes and hornfelsic volcanic rocks. Work to date on this property has not been encouraging. Intrusive rocks in the area appear relatively little deformed and, hence, are probably of Devonian age.

Deposits with "Porphyry Affinities"

The molybdenum deposits at Rencontre East in Newfoundland have been described by White (1940) and Snelgrove and Baird (1953). A number of deposits in aplites, pegmatites, and quartz veins occur in association with the Ackley batholith. Although neither author has examined these deposits, available descriptions indicate that most of the sulphide mineralization is too erratic and too closely associated with aplites and pegmatites to be considered typical porphyry mineralization. Hence, for the time being even though other authors (Hollister *et al.*, 1974) consider this a porphyry deposit, we would prefer not to classify it as such.

Buchans, Newfoundland is famous for its high grade, volcanogenic massive sulphide deposits. However, as shown by Thurlow (1974, p. 73) some large pyritic stockwork zones occur in highly altered volcanic rocks in the Buchans area. For the most part these pyritic stockworks are barren, but the easternmost body at Little Sandy Lake contains some copper mineralization. Nevertheless, at the present time it is not known whether or not this mineralization is similar to the stratigraphically-controlled stockwork orebodies below the Lucky Strike and Oriental stratiform massive sulphide deposits (E. Swanson and E. Perkins, pers. comm.). It should be noted that the Little Sandy Lake pyrite zone is greater than 15,000 feet long and 5,000 feet wide and unlike the stratiform massive sulphide deposits, which are restricted to volcanic Cycles One and Two, it cuts Cycle Four volcanic rocks (Thurlow, 1974). Further work is necessary to document the three dimensional nature of these pyrite zones, but, judging from the first author's observations in the Canadian Shield, it would not be unusual to find porphyry-type mineralization in a massive sulphide district.

At McCormick Lake on Cape Breton Island very minor chalcopyrite in sparse quartz veins has been exposed in some very long trenches in the contact zone of a quartz monzonite body and adjacent pyritic hornfels. Sparse but widely distributed chalcopyrite and molybdenite have also been noted in a diorite body (Hawkes, 1967). Although this mineralization could have some genetic affinities to typical porphyry mineralization, from what the first author was able to observe during a visit in 1970, the mineralization is simply too sparse to justify classification as a porphyry deposit.

The Price Point deposit occurs on St. Ann's Mountain in a brook about one mile west of Price Point, Nova Scotia. Minor pyrite, chalcopyrite, and trace amounts of molybdenite occur along fractures and disseminated in altered granitic rocks. Based on rubidium-strontium work of Cormier (1972) and the distribution of old granitic rocks in this part of Cape Breton Island, there is a strong possibility that granitic rocks in this area are about the same general age as Kelly Mountain (568±35 m.y.) and Coxheath Hills (580±70 m.y.). The mineralization observed by the first author during a visit in 1973 is too erratic and sparse to justify the classification as a porphyry deposit; nevertheless, it has some similarities to typical porphyry mineralization.

Figure 2. Folded quartz veins with chalcopyrite and molybdenite in altered quartz diorite(?) Coxheath Hills, Nova Scotia.

At Eagle Lake, New Brunswick, pyrite mineralization with very minor amounts of chalcopyrite and trace amounts of molybdenite occur along fractures, in quartz veins, and disseminated in a porphyritic quartz monzonite stock (Ruitenberg, 1969). Although this deposit has some "porphyry affinities" it is far too sparse to justify calling a porphyry deposit.

At Mount St. Sébastien, Quebec pyrrhotite, molybdenite and minor chalcopyrite occur in quartz stringers in hornfels adjacent to a biotite quartz monzonite plug. A small tonnage of moderate grade molybdenum ore has been blocked out on this property. Many features of these deposits are similar to those of porphyry molybdenum deposits; however, the mineralized zones documented to date are too small to be considered a porphyry deposit, even though they probably have genetic affinities to more typical porphyry deposits. The intrusions in the area have been dated as Devonian by K/Ar methods.

The important complex Mount Pleasant W, Mo, Bi, Sn, Cu, Zn, Ag, fluorite deposits (Parrish and Tully, 1973; Petruk, 1973; Dagger, 1972) have some similarities to Cordilleran porphyry deposits yet also have some basic differences. The main body of W, Mo, Bi mineralization occurs in highly silicified rhyolite porphyry breccia pipes with the Sn, Cu, Zn, Ag mineralization occurring in more restricted zones around their periphery. The size, setting, and structural control of mineralization is similar to that of typical Cordilleran porphyry molybdenum deposits; however, the complex polymetallic nature of the mineralization with major amounts of W, Bi, Sn, Zn, F, and As, the complex mineralogy, the very marked telescoping of mineral zones, and the very intense metasomatism with numerous erratic replacement pods make this mineralization quite distinct from a typical porphyry deposit. A tentative suggestion to explain these major differences is that at Mount Pleasant fluorine dominated the anion chemistry of the ore fluids, whereas, chlorine dominated the anion chemistry of the ore fluids of typical porphyry deposits. To avoid possible confusion, for the time being the present authors would prefer not to classify Mount Pleasant as a porphyry deposit (*see* Hollister *et al.*, 1974). The age of Mount Pleasant mineralization and associated intrusive and extrusive rocks has been established as Lower Mississippian (van de Poll, 1967).

Similar polymetallic Mo, Bi, Cu, Zn, Pb, Ag mineralization occurs at Gabarus Bay, Cape Breton Island. Pyrite, pyrrhotite, molybdenite, chalcopyrite, and lesser sphalerite, galena, and bismuthinite occur along fractures, in quartz veins, and disseminated in small, altered quartz monzonite porphyry bodies and adjacent hornfels. Cormier (1972) has indicated that the age of intrusion in this area is 350±25 m.y. This mineralization has some general similarities to typical porphyry mineralization but its polymetallic nature, the presence of widely separate copper and molybdenum zones and other features suggest some significant differences.

At Gaspé Copper pyrite, chalcopyrite, pyrrhotite, bornite, and molybdenite occur disseminated and in fractures in skarns and to a lesser degree in small bodies of Devonian porphyries. Allcock (1974) has recently suggested a multistage model for sulphide deposition with skarn mineralization being followed by more typical porphyry-type mineralization with associated hydrous potassic alteration. These important deposits are analogous to the large skarn deposits south of Tucson, Arizona that are frequently referred to as porphyry deposits. Even though the present authors would prefer to refer to the main deposits as skarns or contact metasomatic deposits, they would like to stress that this type of skarn deposit is very closely genetically related to typical porphyry deposits and commonly occur in the same area as typical porphyry deposits or as part of much larger "porphyry systems".

Conclusions

Numerous minor copper and molybdenum occurrences associated with granitic rocks and some porphyry deposits, not unlike some economic Cordilleran porphyry deposits, are known in the Canadian Appalachians. Nevertheless, with the possible exception of Gaspé Copper, exploration to date has not been particularly encouraging for the discovery of major economic deposits or indicating that porphyry deposits are particularly abundant in the Appalachian System. However, known occurrences are poorly documented and much exploration remains to be done before the nature and distribution of porphyry deposits in the Canadian Appalachians can be properly assessed.

Known deposits range in age from possibly late Precambrian(?) (Coxheath Hills) to Mississippian (Mount Pleasant) with most of them probably being Devonian. Some old deposits such as Coxheath Hills have undergone low grade regional metamorphism and local penetrative deformation. Reconstructions of such deposits may be quite difficult.

The distribution of deposits is still not well established although old deposits such as Coxheath Hills might be expected to occur in old volcanic-intrusive terranes such as, those within the Caledonian Highlands of New Brunswick, the Cobequid Highlands of Nova Scotia, Cape Breton Island and the Avalon Zone of Newfoundland. Devonian deposits may occur in a series of approximately north-south belts, such as the broad belt extending from the Gaspé area into southern New Brunswick.

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74. GEOLOGY OF COPPER AND MOLYBDENUM DEPOSITS IN CANADA

Project 700059

R.V. Kirkham
Regional and Economic Geology Division

Work continued on the general investigation of copper and molybdenum deposits in Canada with field examinations being concentrated in the Canadian Appalachians and, to a lesser extent, in the Superior Province in Quebec. Major stratiform "sedimentary" copper deposits in Poland and Zambia were visited in order to compare with Canadian occurrences. This first hand knowledge of these important deposits should prove useful in the study of Canadian occurrences. Selected volcanogenic massive pyrite deposits and associated copper "stringer zones" in the Rio Tinto district of Spain were briefly visited in order to gain a better understanding of hydrothermal feeder systems of typical massive sulphide deposits. Aspects of these field examinations will be incorporated with other studies and reported elsewhere.

75. NICKEL POTENTIAL OF THE PRINCE ALBERT GROUP, N.W.T.

Project 630037

O.R. Eckstrand
Regional and Economic Geology Division

Previous mapping of the Prince Albert Group (Heywood, 1961, 1967; Campbell, 1974; Frisch, 1974 and Schau, 1974) has revealed the presence of numerous ultramafic bodies, a compilation of which is shown in Figure 1. During the 1974 field season, the writer examined some of these ultramafic rocks in 6 separate areas in order to gain some appreciation of their nickel potential. The writer gratefully acknowledges helicopter support and field guidance supplied by V. and D. Kretschmar, Cominco Ltd., in the Hayes River area, (A and B, figure 1) and the following Geological Survey officers: T. Frisch, in the Mackar Inlet area (C and D), M. Schau, in the Hall Lake area (E and F) and J.E. Reesor, in southern Melville Peninsula.

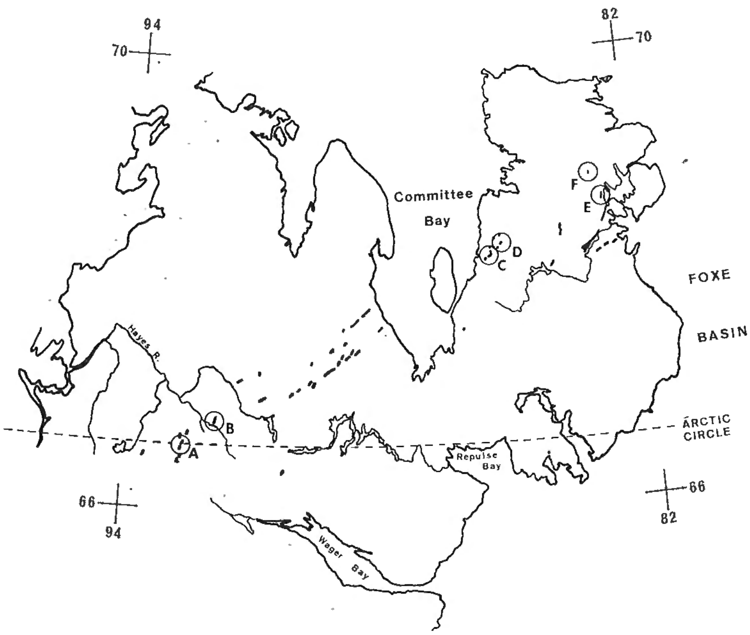

Figure 1. Compilation map of ultramafic bodies in parts of the Districts of Franklin and Keewatin. From data by Heywood (1961, 1967), Campbell (1974), Schau (this publication), J.E. Reesor (pers. comm.) and T. Frisch (pers. comm.). Letters indicate localities visited by the writer during the 1974 field season.

The most noteworthy finding was that a significant proportion of the ultramafic rocks seen are of extrusive origin, closely similar in morphology and primary textures to the ultramafic flows of Munro township (Pyke *et al.*, 1973). Of the six localities shown in Figure 1, two (A and C) contain sequences of clearly identifiable, spinifex-bearing flow units, from which unequivocal facings were determined. In two other localities (B and D), the presence of flows seems likely.

Locality A in Figure 1 is an area with a great concentration of ultramafic rocks (*see* Schau, this publication, reports 94, 95). In one outcrop, 1 to 2 metres thick, ultramafic flow units exhibit well preserved grain-size gradation of the spinifex zones (Fig. 2, 3) all indicating northwest-facing of the flows. Weathering of the flows produces colour bands, the spinifex layers appearing as dull grey-green bands and the cumulate layers (originally more olivine-rich) as brighter reddish-brown bands. Tremolite-actinolite and chlorite are the principal minerals in the spinifex

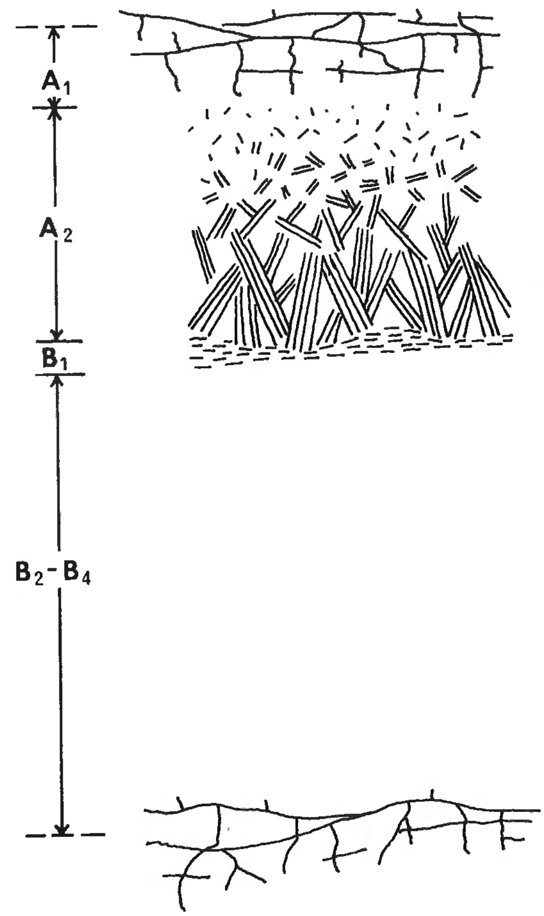

Figure 2. Schematic diagram of layering within one single flow unit at locality A, Figure 1. A_1 = chilled and fractured flow top; A_2 = spinifex zone, showing grain size gradation; B_1 = foliated skeletal olivine layer; B_2-B_4 = massive peridotite (designation of layers as in Figure 8, Pyke *et al.*, 1973). Precise traces of upper and lower contacts are uncertain within a few centimetres. Total thickness of flow unit is about one metre.

layer, but abundant biotite was also noted in the interstices between laths (originally olivine) of coarse spinifex in one flow unit (Schau op. cit.). Other ultramafic rocks also seen at this locality include thicker units, with minor spinifex texture, that are probably flows; two large equant outcrops of massive serpentinized peridotite that are probably parts of intrusions; and a conformable tremolite-talc rock intercalated with amphibolite, quartzite, and paragneiss. Few sulphides were seen in the ultramafic rocks.

At locality B, conformable ultramafic lenses occur in thin-bedded, mafic and quartzitic metasediments. These sediments contain abundant sulphides, mainly pyrite and pyrrhotite, in many cases immediately adjacent to the ultramafic lenses. These sulphide zones, sampled by King Resources Co., yield assay values up to 0.18% nickel and 0.05% copper (Laporte, 1974, p. 121). Some of the ultramafic rocks contain minor amounts of disseminated sulphides. Deformation, alteration and recrystallization of these ultramafic rocks has been intense, and could account for the lack of recognizable spinifex texture. Nevertheless, the presence of interlayered tremolite-rich and chlorite-rich rocks suggests that they could represent flows of mafic to ultramafic composition. Analyses of such rocks from areas A and B are reported by Schau elsewhere in this publication.

In one outcrop area in locality C, metre-thick ultramafic flows with good "graded" spinifex permit reliable top determinations, apparently the only ones in this area (*see* Frisch, this publication, report 87). Brown and green colour bands in these rocks are even more prominent than at locality A. Identical colour-banded ultramafic rocks at locality D contain no recognizable spinifex, but probably represent spinifex-bearing flows in which primary textures have been destroyed by recrystallization. It is suggested that ultramafic rocks displaying alternating brown and green colour bands of the appropriate width, without spinifex but with obviously recrystallized textures may tentatively be interpreted as sequences of ultramafic flows. Closely associated with the flows and suspected flows in localities C and D, are massive serpentinized peridotites and their talc-carbonate altered equivalents, which seem more likely to be intrusive.

The ultramafic rocks at locality E are sufficiently deformed and recrystallized that their original character remains obscure.

At locality F, a feldspathic meta-pyroxenite stock, about 150 to 300 metres wide, is conspicuous because of the extensive gossanous weathering developed on contained disseminated nickel-copper sulphides. Aquitaine Co. of Canada Ltd. carried out 2000 feet of drilling on this prospect in 1973. (Department of Indian Affairs and Northern Development, 1974, p. 22). The outline of the stock appears to transect layering in the surrounding granitic and migmatitic paragneisses. The texture of the pyroxenite is medium-grained, granular and unfoliated. The sulphides are most abundant at the margins, diminishing in abundance toward the centre of the stock. They are mainly disseminated, but are also found as fracture fillings. It appears that the pyroxenite mass with its attendant magmatic sulphides was intruded into the gneisses after their main period of deformation, but that later shearing and metamorphism have affected the mass.

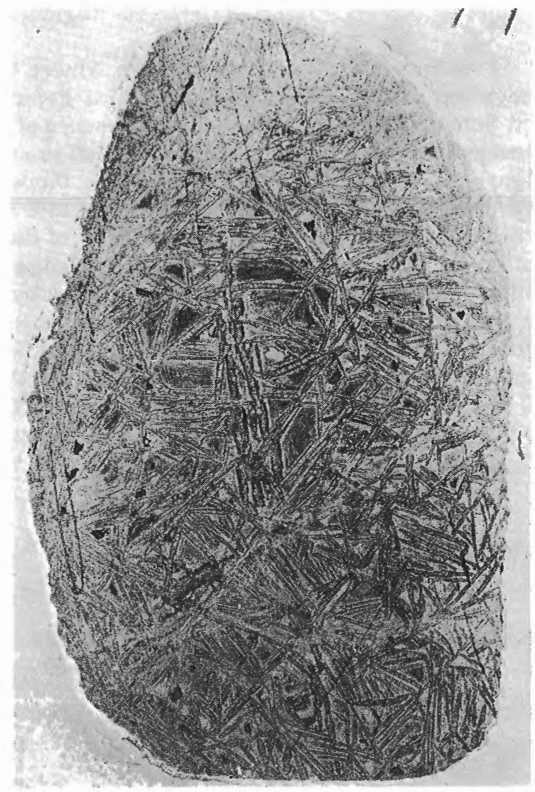

Figure 3. Photograph of spinifex texture in a polished thin section, specimen from locality A. GSC 202660-B.

Nickel potential

Few nickel sulphide occurrences have been reported in the Prince Albert Group (Laporte, 1974). The only significant occurrence is that of Aquitaine at locality E. However, the nickel potential of the Prince Albert Group must be regarded as significant because of the nature and environment of the contained ultramafic rocks. They bear certain similarities to ultramafics containing nickel and sulphide deposits in a number of Archean terranes including the Abitibi orogenic belt in Ontario and Quebec, the Yilgarn and Pilbara blocks of western Australia, and the Rhodesian Craton. Some of the points of similarity are the following:

1. A large proportion of the ultramafics are conformable lenses, and many of these are demonstrably extrusive.
2. The ultramafics are part of a supracrustal suite of rocks comprising volcanics, and siliceous and other sediments including iron formation (*see* Campbell and Schau, 1974).

3. The ultramafic rocks are commonly found in close spatial association with oxide or sulphide iron formation and sulphide-rich sediments (Campbell, 1974).

Because of these similarities it is reasonable to expect that some nickel sulphide deposits similar to those in the other terranes might also be found in the Prince Albert Group ultramafics. Such deposits could be either of the Kambalda type, associated with flows, or of the Mt. Keith type, associated with sills (Eckstrand, 1973).

Age of the Prince Albert Group

Apart from the Prince Albert Group, all of the presently known spinifex-bearing ultramafic flows whose ages are known with reasonable assurance are Archean in age. Consequently, even though lithology can rarely if ever be used as a sure indicator of age, the presence of such rocks in the Prince Albert Group supports an Archean age interpretation.

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Project 680060

R.I. Thorpe
Regional and Economic Geology Division

Field studies of the geology of gold were started during the summer of 1974 with visits to 15 gold properties in Nova Scotia and about 115 gold properties and mines throughout the Superior Province from Chibougamau to southeastern Manitoba. Underground visits were made at 23 mines, including 5 base metal producers.

Nova Scotia Properties

Gold-bearing quartz veins at past-producing properties in Nova Scotia are in sediments of the Halifax and Goldenville formations, predominantly slate and greywacke respectively. Samples were systematically collected from these formations at a number of localities for determination of background gold values by neutron activation analysis. A section 7,500 feet long (horizontal distance) across the strike in greywacke of the Goldenville Formation was sampled at 100- to 200-foot intervals, exposure permitting, at Owl's Head in the Ship Harbour area. A section in slate of the Halifax Formation at the Ovens, Lunenburg area, was sampled at about 200-foot intervals for a horizontal distance of 8,700 feet across the strike. At Liverpool Bay greywacke was also sampled for a distance of 3 miles at intervals of 200 to 250 feet, insofar as possible. At Mount Uniacke 15 samples were taken in a 90-foot section starting at the contact of a gold-bearing quartz vein in an interbedded slate-greywacke sequence. Core samples of greywacke were collected, at about 50-foot intervals, from a 2,000-foot vertical hole drilled at Oldham by the Nova Scotia Department of Mines. Slate interbeds greater than 2 feet thick and 25 feet or more apart were also sampled. Analytical priority is to be given to the Mount Uniacke and Oldham samples.

Preliminary Impressions of Gold Properties in the Superior Province

At many gold properties in the Superior Province the presence of rusty-weathering carbonate minerals is noteworthy and appears to indicate that carbonatization of a wide range of rock types (volcanics, greywacke, conglomerate, gabbro, granitic rocks) has occurred in association with the deposition of gold. The origin of more massive carbonate zones, some of which contain mariposite and most of which are cut by quartz veins, such as occur at the Kerr Addison and Dome mines in the Red Lake area, is a problem requiring further study, requiring careful documentation of their chemistry and field relationships. An impressive number of the major gold mines in the Superior Province have a spatial association with talc-rich rocks (e.g. Timmins and Red Lake areas; Kerr Addison mine).

The talc is probably derived by intense alteration and deformation of ultramafic rock. Field evidence in support of this suggestion includes the following: (1) a typical sample from a carbonate zone closely associated with talc-rich rock at the Dome mine, Timmins area, consists principally of magnesite (O.R. Eckstrand, pers. comm.), (2) talc zones at Madsen Mine and Cochenour (Wilmar) Mine in the Red Lake area are spatially closely associated with peridotite sills, and (3) rock which appears to be ultramafic in composition, as well as talc rock, occurs on the dumps of the Naybob, Buffalo Ankerite and Aquarius properties in the Timmins - Nighthawk Lake area. Sericitization also appears to be a commonly associated alteration, although it is often overlooked and goes unrecorded in property descriptions. Thus intense rock alteration and structural "breaks" may be related features that can serve as they have in the past, as the best guides to many of the large gold deposits.

Some information bearing on the relationship between gold and iron-formation was obtained during field work. At the Camflo Mine, Quebec, a minor ore type consists of almost completely pyritized oxide facies iron-formation which occurs where the iron-formation is cut by faults. Samples from the dumps of the Hard Rock and McLeod Cockshutt mines, Geraldton, Ontario, consist almost entirely of interlaminated carbonate-oxide iron-formation and show that pyrite and arsenopyrite mineralization are related to fractures and dragfolds in the rock. Arsenic and sulphur would thus appear to have been introduced during a superimposed epigenetic mineralization. It is possible that gold was also introduced at this time.

The vein quartz in many gold-bearing veins is dark grey to black. According to R.W. Boyle (pers. comm.) the black colour is in many cases due to the presence of included carbon. One interpretation consistent with this fact is that the ore-forming fluids were rich in carbon dioxide and that deposition took place under conditions of high carbon dioxide fugacity relative to oxygen fugacity. In some cases e.g. the Nova Scotia veins, graphite-bearing country rocks could have controlled these fugacities. An impression, which needs to be tested further, is that dark grey and black quartz generally is present only where carbonate minerals are not abundant in the country rocks, but the reasons for this relationship are not understood.

BARITE, FLUORITE, AND CELESTITE DEPOSITS AND OCCURRENCES IN CANADA

Project 720095

K.R. Dawson
Regional and Economic Geology Division

About two months were spent examining barite and fluorite deposits and occurrences in the Selwyn fold belt of the Yukon Territory, at the junction of the Mackenzie fold belt and the Rocky Mountain thrust belt, in the Rocky Mountain Trench, and in the Omineca crystalline belt of the east-central British Columbia (*see* Figure 1). The 15 properties visited include past, present, and potential producers. These deposits are here classified on the basis of major mineral constituents and deposit type. The report (Taylor and Stott, 1973) that bedded barite deposits of the type described by Zimmerman (1969) occur in northern British Columbia and eastern Yukon is confirmed.

The deposits examined are grouped according to their major mineral components as follows:

Barite	Galena, sphalerite, barite
Brisco Mine	Mineral King Mine
Sulphur Creek	Silver Giant Mine
Moose Property	Tom Property
Barite Mountain	Homestake Mine
Mile 472 Creek	

Fluorite, barite	Fluorite
Liard Fluorite	Rock Candy Mine
110 Creek	Eaglet Property
	Rexspar Property
	Whiteman Creek

A classification by deposit type is:

Fissure Veins	Replacements
Brisco Mine	Mineral King Mine
Barite Mountain	Silver Giant Mine
Eaglet Property	Rexspar Property
Whiteman Creek	110 Creek (part of)
Rock Candy Mine	Liard Fluorite

Stratiform	Residual
Moose Property	Mile 472 Creek
Tom Property	
Sulphur Creek	
110 Creek (part of)	
Homestake Mine (part of)	

The fissure veins occupy dilatant zones that appear to be related to fault zones. The Brisco (Ross, 1960) and Barite Mountain veins crosscut the bedding of carbonate sedimentary rocks; contain almost exclusively barite; have no spatial proximity to either intrusive or extrusive igneous rocks and have characteristics in common with deposits of the Mississippi Valley type. The veins, in particular the Brisco Mine vein, are spatially related to faults. The Rock Candy vein (Bartley, 1961; Wilson, 1929) occupies a through-going fault whereas the Eaglet and Whiteman Creek occurrences have a less certain relationship to major faults. All three are in or near acid or alkaline intrusive rocks and occupy either local faults or joints that rarely extend a few tens of feet. The mineralization is related to pegmatite formation or the hydrothermal stage of differentiation of the related intrusive body. The three deposits resemble the occurrence of fluorite at St. Lawrence, Newfoundland.

The deposits interpreted here as wall-rock replacements are, with the exception of the Rexspar property, associated with carbonate and argillaceous sedimentary rocks. The highest grades commonly are immediately beneath an argillite-limestone contact and rarely in the overlying argillite. The base metal barite ore in the Mineral King Mine (Fyles, 1959) replaces dolomite in bodies that, "appear to conform to fold structures" and also to occur in faults. In the Silver Giant Mine, Jubilee limestone is replaced along the contact with the overlying McKay shale at the crest of a fold. The exposures in 110 Creek and the Liard Fluorite occurrences show a clear association with solution cavities and collapse breccias in that they contain clasts derived from the adjoining host. There is in the 110 Creek exposures a prominent replacement of the clasts and the walls of breccia zones by needles of barite up to half an inch long. The breccias extend for a few feet to a few hundred feet, and there is no evidence to indicate they were open to the surface as sinkholes. The breccias rarely contain voids and have been cemented by calcite, dolomite, barite, fluorite, and witherite and locally constitute economic deposits of one or more of the last three minerals. Economic amounts of base metal sulphides present in a barite gangue were successfully mined from both the Silver Giant and Mineral King mines leaving a substantial reserve of barite in the tailings ponds. Such sulphide mineralization was not identified in economic amounts in the other replacement deposits examined. The Rexspar property is unique in that a foliated alkaline porphyry has been extensively replaced by fluorite and disseminated pyrite.

Stratabound barite deposits, believed to be oceanic sediments (Zimmerman, 1969) outcrop in the Selwyn fold belt in the MacMillan Pass area and at the junction of the south end of the Mackenzie fold belt and the north end of the Rocky Mountain thrust belt between Summit Lake and the Liard River bridge on the Alaska Highway. The deposits at MacMillan Pass, the Tom and Moose properties, are believed to be primary baritiferous sediments. They are characterized by thin rhythmic beds of barite and limestone or argillite that occur near black non-fossiliferous carbonaceous argillite and a black conglomerate consisting mainly of subrounded chert clasts in a chert grit matrix. The barite limestone on the Tom property contains a lead orebody. The Sulphur and 110 Creeks occurrences, are less certainly baritiferous sedimentary rocks. The exposures show a cyclical repitition of nearly pure white barite and grey to buff coloured interbeds of argillite or limestone. These outcrop at the head of Sulphur Creek where there is a large deposit of barite and on 110 Creek near the Alcan Highway where the exposure is small. Neither deposit is near graphitic shales or bedded cherts. There are numerous dolomite, calcite, barite, fluorite mineralized breccia zones in the adjoining limestone strata. In both deposits the beds range in thickness from .5 inch to several inches and average a few inches. The Sulphur Creek baritiferous section is up to 50 feet thick and several hundred feet long but the dimensions of the 110 Creek section are unknown. Both deposits are conformable to the enclosing strata; possible feeder structures have not been identified; no nearby outcrops of igneous rocks are known; neither deposit carries economic quantities of sulphides. The barite deposit in the Homestake Mine is mentioned in connection with the stratabound ones because it is tabular. It is conformable to schistosity in strongly sheared sericite and chlorite schists and its relationship to original bedding is unknown.

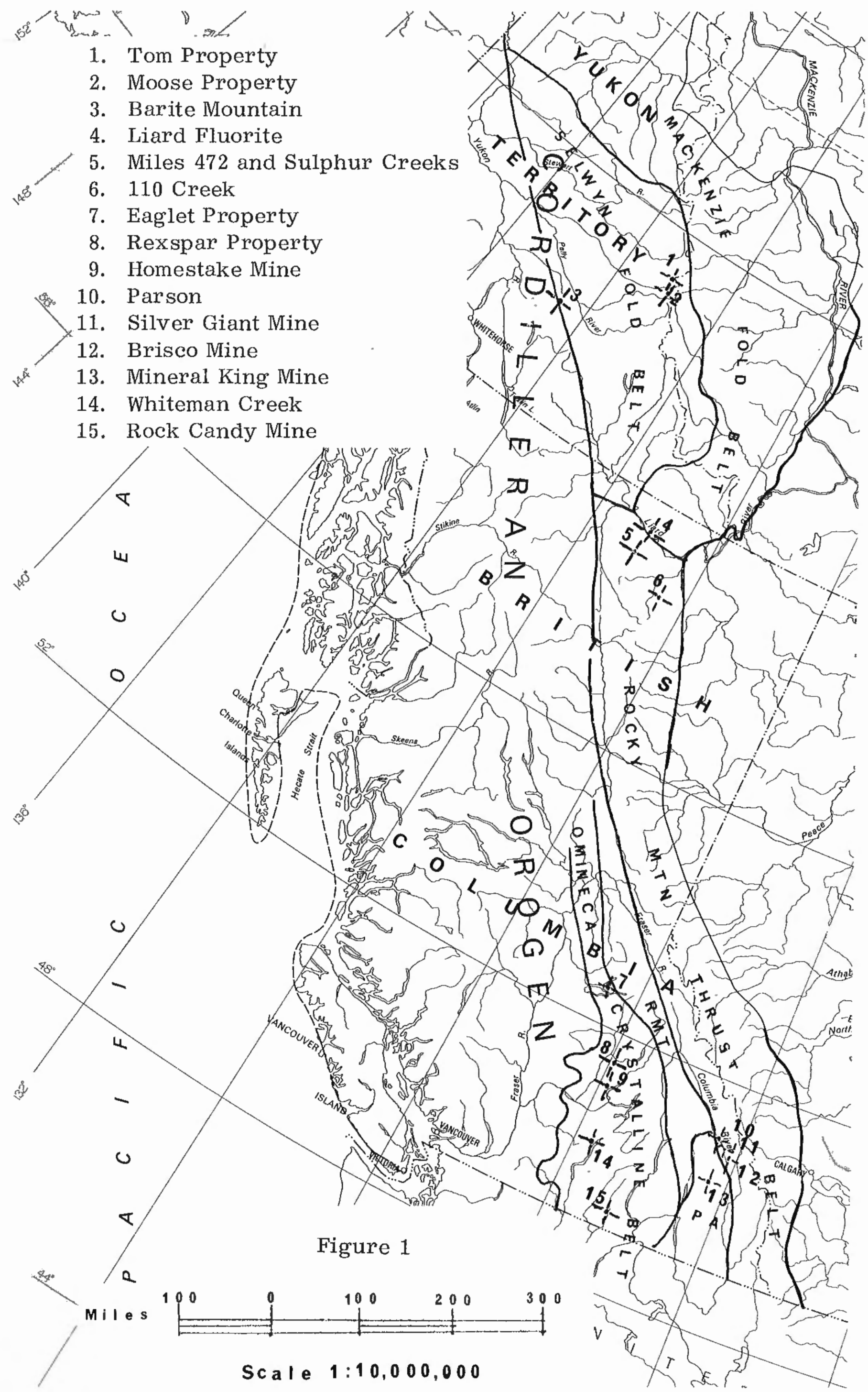

Figure 1

Consolidated residual or lag barite deposits have been reported on the erosion surface on top of the Wokkpash Formation (Taylor and Stott, 1973) and on the mountain ridge east of Mile 472, Alcan Highway (Taylor, pers. comm.). A search along a creek in that vicinity showed an abundance of barite in the alluvium as fragments of pure white barite, bedded barite, and boulders of conglomerate containing barite clasts up to a few inches across. A small lens of barite-bearing conglomerate was found near the head of the first branch entering from the south. A more lengthy search will likely identify the source of the conglomerate boulders and confirm the existence of lag deposit.

The Silver Giant and the Mineral King mines, former producers of lead and zinc are producing barite from accumulated tailings. The life of the first operation is being extended by the treatment of ore quarried from the open pit and that of the second by a small base metal operation that will remove the remaining ore with its barite gangue from the underground workings. The Tom property in MacMillan Pass has a reserve of lead-zinc ore that will be mined in the future and barite is a potential by-product.

Between Golden and Radium Hot Springs, the Parson quarry (not visited) and the Brisco Mine, owned and operated by the Mountain Minerals Company are currently the only barite producing mines in British Columbia that have had no base metal production. The first produces a high grade product suitable for the chemical and paint industries whereas the latter produces for the drilling mud trade.

Fluorite was produced by COMINCO from the Rock Candy Mine north of Grand Forks, B.C. Lithological and structural similarities between the Rock Candy and the St. Lawrence, Newfoundland fluorite deposits suggests that the former area has a potential for the discovery of more mineralized veins. The Eaglet property on the north arm of Quesnel Lake is a potential producer of fluorite that is being evaluated by the owners. The Rexspar property has a published reserve of fluorite in a foliated alkaline porphyry and the Liard Fluorite prospects north of Liard River bridge has a published reserve that will probably be mined.

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78.

SECONDARY MINERALS IN AN ULTRAMAFIC INTRUSION, AMOS AREA, QUEBEC

Project 700041

J.L. Jambor
Regional and Economic Geology Division

Mining of low-grade (<0.5% Cu) porphyry copper deposits is a well-established part of the Canadian mining scene, and the exploitation of large-tonnage, low-grade primary nickel deposits (0.3% Ni) may be in the not-too-distant future. One such prospect which has aroused and maintained the interest of major mining companies is a nickel-bearing ultramafic intrusion near Amos, Quebec. The intrusion, held largely by Dumont Nickel Corporation, is about 4.5 miles long and up to 2,000 feet wide. From more than 69,000 feet of drilling in 57 holes, reported reserves to a depth of 1,000 feet (Northern Miner, Sept. 20, 1973) are more than 500 million tons averaging 0.327% Ni. A central high-grade zone of 15.5 million tons grades 0.646% Ni.

Most of the recoverable nickel in the intrusion is present as pentlandite, awaruite, and minor heazelwoodite. However, these minerals are extremely fine-grained, and standard milling procedures give low nickel recoveries. In order to better understand the character of the nickel mineralization, the distribution and mineralogy of both the opaque and non-opaque phases in the Dumont body will be studied in detail. This will represent the initial thrust in a program intended to supplement the much broader commodity study of nickel (O.R. Eckstrand, project 630037).

Secondary Minerals

The Dumont drill core was sampled during the summer of 1974. Although stored in a dry warehouse, much of the core has fractured extensively, and in some cases disintegrated, because of the expansion effects from the in situ growth of coalingite. This mineral, ideally $Mg_{10}Fe_2(OH)_{24}(CO_3).2H_2O$, was first described by Mumpton *et al.* (1965) in the New Idria serpentinite, California; the second occurrence, compositionally more iron-rich, was in drill cores from the Muskox Intrusion, N.W.T. (Jambor, 1969a). Formation of the Muskox coalingite was attributed to in situ growth during storage. Preliminary study of the Dumont mineral suggests that it is compositionally more similar to the Muskox than to the New Idria coalingite.

Small amounts of muskoxite-type minerals have been identified in two pieces of drill core. X-ray powder diffraction patterns of the minerals give cell sizes substantially smaller than that of muskoxite; microprobe analyses by A.G. Plant suggest that the Dumont minerals are compositionally more similar to less well-defined manganiferous oxides related to muskoxite (Jambor, 1969b) than to muskoxite proper.

Other minerals that occur as fracture coatings are pyroaurite, stichtite, and sjogrenite. Brucite is abundant, and small amounts of valeriite and tochilinite have been found along minor slips. Tochilinite (Organova *et al.*, 1971) is a mixed-layer sulphide-hydroxide of iron and magnesium; the mineral is probably identical to the unnamed fibrous iron sulphides described by Jambor (1969b) and Clark (1970). Microprobe analyses of the Dumont mineral indicate that it lacks the appreciable alumina (1.6 - 5.0 wt % Al_2O_3) of the Russian material, but is compositionally similar to the Muskox mineral.

Chlorides

Several pieces of drill core contain sparse amounts of green chlorides which have obviously formed during storage as they occur on the surfaces of both whole and split cores. Almost all of the green material is paratacamite, a hydroxyl-chloride of copper, but two pieces of core contain chlorides of nickel. The more abundant of the chlorides gives an X-ray powder diffraction pattern with strongest lines of 10.86(10), 5.30(8), 7.30(6), 3.85(5), 2.397A(4). Microprobe analysis by A.G. Plant gave Ni 48.8, Cl 20.6 wt %. A synthetic nickel compound corresponding to this composition was not found in a literature search.

The less abundant of the nickel chlorides occurred as a "deliquescent" spot about 2 mm in diameter adjacent to the above-mentioned compound. The X-ray powder pattern of the "deliquescent" material corresponds to $NiCl_2.6H_2O$. The hexahydrate is commercially produced; optical properties are given in Winchell (1964).

Cell dimensions of $NiCl_2.6H_2O$ as obtained by Mizuno (1961; quoted in Kleinberg, 1969) were used for the initial indexing of the X-ray patterns of the Dumont and synthetic materials listed in Table 1 the powder patterns yield a = 10.30, b = 7.05, c = 6.614A, β = 122.365°, in good agreement with Mizuno's values of a = 10.23, b = 7.05, c = 6.57A, B = 122.167°, space group C 2/m. The cell dimensions of the Dumont material give a calculated density of 1.951 g/cm³ with Z = 2.

Although chlorine is known to occur in serpentines, the source of the anion for the Dumont chlorides has not been established.

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Table 1

X-ray powder diffraction data for $NiCl_2 \cdot 6H_2O$

PDF 1-0200		Artificial (this study)		Dumont Nickel			
I	d(A)	I_{est}	d_{meas} (A)	I_{est}	d_{meas} (A)	d_{calc} (A)	hkl
100	5.5	10	5.59	s	5.55	5.59	001
			5.48		5.44	5.48	110
		2	4.98	f	4.97	4.95	201
100	4.85	8	4.80	s	4.81	4.80	111
		$<<\frac{1}{2}$	4.34	vf	4.37	4.35	200
50	3.53	5	3.53	ms	3.54	3.53	020
		$\frac{1}{2}$	3.39			3.38	111
		$<<\frac{1}{2}$	3.29	w	3.31	3.28	202
4	3.08	2	3.088	vw	3.089	3.086	311
50	2.95	3	2.987	vw	2.994	2.981	021
		2	2.919	ms	2.917	2.918	112
		2	2.793	vw	2.794	2.793	002
50	2.70	6	2.739	m	2.736	2.739	220
		6	2.681	m	2.682	2.682	310
30	2.54	4	2.538	mw	2.542	2.537	401
				vf	2.457	-----	---
50	2.40	6	2.406	m	2.405	2.402	222
		1	2.218	f	2.221	2.212	131
50	2.18	6	2.178	mw	2.178	2.175	400
		$<<\frac{1}{2}$	2.090			2.089	313
6	2.05	2	2.058	w	2.056	2.059	421
						2.054	311
6	2.02	1	2.028	mw	2.021	2.025	422
20	1.97	5	1.970	m	1.970	1.968	512
		$<<\frac{1}{2}$	-----	f	1.942	1.939	331
		1	1.922	vw	1.921	1.916	511
20	1.90	6	1.897	mw	1.897	1.895	132
14	1.86	3	1.857	w	1.857	1.859	223
						1.851	420
		$\frac{1}{2}$	1.829			1.826	330
2	1.81	$\frac{1}{2}$	1.803			1.801	513
						1.800	013
		$<<\frac{1}{2}$	1.780			1.779	423
14	1.77	2	1.767	w	1.768	1.762	040
20	1.69	3	1.693	w	1.692	1.691	222
						1.689	510
		$<<\frac{1}{2}$	-----	vf	1.658	1.660	241
		$\frac{1}{2}$	1.635	vf	1.636	1.634	240
						1.632	601
14	1.60	2	1.606	w	1.607	1.606	113
		1	1.586	f	1.585	1.585	331
		$\frac{1}{2}$	1.559	f	1.562	1.558	421
16	1.54	2	1.546	w	1.546	1.549	133
2	1.50	1	1.496	vw	1.498	1.494	623
		$\frac{1}{2}$	1.476				
6	1.46	$\frac{1}{2}$	1.462				
		$<<\frac{1}{2}$	1.452				
2	1.39	$\frac{1}{2}$	1.397				
		$<<\frac{1}{2}$	1.383				
4	1.37	$\frac{1}{2}$	1.373				
		$<\frac{1}{2}$	1.363				
3	1.34	$\frac{1}{2}$	1.338				
2	1.31	$<\frac{1}{2}$	1.306				
		$<<\frac{1}{2}$	1.294				
		$<<\frac{1}{2}$	1.286				
4	1.27	$\frac{1}{2}$	1.265				
2	1.24	$\frac{1}{2}$	1.258				
		$<<\frac{1}{2}$	1.241				
2	1.20	$\frac{1}{2}$	1.227				

* Filtered Cu radiation, camera diameter 114.6 mm. Intensities estimated visually; Dumont material spotty and estimated as s = strong, ms = medium-strong, mw = medium-weak, vw = very weak, f = faint, etc. Indexed with a = 10.30, b = 7.05, c = 6.614A, β = 122.365°.

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79. STUDIES OF GRANITOID ROCKS IN THE CANADIAN APPALACHIANS

Project 730044

K.L. Currie
Regional and Economic Geology Division

Granitoid rocks underlie nearly one quarter of the Canadian Appalachians, but have been relatively little studied compared to the sedimentary rocks. Theories of the tectonic development of the Appalachian region have evolved rapidly in the past few years, placing new significance on the origin, method of emplacement, and tectonic style of the granitoid rocks. Since the vast area of the granitoid rocks, as well as generally poor to non-existent outcrop, render a compendious study impractical, the present study directs itself to specific, relatively small areas where good outcrop and scientific relevance coincide. Field work commenced in 1974 in three localities, namely northwestern Cape Breton Island, the Roberts Arm area of Newfoundland, and the Pocologan district of southwestern New Brunswick.

Granitoid Rocks in the Cheticamp-Pleasant Bay Area, Northwestern Cape Breton

The rugged highland of Cape Breton Island northwest of the Aspy fault (Neale, 1954) consists of three distinct, polymetamorphic and polydeformed Precambrian crystalline terranes, unconformably overlain by a greenstone-slate-greywacke assemblage, probably of Paleozoic age, and by narrow, fault-bounded slivers of upper Paleozoic sedimentary rocks.

The oldest rocks appear in the Precambrian Pleasant Bay complex, a sequence of quartzofeldspathic gneisses characterized by white or grey colour, strong gneissosity, and simple mineralogy of quartz, sodic plagioclase and biotite. In general aspect the rocks are reminiscent of the "grey gneisses" of the Grenville province (Laurin *et al.*, 1972). These rocks pass gradationally into the presumably Precambrian Corney Brook complex by increase of potash feldspar, appearance of augen and agmatitic structure, common occurrence of amphibole, and loss of gneissosity. Much of the matrix of the Corney Brook complex is a gritty, buff-coloured granodiorite gneiss, but locally this grades to essentially massive red hornblende granite. North of Grande Anse River the rocks resemble the Pleasant Bay complex in some respects, but contain lenticular masses of anorthosite, and intensely sheared and chloritized horizons of mafic to ultramafic rocks. This sequence is provisionally distinguished as the Grande Anse complex, believed to be separated from the Pleasant Bay rocks by faults of substantial displacement (Neale, 1954).

The Trout Brook complex, possibly of early Paleozoic age, unconformably overlies the Corney Brook complex at Grande Falaise, where dykes feeding the overlying lavas can be readily distinguished

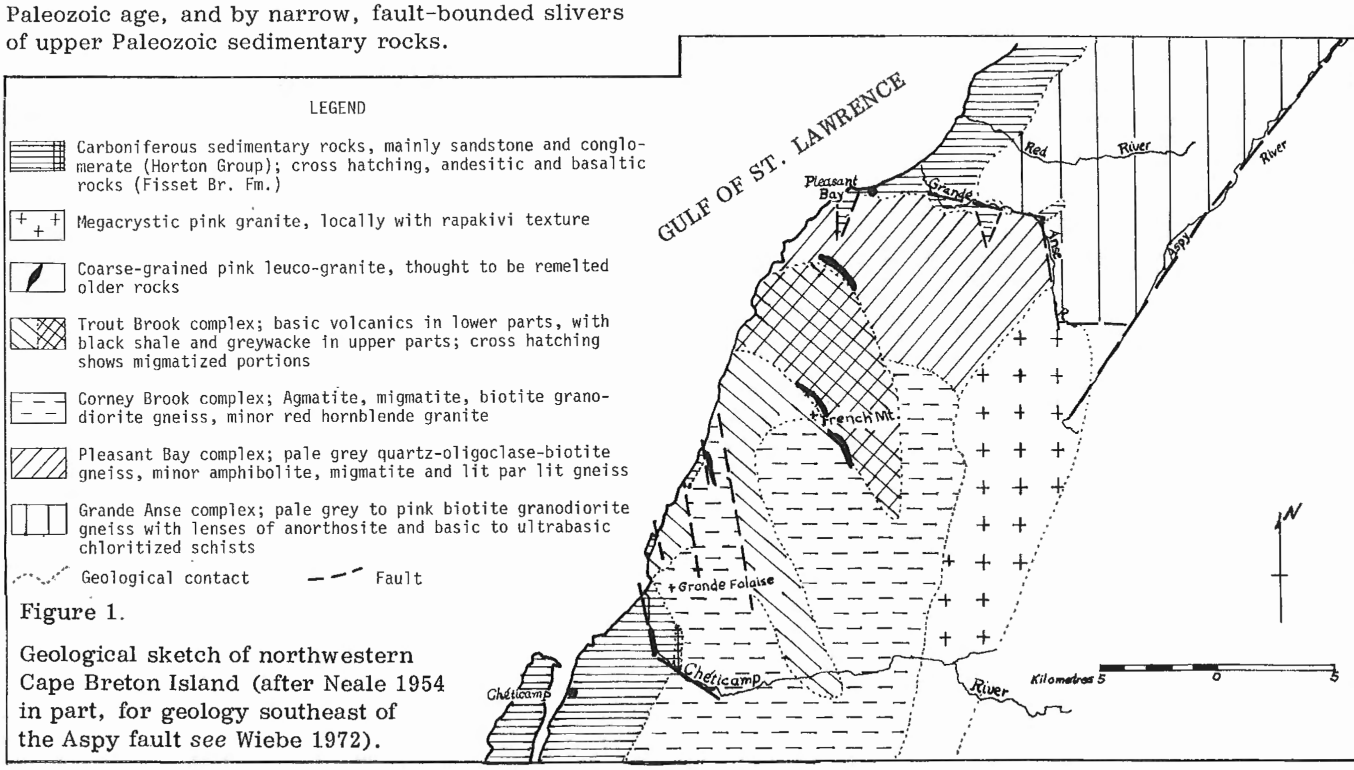


Figure 1.

Geological sketch of northwestern Cape Breton Island (after Neale 1954 in part, for geology southeast of the Aspy fault *see* Wiebe 1972).

cutting the amphibolite blocks of the Corney Brook. The basal part of the Trout Brook complex consists mainly of metabasalt, with rare rhyolite horizons. Black slate becomes more abundant in the middle parts of the complex, which is capped by an upper unit of monotonous, near massive greywacke. Naturalists of Cape Breton National Park recovered a possible molluscan fossil from the slate in the Cheticamp River Valley in May, 1974. The metamorphic grade of the Trout Brook complex rises from sub-greenschist grade in the southwest, through garnet-staurolite grade, into migmatitic assemblages on French Mountain. Larger, faintly gneissic, leuco-granite bodies, resembling the migmatitic mobilizate, occur along the base of the Trout Brook complex, apparently representing reactivated basement material.

All older rocks are cut by a massive, megacrystic granite, locally displaying rapakivi texture. Dykes of this body resemble in texture and composition the volcanic detritus noted in Mississippian Horton conglomerate north of Pleasant Bay (Neale, 1954) suggesting that this batholith may have had volcanic equivalents.

Carboniferous rocks occur within the map-area as narrow, low-lying, fault-bounded slivers along the seacoast. Near Cheticamp River andesitic and basaltic rocks (Fisset Brook Formation) are interbedded with fanglomerates and slide breccia of the basal Horton Group. A reasonably complete section of several hundred metres of Horton Group appears on Presqu'ile, where montonous pebble and cobble conglomerates alternate with thin grey sandstone and coaly layers. No rocks stratigraphically higher than Horton Group were definitely identified north of Cheticamp River, but a displaced block several hundred metres long lying at the entrance to Cape Breton Park, resembles the flaggy grey-green sandstone of the Canso Group which outcrops on Cheticamp Island.

The Precambrian rocks within the map-area have been so remobilized and recrystallized that tectonic events preceding deformation of the Trout Brook complex can no longer be consistently recognized, although a weak north-northwest-trending gneissosity is evident. At Grande Falaise basement-cover relations are spectacularly displayed. Within 100 metres of the contact the basement complex shows strong fissile schistosity parallel to the northeast-trending schistosity in the overlying Trout Brook complex. This strong phyllitic or slaty fissility parallels the axial plane of an early isoclinal fold overturned to the east. This isoclinal fold has been refolded into a broad, gently north-plunging fold, whose eastern limb is smeared out and obscured in the migmatitic zones. The western limb displays one or two generations of microcrenulation, or offset of schistosity, believed to be related to the post-Carboniferous deformation expressed along the seashore as a series of high angle reverse faults trending south and dipping east. These faults die out inland, but along the coast they are associated with isoclinal, west-verging folds in the Horton Group, and with calcite-fluorite-gypsum veining. Intense and widespread shattering of the Corney Brook complex accompanies these faults, and locally minor copper mineralization is found in the shattered zones. The east-trending valleys of the Cheticamp and Grande Anse rivers conceal very complex zones of graben faulting which die out inland. The Grande Anse valley appears to be truncated by a north-trending fault suggesting that the latter trend may be the younger.

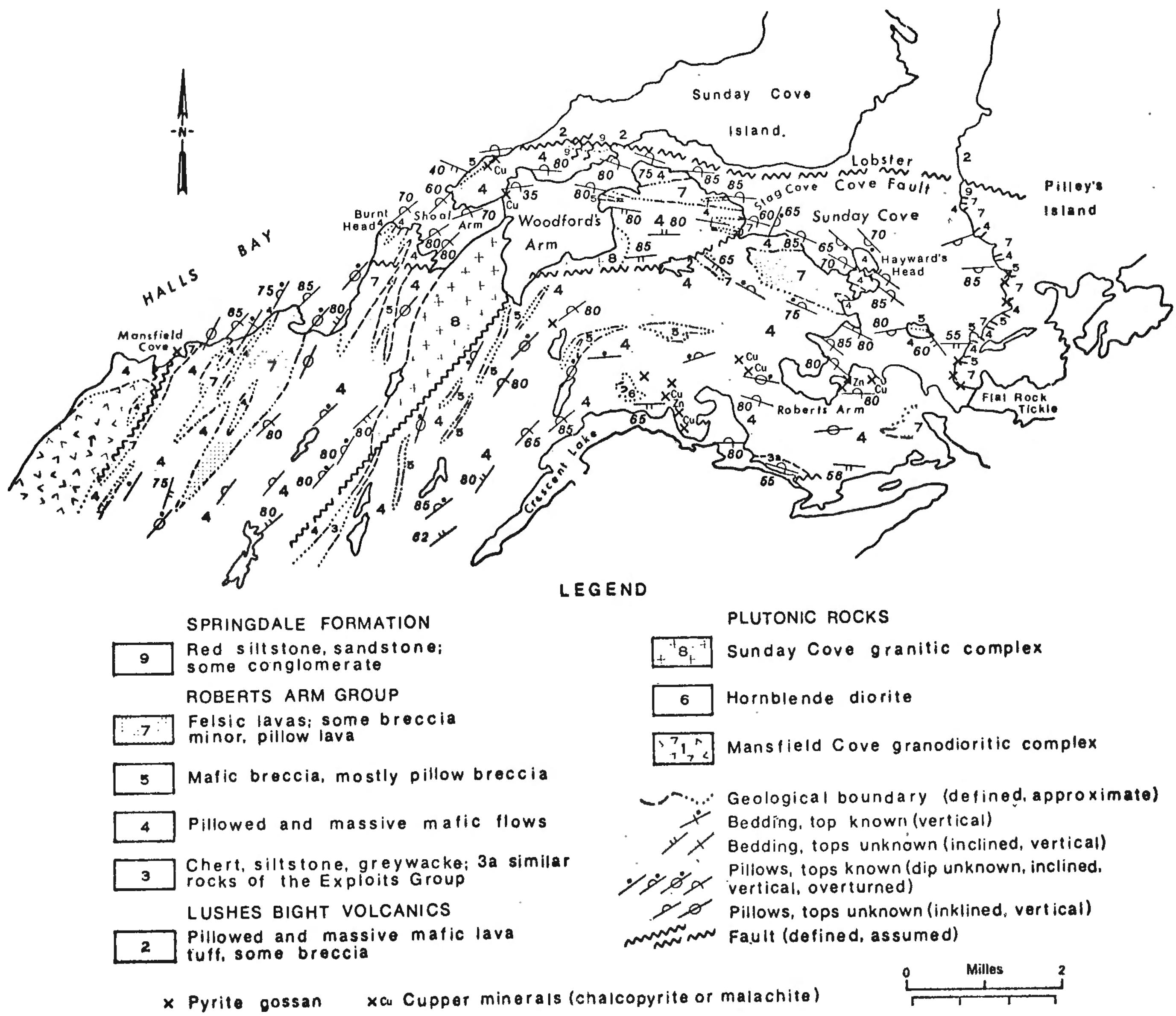
The geology of the mapped area appears strikingly different from the geology of northeastern Cape Breton Island (Wiebe, 1972), suggesting that the Aspy fault must represent a rather major suture between disparate terranes. Brown (1973) suggested that it represents an early Paleozoic subduction zone along which ancestral America and Africa collided. This interpretation is compatible with the present mapping, since the megacrystic granite which obliterates the Aspy fault over much of the map-area seems to be Devonian from stratigraphic evidence, and hence much younger than the presumed subduction. Post-Carboniferous movement on the Aspy fault (Neale, 1954) seems to be rather minor, as the stratigraphic offsets do not exceed a few hundred metres.

Granitoid Rocks in the Roberts Arm Area, Newfoundland

According to current plate tectonic models, the central mobile belt of Newfoundland comprises a lower paleozoic oceanic and island arc terrane welded to the continent during a lower Ordovician episode of convergent plate motions (Williams *et al.*, 1972; Strong, 1973). A basic premise of this model is that none of these rocks rest on sialic basement, and sialic rocks older than the basic igneous rocks, if present at all, can only be slivers torn from the continents during some earlier period of divergent plate motions. During detailed mapping of the volcanic "island arc terrane" around Roberts Arm, H.H. Bostock discovered complex contact relations in granitoid bodies previously mapped as Devonian in age. These relations pose serious difficulties to current models.

Four major bodies of granitoid rocks occur in the general region of Roberts Arm, which may be designated respectively as the South Brook, Mansfield Cove, Sunday Cove, and Loon Pond plutons. The South Brook pluton forms a massive, homogeneous, coarse-grained potash leucogranite, which structurally truncates the southwest-trending Roberts Arm volcanics and intrudes the Silurian Springdale volcanics. The rocks are strikingly "clean" and homogeneous over areas of thousands of square metres. This pluton has all the properties ascribed to Acadian (upper Devonian) granites, and may be taken as a local type example. The totally different character of the other plutons immediately suggests that they are not Devonian.

The Mansfield Cove pluton is a heterogeneous mass, generally characterized by high quartz content, and bluish quartz eyes up to 2 cm in length. The oldest component appears to be a strongly foliated grey-green hornblende-biotite granodiorite augen gneiss, which shows various transitions to massive pink alaskitic rocks consisting of roughly equal amounts of



quartz and alkali feldspar. All varieties contain large numbers of more or less assimilated inclusions ranging in composition from quartzite through amphibolite to rather fresh-looking basalt. The pluton is cut by a swarm of near vertical, north-northeast-trending basalt dykes displaying a variety of delicate intrusive phenomena in the form of apophyses, chilled margins, non-tectonic offsets (Currie and Ferguson, 1970), and zoning indicating vertical emplacements. These northeast-trending dykes are shattered and veined with epidote and calcite, while the granitoid rocks on the margins of the dykes contain large amounts of epidote and chlorite. A few very fresh, coherent dykes trend northwest, parallel to the major dyke direction in the Roberts Arm volcanics. Some of these fresh dykes have melted parts of the host rock causing local development of granitoid back-veining. Road-cuts along Newfoundland Highway 380, which crosses perpendicular to the major dyke swarm, suggest that 5-10 per cent of the volume of the Mansfield Cove pluton is occupied by dykes.

Enclaves of metamorphosed volcanic rocks bearing hornblende porphyroblasts are found within the Mansfield Cove pluton at South Brook and at Mansfield Head. Although pillows are occasionally recognizable, the rocks are commonly intensely deformed to masses of fragments in a sheared paste. Small amounts of shattered acid volcanics partially rim the occurrence at Mansfield Head. These enclaves are cut by irregular lenticular dykes of Mansfield Cove rocks, in some cases fine-grained and mylonitic, with remnant quartz eyes, but in others strongly zoned dykes with a complex series of marginal hybrids. Basaltic dyke swarms may also be found in the contact zone, yielding a mélange of dykes, breccias and agmatites, superbly exposed on the seashore northeast of South Brook.

The southern extension of the Mansfield Cove pluton passes through a poorly exposed series of hybrid rocks into an agmatitic gabbro-diorite-hornblendite complex. Poor exposure prevents precise correlation, but this may represent a deeper level equivalent of the basaltic enclaves.

The eastern limit of the Mansfield Cove granite is marked by a major fault separating it from the Roberts Arm volcanics, a sequence of Ordovician basaltic and felsic volcanics trending northeast, standing about vertical, and facing northwest. This sequence is essentially unmetamorphosed, and rarely displays cleavage or fissility. However pervasive shatter jointing and epidote-chlorite veining riddle the rock. In general aspect the basaltic rocks are strikingly similar to the basaltic dykes in the Mansfield Cove pluton.

Bostock (1974) showed that the Roberts Arm volcanics occur in a series of rather thin fault slices. The Sunday Cove and Loon Pond plutons form the stratigraphically lowest part of one of these slices. Although separated by several kilometres, their petrographic similarity and structural position suggest that they may be parts of the same pluton. At their northwestern margins both bodies display very fine-grained, flinty rocks resembling mylonites, but also similar to some of the felsitic members of the Roberts Arm Group. Veins and dykes of felsitic material can be traced several metres from the pluton into the Roberts Arm volcanics, which also displays a narrow contact metamorphic aureole characterized by amphibole porphyroblasts. To the southeast the plutons gradually become coarser grained, and the very heterogeneous nature of the rocks becomes clear. Some large outcrops of the Sunday Cove pluton consist of more than 70 per cent inclusions in various stages of assimilation, including quartzite, amphibolite, and various types of fine-grained intermediate rocks. Schliers, and dyke-like masses of quartz-eye rocks identical to the Mansfield Cove pluton occur locally, while the coarser-grained southeastern part of the Sunday Cove pluton approaches the finer-grained parts of the Mansfield Cove. Farther along the bounding fault, the Sunday Cove pluton displays hybridization and gradation to gneissic quartz diorite, identical to the most metamorphic looking rocks of the Mansfield Cove pluton. Numerous relict northeast-trending basalt dykes occur, now boudined and partially assimilated, in some cases with extraordinary amoeboid contacts. Rare, thick, northwest-trending dykes are unbrecciated and very fresh.

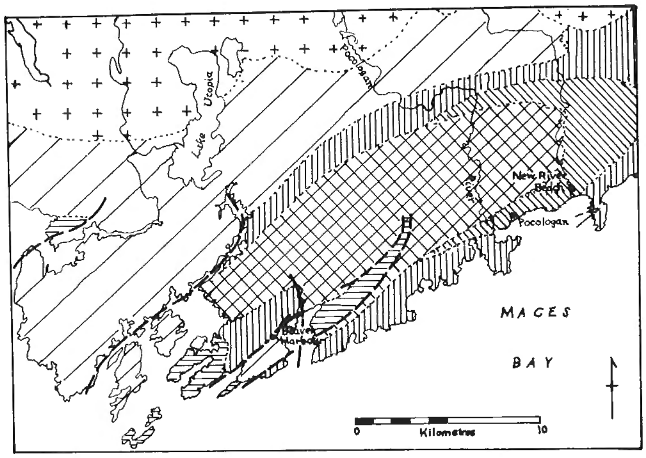
The salient features of the granitoid plutons associated with the Roberts Arm volcanics may be summarized as follows: (1) The Mansfield Cove pluton is cut by a basaltic dyke swarm which in composition and structural style resembles basalts of the Roberts Arm volcanics, but similar dykes in the Sunday Cove and Loon Pond plutons are brecciated and partially assimilated. (2) The Sunday Cove and Loon Pond plutons intrude the Roberts Arm volcanics, and the Mansfield Cove pluton also intrudes volcanic rocks probably correlative to the Roberts Arm (Neale and Nash, 1963; Bostock, 1974). (3) The Roberts Arm volcanics and presumably the Sunday Cove pluton have been rotated to vertical but not folded nor metamorphosed. The structure of the dyke swarm suggests that the Mansfield Cove pluton has not been rotated but has been significantly metamorphosed.

Similar complex and apparently contradictory relations have been reported for other, and larger, granitoid plutons in the Notre Dame Bay region, notably the Burlington granodiorite (Neale and Nash, 1963) and the Twillingate granodiorite (Williams, 1963). The widespread occurrence of such relations demands an explanation in any comprehensive tectonic model. Although a complete explanation is not yet in sight, the following points are already clear: (1) Gneissic hybrid rocks, infested by dykes and extensively deformed are not new, post-tectonic Devonian granite, although reworking in Devonian time is possible. (2) The Ordovician ("Taconic") age proposed for some older granites (Neale and Nash, 1963) lacks field evidence for the Mansfield Cove pluton. The gneissosity of the Mansfield Cove pluton contrasts strangely with the lack of foliation in the presumably older Roberts Arm volcanics. (3) If the Mansfield Cove pluton is pre-Ordovician or at least pre-Roberts Arm volcanics, as suggested by its foliation and the presence of a dyke swarm similar to the Roberts Arm basalts, then a substantial part of the Roberts Arm volcanics may have been deposited on sialic crust. The gradations of the Sunday Cove pluton towards Mansfield Cove type material suggest that its protolith may also have been pre-Roberts Arm, although it has clearly been active after deposition of the Roberts Arm volcanics. Further, the derivation of felsitic dykes from the Sunday Cove pluton suggests that some of the acid volcanics of the Roberts Arm volcanics could have been derived from older granitoid rocks, that is from Sialic crust, and not from mantle material. Such a conclusion, if substantiated, would gravely compromise the model suggested by Strong (1973) for origin of these rocks. (4) A further consequence of a pre-Ordovician age for the Mansfield Cove granite requires that it act as a rigid block during deformation of the Roberts Arm volcanics, in such a way that it remains unrotated while the slabs of volcanic rock rotate and pile up against it. (5) Regardless of the original age of the plutons, there is strong evidence for one or more periods of reworking, as shown by the assimilation of dykes, and the gradations toward felsite in the Sunday Cove pluton.

The solution of many of the apparent paradoxes raised by the field relations lies in correct determination of their original age of formation and in the genetic relations of the acid plutonic and volcanic rocks. Such problems appear particularly appropriate for age determination on zircons and for Sr/Rb isochron studies. Such studies are actively being pursued. Since complex relations similar to those of the Mansfield Cove and Sunday Cove plutons have also been observed in the much larger Burlington and Twillingate plutons, the correct resolution of these problems provides a key element to evaluate current plate tectonic models based on northern Newfoundland.

Granitoid Rocks in the Pocologan District, Southwestern New Brunswick

In the area bounded by New River Beach, Beaver Harbour, Lake Utopia, and Fowle Lake the following rock units were distinguished. (1) The Precambrian



LEGEND

Upper Devonian and Carboniferous (post-Acadian orogenic) sandstone and conglomerate with minor volcanic rocks (Perry, Mispec, Lancaster Fms.)

St. George batholith, middle Devonian massive hypidiomorphic biotite granite and quartz monzonite, minor gabbro and intermediate rocks

Grey to brown, highly cleaved porphyritic felsite, minor mafic igneous and sedimentary intercalations, may be intrusive. Probably Silurian

Cambrian to lower Devonian metasedimentary rocks, with intercalated acid and basic volcanics. Strongly deformed, but mildly metamorphosed

Coldbrook Complex (Precambrian); mafic metavolcanic rocks with intercalated greywacke and slate, minor granitoid rocks

Golden Grove complex; Granitoid gneiss with interleaves of Coldbrook. Intruded and reactivated in Phanerozoic time, hence including Devonian and younger granitoid material

Fault   Geological contact

Figure 3. Geological sketch of the Pocologan District southwestern New Brunswick.

Coldbrook Complex consists of metamorphosed basic volcanic rocks with intercalated greywacke and slate. Deformation ranges from mildly brecciated amphibolites veined by epidote, to fissile chlorite schists. Continuous transition between these extremes can be examined at various localities, particularly along the Old St. John Road east of New River. Granitoid rocks are always present in the form of lenticular schliers and narrow veinlets, but never exceed 15 per cent by volume. In the more deformed phases of the Coldbrook these veinlets show rootless intrafolial folds, a characteristic of the Coldbrook rocks. (2) Migmatitic granite outcrops along the southern and eastern margins of the study area, and forms an ill-defined belt stretching from New River Station to L'Etang. Transitions from the Coldbrook Complex to migmatitic rocks may be examined along the seacoast. Commonly the schists become increasingly "dirty" and hybrid looking, passing through rocks full of rounded, nebulous, amphibolitic blocks, into a variety of granitoid phases ranging from gneissic, greenish granodiorite, through foliated but homogeneous, pink quartz monzonite, to massive leuco-quartz monzonites and granites. The relations between these phases are well displayed in a large road-cut just east of L'Etang. A sizable body of massive but altered gabbro occurs in this unit west of Pocologan Station along the Old St. John Road. (3) A broad belt of grey to buff felsitic rocks extends from Beaver Harbour east to New River. Although strong cleavage is commonly present, these rocks rarely show any primary volcanic features, except rare flow banding, commonly associated with intercalations of mafic rocks. Contacts with the Coldbrook Complex can be examined at the mouth of the Pocologan River, and along New River. Minor faulting commonly obscures the relations, but deformation of the felsitic rocks is clearly much less than that of the Coldbrook Complex, although gradation seems to exist over a distance of about 20 m. (4) Recognizable metasedimentary rocks in the form of well-bedded argillites and red siltstones occur closely associated with felsitic rocks at the northeast corner of Beaver Harbour, and 4.5 km west of Pocologan on the highway. On the New River north of the Old St. John Road a rhyolite flow is intercalated in the sediments, but at the other localities there appears to be less deformation in the sedimentary rocks than in the felsite. However on the road to Lake Utopia, a slice of red argillite and conglomerate shows pebbles with elongations exceding 2:1. The sedimentary rocks are considered by Hay (1968) to be Silurian in age, but they occur in no obvious pattern, nor are their relations with the surrounding felsites at all certain. The latter may possibly be intrusive rather than volcanic. (5) Massive biotite leucogranite of the St. George batholith was encountered at the north end of Lake Utopia. Petrographically identical granites occur at a number of places within the migmatite, and as lenticular masses in the Coldbrook Complex. The granular, hypidiomorphic massive texture of these rocks, with euhedral to subhedral mafics, is highly characteristic. Radiometric age determination suggests a Middle Devonian age for the St. George granite, and a similar age is inferred by analogy for the other granites. In the Coldbrook Complex thin leaves of such granite are completely undeformed in some outcrops, implying post-deformation emplacement, while in others they are strongly schistose. The distribution of schistose bodies seems essentially random, although they are more common near the seacoast. (6) Post-granite and post-schistosity sedimentary rocks are found at three places. The most extensive occurrence lies on the east shore of Beaver Harbour, where siltstone, conglomerate, and a variety of fragmental volcanic rocks are mildly folded about southwest-plunging axes. These rocks may belong to the Upper Devonian Perry Formation, although a Carboniferous age cannot be excluded. A narrow wedge of coarse red conglomerate occurs west of Pocologan, best exposed in a highway cut. These rocks seem best interpreted as a down-dropped sliver of Mississippian or Triassic rocks, similar to the sliver of Pennsylvanian Lancaster Formation, discovered by Rast and Grant (1973) faulted down into the migmatite south of New River Beach.

The outcrop pattern outlined by these units accords poorly with previous interpretations of the structure. The simplest interpretation postulates a structure dominated by gently southwest-plunging folds, modified to a rather minor extent by faulting although three ages of folding can be recognized. All of these episodes of folding appear to be middle Paleozoic. The dip of the axial plane of the folds decreases from northwest to southeast, while the closure increases, in accordance with the suggestion of Rast and Grant (1973) according to which material was thrust from the southeast in post-Carboniferous time. However demonstrable thrust movements are either negligible, as in the case exposed south of New River Beach, or in the reverse sense to that postulated by Rast and Grant (1973), as in the village of Beaver Harbour where migmatite is thrust over Silurian sedimentary rocks from the northwest. The major thrust postulated by Rast and Grant (1973) at Pocologan shows no clear displacement, but rather a strong contrast in tectonic style marking the junction of the migmatite and the Coldbrook Complex. Such abrupt juxtapositions occur at several places, and seem to represent only trivial movements along a juncture between plastic and rigid materials, where the cleavage disappears in the rigid block. The "Beaver Harbour fault" of Hay (1968) and Alcock (1944) does not exist in the sense of separating Silurian from Precambrian rocks, as postulated, but a narrow zone of late normal faulting lies approximately in this position.

The migmatite unit, postulated to be Silurian by Hay (1968), seems clearly to contain a Precambrian protolith, as it grades to the Precambrian Coldbrook Complex, and is unconformably overlain by presumed Silurian sedimentary rocks along the New River. However a variety of granitoid rocks younger than the oldest foliated green granodiorite are present within the unit, including some bodies south of New River Beach which are not affected by the Carboniferous cleavage. The migmatite is thus a composite unit which has been re-intruded or reactivated on several occasions. The unravelling of the history of this unit is in progress.

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PETROLOGY OF THE RED WINE ALKALINE COMPLEXES, CENTRAL LABRADOR AND A COMPARISON WITH THE ILIMAUSSAQ COMPLEX, SOUTHWEST GREENLAND

Project 680071

K.L. Currie, L.W. Curtis* and J. Gittins*
Regional and Economic Geology Division

The agpaitic chemistry and mineralogy of the Red Wine alkaline complexes (Curtis *et al.*, 1974) resemble those of the Ilimaussaq alkaline complex (Ferguson, 1964) whereas the Seal Lake Group basalts and quartzites lying just north of the Red Wine rocks, resemble similar rocks of the Eriksfjord Formation (Baragar, 1974) which is penetrated by the Ilimaussaq complex. Continental reconstruction suggests continuity of Helikian rocks from Labrador to Greenland, but the Canadian rocks are strongly deformed and metamorphosed, whereas those of south Greenland are unmetamorphosed and virtually undeformed. If reliable correlations could be established across Davis Strait, the history of the Labrador alkaline rocks would be clarified. Through the courtesy of Dr. Henning Sorenson of the Mineralogical-Petrological Institute, University of Copenhagen, we spent three weeks of July, 1974 in south Greenland under the auspices of the Greenland Geological Survey.

RED WINE ALKALINE PROVINCE

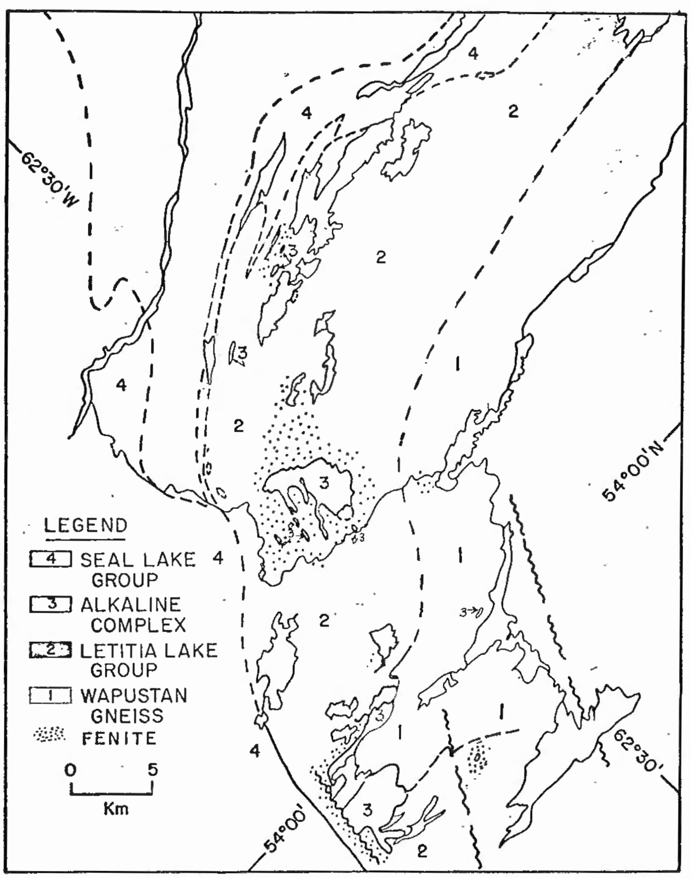


Figure 1. Regional geology around the Red Wine Alkaline complexes.

The Red Wine Complex

Alkaline rocks occur in central Labrador as a series of elongate, sinuous, tectonically deformed lenticles of amphibolitic aspect enveloped by rocks of the Letitia Lake Group, and the Wapustan Gneiss (Fig. 1). The Wapustan Gneiss, a polydeformed, polymetamorphosed basement complex contains narrow belts of pelitic and other metasediments within an intermediate to basic gneiss and migmatitic terrane. Gabbroic and metagabbroic bodies resemble lenticles deformed with the surrounding gneiss. The Letitia Lake Group of quartz-feldspar porphyries and intercalated clastic sedimentary rocks displays only one major period of deformation and metamorphism, whereas the overlying Seal Lake Group, though strongly deformed, is only feebly metamorphosed. Of the known occurrences of alkaline rocks, two are sufficiently large to warrant mapping in detail. The North Red Wine complex forms a trident-shaped mass with three narrow arms trailing southward (Fig. 2) whereas the South Red Wine complex consists of a deformed dumbbell-shaped mass (Fig. 3). Minor occurrences northeast of the North Red Wine complex are elongated masses of mafic rocks, interpreted as metamorphosed and boudined dykes, or irregular lenticular masses of heterogeneous syenitic

NORTH RED WINE COMPLEX

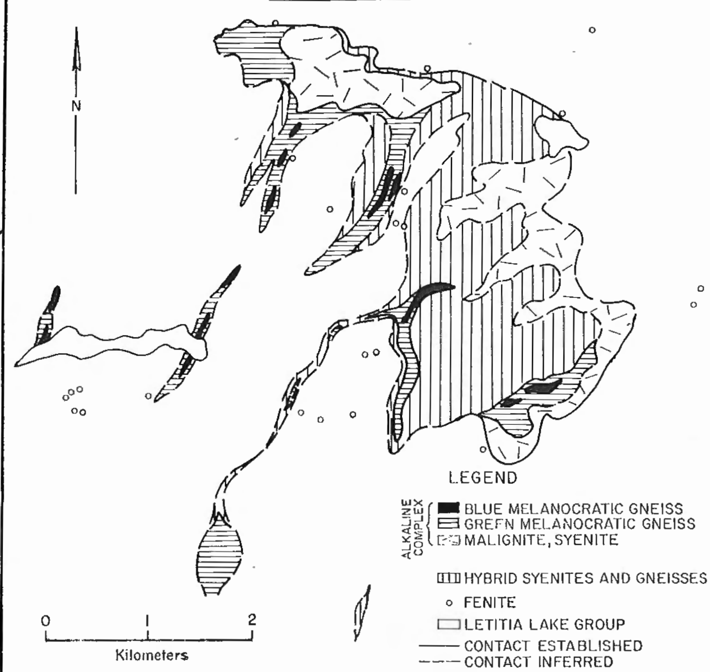


Figure 2. Geological sketch of the North Red Wine alkaline complex.

*Department of Geology, University of Toronto, Toronto, Ontario, M5S 1A1.

Table 1

Chemical and Modal Compositions of Rock Units in the Red Wind and Ilimaussaq Complexes

	RED WINE COMPLEX						ILLIMASSAQ COMPLEX						
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	61.1	57.1	55.3	51.7	47.0	57.5	55.75	49.97	46.85	51.83	53.12	52.89	49.79
TiO_2	0.34	0.62	0.48	1.33	1.01	0.60	1.42	0.55	0.30	0.29	0.28	0.35	0.32
ZrO_2	0.24	0.36	0.24	0.07	0.10	0.23		0.43	0.41	1.16	1.12	0.64	0.72
Al_2O_3	13.9	14.5	12.3	11.2	8.3	13.3	16.31	18.35	22.30	15.97	15.96	14.59	18.72
Fe_2O_3	3.14	3.66	11.45	2.61	3.32	4.8	3.09	4.96	3.07	6.15	9.15	6.30	5.02
FeO	5.20	6.84	3.66	9.90	19.94	6.1	6.23	4.04	2.21	4.90	1.32	6.77	3.58
MnO	0.22	0.24	0.24	0.36	0.70	0.25	0.21	0.15	0.13	0.29	0.22	0.41	0.23
MgO	0.23	0.22	0.13	2.27	0.92	0.57	1.32	0.43	0.09	0.25	0.20	0.54	0.22
CaO	1.17	2.11	1.41	4.37	4.62	1.98	3.54	1.79	1.40	2.01	0.74	0.39	1.40
Na_2O	8.4	9.1	10.8	10.3	7.9	9.3	5.91	12.67	15.76	10.40	11.20	10.72	12.99
K_2O	4.65	4.60	2.50	3.10	3.39	3.95	4.92	3.17	3.58	4.10	3.35	3.28	3.67
$H_2O^{\pm}$	0.50	0.48	0.74	0.89	1.59	0.62	0.57	1.70	1.46	2.22	3.15	2.67	1.97
P_2O_5	0.06	0.08	0.06	1.1	0.58	0.25	0.50		0.03	0.03	0.03	0.41	0.07
Cl_3F_1		0.10		0.10	0.25			1.69	3.15	0.41	0.09	0.34	1.63
No. of Analyses	9	5	3	1	2		8	2	9	12	7	6	
Albite	40-45	20-35	5-25	1-5	0-1					0-13[f]	0-23	0-30	
Microcline	5-30	5-25	0-5								16-32	8-24	
Perthite	0-5	1-30	0-5				69-76	18-46	6.36	2-60			
Sodalite								3-32	31-54		0-3	0.5-8	
Nepheline	1-5	3-15	5-25	20-40	15-25		0-2.9	1-18	4-18	0-50	4-19	1-15	
Alkali Pyroxene	5-30	5-45	30-75	1-25	0-25		6-11.5[a]	5-16	2-12	0.22	25-40	1-16	
Arfvedsonite	5-20	5-40	1-25	25-60	40-75		2-10[b]	1-16	1-16	0-72	0-6	31-57	
Anigmatite	0-1.5	0-15	0-5	0-0.5	0-8		1-7[c]		0-6	0-0.6			
Pectolite	0.3	0.1	0.5-2.5	1-10	0-7								
Eudialyte	0-2	0-15	0-5						0.1-13	2-43	6-13	5-10	
Apatite	0-0.5	0-0.5	0-0.5	2-3	1-3		0.5-1.5						
Others				3-5			2-6[d]	8-36[e]	0-14[e]	0-38[e]	0-40[e]	3-30[e]	
K/Al (atomic)	1.37	1.38	1.55	1.72	1.97	1.44	0.98	1.24	1.24	1.31	1.31	1.38	1.28
Area (%)	42.5	19.5	19.9	17.6	0.3			9	24	11	14	16	

Columns 1-6, composition of the Red Wine Units:

1. Leucocratic gneiss
2. Malignite and nepheline syenite
3. Green and black melanocratic gneiss
4. Blue melanocratic gneiss
5. "Melteigite"
6. Average composition on an areal basis.

Columns 7-13, composition of the Ilimaussaq units after Ferguson (1970, 1970a)

7. Augite syenite
8. Sodalite foyaite
9. Naujaite
10. Kakortokite (weighted average)
11. Green lujavrite
12. Black lujavrite
13. Average Ilimaussaq agpaitic nepheline syenite. Analyses for each complex are listed in order of increasing agpaitic index.

Modal analyses, superscripts refer to:

(a) Augite
(b) Kaersutite
(c) Fayalite
(d) Opaques
(e) Analcine, natrolite
(f) Combined red, white and black kakortokites

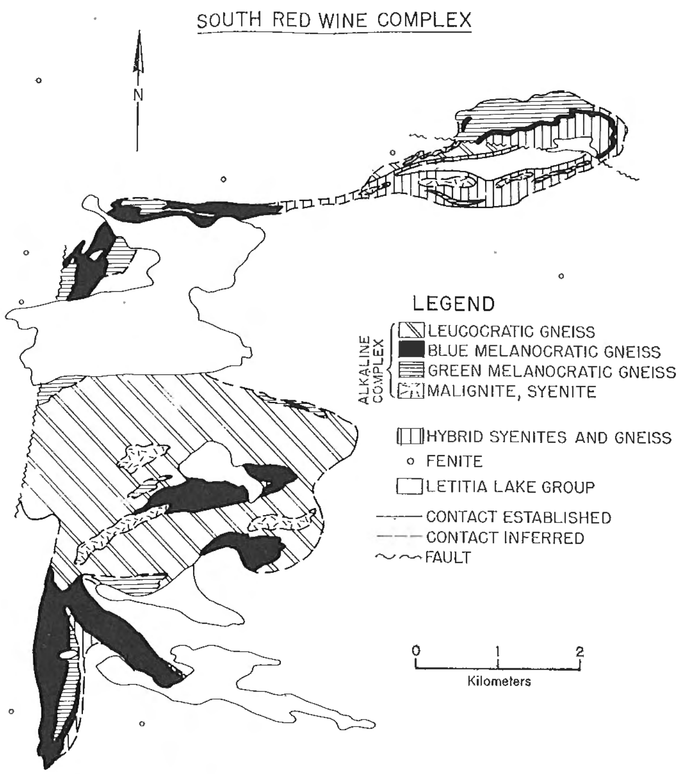


Figure 3. Geological sketch of the South Red Wine alkaline complex.

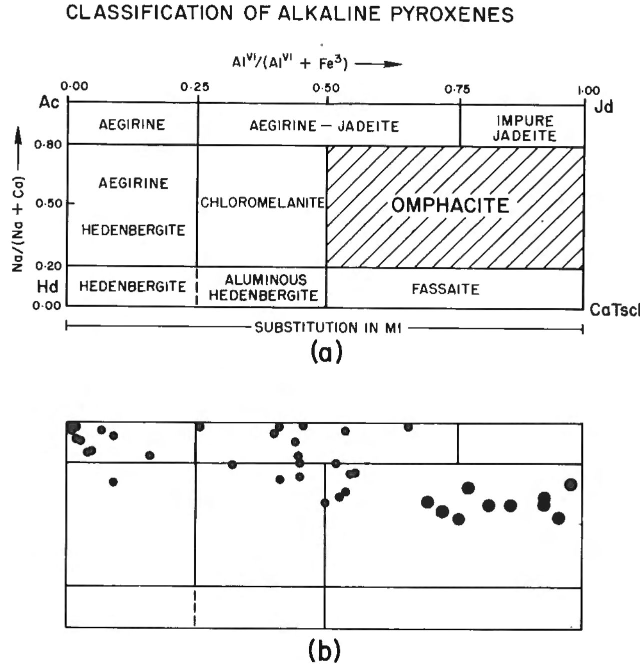


Figure 4. Composition and classification of alkaline pyroxenes from the Red Wine complexes.

hybrid rocks thought to be metamorphosed fenites. South of the North Red Wine complex, the minor occurrences form lenticles in the surrounding gneisses, and commonly contain coarse-grained igneous-textured rocks. Regardless of locality, five main varieties of alkaline rocks appear, although relative proportions vary greatly. The overall proportions of the nepheline-bearing types, together with their modal and chemical compositions are displayed in Table 1. Hybrid phases, mainly developed by metasomatism and reconstitution of the Letitia Lake Group, form an extensive aureole of leucocratic saccharoidal syenites which surround the alkaline rocks proper. Metasomatized rocks, commonly greenish, granitoid rocks with porphyroblastic feldspar, and containing one or more distinctly alkaline minerals, notably acmite, aenigmatite or astrophyllite, can be found up to 10 kilometres from the alkaline rocks along cataclastic zones.

Types 1 to 3 of Table 1 are gneissic to schistose in outcrop appearance, whereas the syenites and malignites (unit 4) display relict igneous textures, commonly trachytoid or blastoporphyritic, with large recrystallized euhedra of albite. Contacts are abruptly gradational between various rock types, and no clear intrusive relations are known. In thin section, the textures are metamorphic without exception, displaying sutured boundaries and poikilitic porphyroblasts. With the exception of the pyroxenes, all other minerals appear to have reached metamorphic equilibrium, although two generations of eudialyte and aenigmatite can locally be distinguished. The average compositions of the minerals are given in Table 2. The compositions of the feldspars and nephelines remain constant throughout the range of rock types, and the amphiboles vary only slightly. The pyroxenes show a complex optical and compositional zoning ranging across most of Figure 4, and many are strongly aluminous. Unzoned, pale green aegirines ranging in composition from $Ac_{100}Hd_0$ to $Ac_{75}Hd_{25}$ occur mainly in the fenites and hybrids, but may occur as cores in some syenites and malignites. The aergirine-jadeites are found only in the alkaline gneisses, and form a solid solution series from $Jd_{37}Ac_{63}$ to $Jd_{72}Ac_{28}$. Aegirine-jadeites and chloromelanites form pale, bleached zones, commonly discontinuous, separating aegirines from marginal blue titanian ferro-omphacite. The blue omphacitic pyroxenes also occur as a second generation of microlites within feldspar, nepheline and amphibole, and as coronas on arfvedsonite and aenigmatite.

The aluminous pyroxenes are exclusive to the alkaline complex proper, and are not found in the fenite zones. This observation together with the observed zoning suggests that the aluminous pyroxenes formed through a series of metamorphic reactions. Diffusion of aluminum, coupled with Al-Fe cation exchange would convert initial aegirine progressively to aegirine-jadeite and chloromelanite (Fig. 4). Textural and experimental data suggest that the formation of titanian ferro-omphacite is dependent on the presence of aenigmatite and arfvedsonite, in addition to an aluminous phase such as nepheline.

An estimate of the metamorphic conditions involved in the formation of the pyroxenes may be obtained by

Table 2A

Composition of Salic and Accessory Minerals from the Red Wine and Ilimaussaq Complexes

(1) RED WINE COMPLEX

	Microcline	Albite	Nepheline	Pectolite	Eudialyte	Astrophylhite	Rincolite	Ramsayite
SiO_2	63.5-64.1	68.1-68.7	41.7-42.2	51.8-54.0	48.14-52.42	31.47-34.72	28.94-29.63	33.11-34.78
TiO_2	0.00	0.00	0.00	0.00	0.04-0.12	9.38-11.99	9.91-10.58	47.08-47.97
Al_2O_3	18.2-19.0	19.2-20.0	34.0-34.7	0.0	0.00-0.30	0.95-1.48	0.05-0.19	0.05-0.22
*FeO	0.0-0.16	0.0-0.2	0.0-0.1	0.9-2.1	4.09-6.66	31.94-34.80	0.27-0.39	0.07-0.18
MnO	0.00	0.00	0.00	1.0-2.2	0.38-1.65	1.54-1.95	0.15-0.18	0.00
MgO	0.00	0.00	0.00	0.0	0.09-0.12	0.03-1.30	0.13-0.14	0.05-0.11
CaO	0.00	0.00	0.00-0.30	29.9-32.2	8.91-10.60	1.35-2.13	23.73-27.99	0.04-0.13
Na_2O	0.3-0.7	11.5-11.7	15.8-16.5	9.1-9.5	12.69-15.15	2.67-5.41	2.05-5.96	16.48-16.55
K_2O	16.0-17.5	0.2	6.9-7.5	0.1-0.3	0.33-0.90	0.60-1.98	0.14-0.22	0.09-0.11
Other				(H_2O)	(Zr, $(RE)_2O_3$)	H_2O, Rb, $(RE)_2O_3$	F, RE_2O_3 TR_2O_3	
Analyses	23	25	16	11	10	4	3	4

(2) ILIMAUSSAQ COMPLEX

	Microcline	Microcline Perthite	Nepheline	Schizolite	Eudialyte	Astrophyllite	Rinkolite	Nephinite
SiO_2	64.68	65.62	40.6-41.9	51.06	47-54-50.28	34.86	29.41	52.28
TiO_2				0.62	0.42-0.61	9.90	8.35	15.75
Al_2O_3	19.04	18.50	33.9-35.8	$(Y,Nb)_2O_3$ 1.56	0.60-1.67	0.70	0.71	0.38
Fe_2O_3	0.24	0.55	0.15-0.70		0.11-1.86	2.06	1.87	3.60
FeO				2.74	2.38-7.16	23.79		11.07
MnO				9.84	.09-1.83	8.80		1.37
MgO			0.0-0.15			0.20	0.15	0.30
CaO			0.40-0.47	22.89	9.66-14.26	1.09	29.91	0.62
Na_2O	0.53	3.50	13.65-15.03	9.97	8.50-13.24	3.26	5.04	6.63
K_2O	15.82	11.86	6.68-7.77		0.41-2.09	4.11	1.35	3.19
Other	(Rb)	(Rb)	(Cl, S, H_2O)	(H_2O)		H_2O, Rb RE_2O_3	F, RE_2O_3 TR_2O_3	L_1, RE_2O_3
No. of analyses	1	1	2	1	3	1	1	1

*Total iron is shown as FeO

(1) Composition of the rock forming salics microcline, albite and nepheline from the Red Wine complex and some accessory phases; L.W. Curtis analyst.

(2) Compositions of the rock forming salics perthite and nepheline and accessory phases from the Ilimaussaq complex, data from Senenov (1972).

Table 2B

Composition of the Mafic Minerals from the Red Wine and Ilimaussaq Complexes.

(1) RED WINE COMPLEX

	Potassium Arfvedsonite	Magnesio-Arfvedsonite	Aegrine	Aluminous Aegrine	Titanian Ferro-Omphacite	Aegirine Jadeite	Titanian Aegirine	Aenigmatite
SiO_2	47.40-48.87	46.41-51.51	52.22	53.81	54.00	55.78	52.51	39.9-41.9
TiO_2	0.54-1.02	0.61-1.62	0.68	1.75	3.79	0.31	8.79	9.48-9.93
Al_2O_3	1.51-2.85	1.68-3.77	1.21	7.43	8.31	16.27	2.35	0.00-0.39
Fe_2O_3	(a)		32.2	21.64	(b)	13.15		
FeO	32.21-33.63	20.38-28.32			12.61	(c)	19.65	39.1-49.7
MnO	0.71-1.30	0.36-0.70	0.30	0.37	0.45	0.08	0.65	0.96-1.63
MgO	0.39-1.73	3.00-6.82	0.11	0.03	2.86	0.00	1.22	0.08-0.47
CaO	0.59-2.65	0.71-3.75	2.42	3.58	9.15	0.84	4.31	0.01-0.10
Na_2O	5.55-6.91	5.80-6.33	11.77	11.27	8.72	13.44	10.39	7.30-7.87
K_2O	3.23-4.00	3.41-3.93	0.12	0.11	0.12	0.12	0.12	0.0-0.2
Other	(F, H_2O)	(F, H_2O)						
No of Analyses	38	21	38	46	16	6	5	14

(2) ILIMAUSSAQ COMPLEX

	(d) Arfvedsonite	Potassian-Kataphorite	Aegirine (d)	Sodic Hedenbergite	Fayalite	Aenigmatite
SiO_2	46.2-49.3	44.2-44.7	52.11	50.80	29.83	37.9-41.4
TiO_2	0.49-0.94	0.85-1.37	0.53	1.46		7.57-8.30
Al_2O_3	0.92-2.53	3.75-5.91	1.81	2.42		nd-3.23
Fe_2O_3		5.22-10.20	30.42	20.55		4.46-5.81
FeO	32.8-33.7	22.75-29.26	0.83	4.91	65.22	35.9
MnO	0.89-1.35	0.78-1.46	0.58	0.09	2.86	1.00
MgO	0.02-0.77	0.25-1.63	0.16	3.22	0.20	0.33-1.78
CaO	0.14-1.98	4.32-5.59	0.41	7.40	1.62	nd-1.36
Na_2O	7.41-7.92	5.14-5.90	12.37	7.96	0.29	6.58-6.87
K_2O	2.15-3.17	1.69-2.10	0.52	0.48		0.04-0.51
Other	(F, H_2O, Zr)	(F, H_2O)	(Zr)			
No of Analyses	10	2	20	1	1	2

(1) Rock forming mafic minerals from the Red Wine Complex, with total iron shown as FeO or Fe_2O_3

(a) $Fe^{2+}:Fe^{3+} \simeq$ 4:1 to 6:1; (b) $Fe^{2+}:Fe^{3+} \simeq$ 2:1 to 12:1; (c) $Fe^{2+}:Fe^{3+} \simeq$ 1:12; Pyroxenes normalized.

(2) Rock forming mafic minerals from the Ilinaussaq Complex, data compiled from Sorenson (1972), authors own material.

Analyst: L.W. Curtis

Table 3.

Comparison between the Red Wine and Ilimauassaq Alkaline Complexes

Feature	Labrador	Gardar
Tectonic setting	Cratogenic; Marginal to Grenville orogen	Cratogenic; Marginal to extension of Grenville zone (?)
Structural control and timing	Incipient rifting, followed by compressional phase	Open rifting, episodic tension and relaxation
Chemistry of Province	Undersaturated*	Oversaturated, saturated and undersaturated
Related volcanism	Sub-alkaline volcanics**	Alkaline and sub-alkaline
Level of exposure	Deep (?)	Shallow
Other intrusive phase	Not found*	Giant dykes, carbonatites kimberlites
Rb/Sr age (m.y.), and Initial Ratio	1264 ± 75, 0.704	1188 ± 30, 0.706**
Rock chemistry	Peralkaline undersaturated	Saturated, Peralkaline oversaturated, and Peralkaline undersaturated
Principal Foids	Nepheline	Sodalite, Nepheline
Pyroxenes, Amphiboles, Feldspar	Aegirine, Aegirine-Jadeite, omphacite Arfvedsonite (magnesio and potassian) sub-solvus, recrystallized, relict perthite	Hedenbergite, Ferrosalite, Aegirine, Arfvedsonite, Kataphorite, Hypersolvus (except in lujavrites)
Nepheline	Consistently $Ne_{73}Ks_{27}$	Variable
Chemistry	Agpaitic	Agpaitic
Fe^{3+}/Fe^{2+}	0.7	1.4
Cl, F, H_2O	<1%	>3%

*A new occurrence of saturated syenite with Gardar characteristics has been discovered on the Labrador coast by K. Collerson (pers. comm. 1974). The absence of related igneous rocks around the Red Wine Complex may be a consequence of level of exposure or lack of outcrop, as well as true absence from the province.

**Seal Lake Group (Baragar, 1974)

considering the equilibrium:

$$\text{nepheline} + \text{albite} = 2\ \text{jadeite} \qquad \ldots.(1)$$

where all the components are assumed to be present in solid solution, that is, the actual mineral assemblage is nepheline in the Buerger-Morozewicz convergence field, alkali feldspar in the low structural state and a pyroxene with jadeite component.

A thermodynamic treatment of reaction 1 gives the lowering of the reaction boundary with progressive solution of Hd, Ac and Di into Jd, resulting in an estimate of the P-T conditions at which the pyroxenes found in the Red Wine complexes equilibrated. Results of these calculations, shown graphically in Figure 5, will be published elsewhere.

In Figure 5 the limiting pyroxene compositions are shown together with the triple points of Holdaway (1971) and Richardson *et al.* (1969), the minimum melting curve for nepheline syenite after Hamilton and Mackenzie (1965) and the experimental curve for reaction 1 as determined by Boettcher and Wyllie (1968), together with our calculated curve for this reaction. If we assume that the sillimanite, developed locally in the Wapustan Gneiss, formed during the latest prograde metamorphism, as suggested by textural evidence, and that the syenitic "sweats" in the alkaline gneisses are due to partial melting, the maximum metamorphic conditions in the Red Wine area are closely defined, falling within the closely stippled area of Figure 5. If we further make the plausible assumption that temperatures must rise

Table 4.

Chemical balance calculations on the origin of the Ilimaussaq agpaites

	1	2	3
SiO_2	55.74	56.40	49.79
TiO_2	1.42	1.54	0.33
ArO_2	0.01	*	0.72
Al_2O_3	16.31	16.04	18.72
Fe_2O_3	3.09	2.88	5.02
FeO	6.32	6.62	3.58
MnO	0.21	0.21	0.23
MgO	1.32	1.44	0.22
CaO	3.54	3.78	1.40
Na_2O	5.90	5.11	12.99
K_2O	4.92	5.06	3.67
P_2O_5	0.51	0.56	0.07
H_2O	0.51	0.35	1.97
Cl	n.d.	*	1.38
Total	99.86	99.79	100.09

* negative value computed

1. Average augite syenite (Table 1, column 7).
2. Residuum after extraction of 10% agpaite from augite syenite. (If more than 10% agpaite extracted, geochemical anomalies become larger).
3. Average Ilimaussaq agpaite (Ferguson, 1970b).

with rising pressure during prograde metamorphism, that is, that the P-T curve always has positive slope, the possible P-T paths cannot depart very far from the schematic path in Figure 5. The strongly jadeitic pyroxenes must be created fairly early under moderate to low thermal gradients, while the thermal gradient must steepen at a later stage, stabilizing omphacitic pyroxene. Such a P-T path is typical for amphibolite facies metamorphism, and the products are stable under amphibolite facies P-T conditions. Stability of highly jadeitic pyroxenes in amphibolite facies rocks can be achieved through the lowering of the jadeite stability in an undersaturated system. That is, the stability of the pyroxene is dependent upon the activity of SiO_2.

The cooling path shown in Figure 5 allows a late retrograde metamorphism to upper greenschist facies, as suggested by muscovite-biotite-epidote assemblages in the Wapustan Gneiss. Although plausible, the cooling curve is not clearly defined by present evidence.

The structure of the Red Wine region is complex and imperfectly understood. On a regional scale, a clear change in tectonic style may be observed from northwest to southeast. The Seal Lake Group is isoclinally folded, apparently by superficial "thin-skin" tectonics, whereas rocks of the adjoining Letitia Lake Group display intense cataclastic deformation along a southwest-trending curvilinear zone 10-15 kilometres wide. Southeast of this zone, intense cataclasis gradually gives way to strong plastic deformation. This change in style accompanies a general, though irregular, increase in metamorphic grade from sub-greenschist in the Seal Lake Group, to amphibolite grade in the Red Wine complexes. Granulite facies assemblages occur a few kilometres southeast of the mapped area.

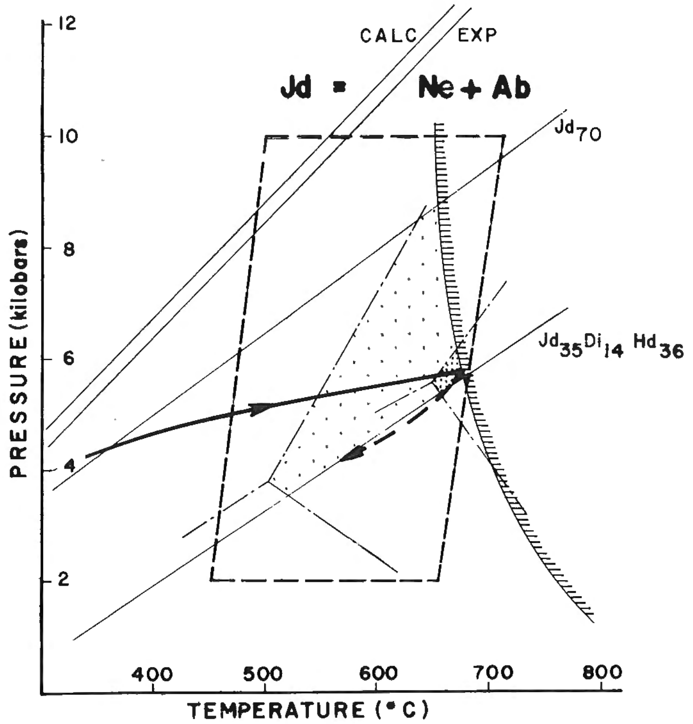
Within the alkaline rocks at least two periods of folding can be distinguished, but no indication of any great time interval between them was found. Extreme plastic deformation is evident in the North Red Wine Complex, and small scale transposition of gneissosity and dissection of boudins is evident in the surrounding gneisses. Competent gabbroic rocks and massive textured alkaline rocks occur as lenticular masses wrapped in schists. Such extreme deformation suggests that some of the occurrences of alkaline rocks may be tectonically dissected parts of a single mass, but no unique reconstruction can be made with the present data.

In the light of available fragmentary geochronological data, the development of the Red Wine region may be reconstructed as follows. The Wapustan Gneiss may be as old as 2700 m.y., since 2700 m.y. lead seems to be present in eudialyte from the hybrid rocks around the alkaline complex (Wanless, written comm., 1973). In any event, it must be substantially older than the Letitia Lake Group, which, on the basis of correlation with the Croteau Group to the east, has a minimum age of 1475 m.y. (Wanless and Loveridge, 1973). The age of the alkaline rocks may be estimated as 1264 m.y. (preliminary Rb/Sr isochron by Teledyne Isotopes (initial $Sr^{87}/Sr^{86} \sim 0.704$). A 1500 m.y. concordant Pb isotope age was obtained on eudialyte, assuming 80% non-radiogenic Pb of 2700 m.y. (R.K. Wanless, written comm., 1973). A preliminary Rb/Sr isochron on the Seal Lake Group gave an age of 1250 m.y. (W.R.A. Baragar, pers. comm.).

The Ilimaussaq Alkaline Complex

The Ilimaussaq alkaline complex lies within the Gardar igneous province, a narrow belt crossing the southern tip of Greenland (Fig. 6). The Gardar alkaline intrusives are emplaced into polymetamorphic basement rocks, orogenically metamorphosed and intruded around 1800 m.y. The formation of mobile belts followed this Ketilidean plutonism, and reactivation of the granites took place around 1500-1650 m.y. Over much of southwestern Greenland, the Ketilidean terrane is dominated by fairly homogeneous granitoid and gneissic rocks, collectively termed Julianehab granite. The development of this basement complex, as well as successive episodes of dyke intrusion predating the Gardar episode have been documented in some detail by Alaart (1967).

The Gardar igneous activity represents a cratogenic episode post-dating these events. The intrusives



______ Mark calculated equilibrium curves for the indicated pyroxene compositions. Experimental data for the transition of pure jadeite is shown for comparison.

(hachured line) Gives minimum melting for nepheline syenite (Hamilton and MacKenzie, 1965), while the higher and lower aluminosilicate triple points are from Richardson et al. (1969) and Holdaway (1971) respectively.

(dense stipple) Indicates possible range of P-T conditions for Richardson's triple point.

(sparse stipple) Indicates possible range of P-T conditions for Holdaway's triple point.

Figure 5. Pressure-temperature conditions of metamorphism of the Red Wine alkaline complexes.

are concentrated along a linear, down-faulted belt extending 150 kilometres from Narssarssuaq to Davis Strait. In the eastern Part, the major intrusion boundaries are linear, marked by Bredefjord and Igalikofjord, but at the west end the province trends irregularly west or northwest for more than 100 kilometres to the Kungnat complex. The dominant linear element within the Gardar province is east-northeast-striking, and has been exploited by giant dykes. The Gardar province displays a vast variety of intrusive styles and compositions. Dykes are ubiquitous, increasing in number and size toward the centre of the depressed area, so that on the island of Tugtutoq they locally form up to 20 per cent of the volume. The majority of the dykes are of mildly undersaturated basaltic composition, but a great range of composition from ultramafic alkaline types through lamprophyre, trachyte and phonolite tinguaite are known as well as saturated types including pantellerite. Central intrusions of varying size and complexity occur irregularly, generally becoming more undersaturated

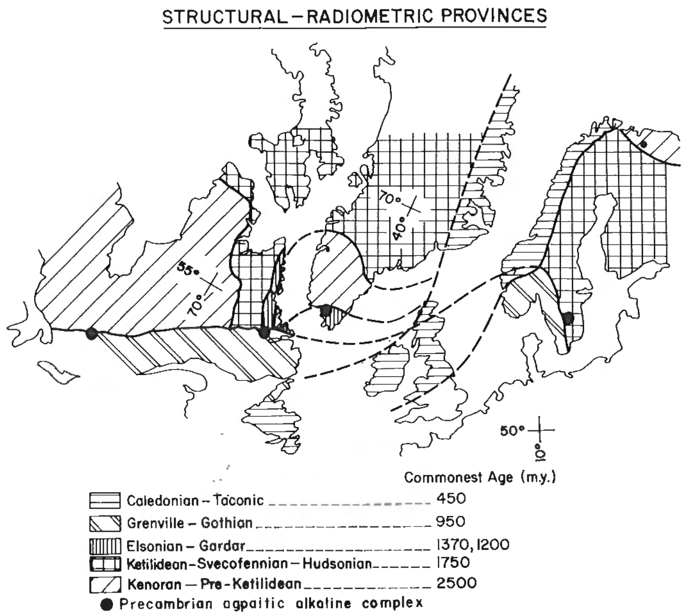


Figure 6. Structural-radiometric provinces across the North Atlantic, showing the position of agpaitic alkaline complexes.

from west to east, although exceptions occur. The most common central intrusions are of just-saturated syenites similar to the augite syenite of Ilimaussaq, but the Ilimaussaq complex and the five interpenetrating complexes of the Igaliko centre 30 kilometres farther east are two of the world's largest occurrences of undersaturated alkaline rocks. Volcanic rocks (Eriksfjord Formation) and diatremes occur only in a small area extending from Narsaq to Narssarssuaq, thought to be the most depressed portion of the graben. The range in composition of the volcanic rocks roughly parallels that of the dykes.

The Ilimaussaq complex displays an elliptical ground plan 17 kilometres along the northwest-southeast axis by 8 kilometres in a northwest-southeast direction, the elongation lying perpendicular to the Gardar trend.

According to the work of Ferguson (1964) the Ilimaussaq complex comprises a nearly continuous outer shell of augite syenite surrounding a sequence of agpaitic, layered syenites. Due to the 1400 metres of relief on the intrusion and possibly to some tectonic events, a large vertical section is displayed from the roof rocks down to rhythmically layered gravitational cumulates, although the base of the latter sequence is not exposed. According to the model of Ferguson (1964), which has not been changed in major outline by more recent work, the complex is thought to have resulted from in situ differentiation of magma of augite syenite composition by gravitational settling. Spectacular rhythmically-layered rocks due to accumulation of arfvedsonite, nepheline and eudialite accumulated on the base of the magma chamber (kakortokite sequence) while sodalite floated upward, producing the unique, sodalite-rich, poikilitic rocks of the naujaite sequence. The residual magma is considered to be represented by the fine-grained, dark-coloured schistose nepheline syenites termed lujavrites, mainly injected in the form of dykes and crystal mush between the naujaite and kakortokite, but also occurring as complex intrusion breccias around the edge of the complex.

The augite syenite, as the putative parent magma, clearly occupies a critical place in the petrology of Ilimaussaq. The finer-grained marginal portions of the augite syenite are commonly palpably hybrid with partially digested inclusions. Clear contacts with the granitoid country rocks are rare, gradational contacts predominating. Further, the contacts with the other members of the complex are equally ambiguous. The syenite is separated from the kakortokite by a zone of pegmatite. Some evidence of gradation into naujaite is found, by way of increase in nepheline and sodalite in various intermediate rocks lacking the characteristic poikilitic texture of naujaite. However, these transitions all take place near the roof, and in many places are obscured by the development of a bewildering variety of hybrid rocks, many of them containing a low tenor of quartz. Alkali granite cuts the upper parts of the complex south of Ilimaussaq Peak. Considering the strongly undersaturated character of the agpaitic rocks, the appearance of quartz-bearing rocks, particularly close to the roof, strongly suggests hybridization and hence unreliability of contact relations in these areas. Within the differentiated complex, Melchior-Larsen (1974) has suggested that most of the exposed kakortokites are younger than the naujaites, rather than contemporary as described by Ferguson (1964) basing this contention on the compositions of mafic minerals, as well as the observed presence of slumped blocks of naujaite in the kakortokite. This conclusion does not significantly affect the model however, as older kakortokites undoubtedly exist in the hidden part of the complex. The compositions of the major rock units (Table 1) also suggest difficulties with the derivation of the lujavrites, because these rocks seem too mafic to be a final residuum.

Ferguson (1970a) has attempted to avoid some of these difficulties by supposing that an ill-defined process of volatile transfer played a major role at Ilimaussaq. Although supported by the ubiquitous occurrence of pegmatitic schlieren, particularly at the contacts of various units, where the host of rare sodic minerals occur which characterize this intrusion, this concept encounters difficulties in explaining the limited metasomatism around the complex, and the very low f_{O_2} indicated by the widespread assemblage fayalite-magnetite-nepheline-albite. Numerous qualitative suggestions have been made that differentiation from some "typical" Gardar magma, such as augite syenite, could produce a magma parental to the Ilimaussaq agpaitic rocks, but chemical balance calculations (Table 4) show that such attempts fail unless implausible compositions richer in Si and poorer in Al than augite syenite are assumed for the extracted material. The compositions shown in Tables 1 and 4 may be seriously in error, for the rocks are coarse-grained and extremely heterogeneous. In any case, the derivation and differentiation of the Ilimaussaq complex are at present poorly understood.

Age determinations by Rb/Sr isochron on the Gardar province show the rocks to fall into two distinct groups (Blaxlund, 1974) the larger with an age of about 1165 m.y., but an important group of geographically and petrographically diverse rocks, dating at about 1310 m.y. Ilimaussaq may be the youngest of the Garder intrusions, but recent redetermination suggests that it falls into the 1165 m.y. group (Blaxlund, 1974).

Comparisons Between the Ilimaussaq and Red Wine Alkaline Complexes

The basic similarities in age and distinctive chemistry and mineralogy between Red Wine and Ilimaussaq are obvious. Beyond these similarities however, are some significant differences (*see* Table 3). The Gardar intrusives are controlled by prominent fault and graben structures. During periods of tension, the faults have been exploited by dykes and have also allowed egress of magma, resulting in rift valley-type volcanism. During periods of compression, more highly fractionated magmas such as represented by Ilimaussaq, developed. In Labrador a contemporaneous and analogous episode seems to have taken place, although many of the igneous rocks emplaced by the Labrador event have probably been destroyed or obscured by the subsequent compressional tectonism and polymetamorphism. Alternatively, the smaller volume of alkaline igneous material, paucity of volcanics and absence of dykes may be a consequence of the level of exposure, or the zone of arching and incipient rifting on the Labrador side of the Davis Strait may have been less pronounced than that in the Gardar province, so that formation or rejuvenation of abyssal faults would not be as successful, and magma access to the surface would be limited.

If the direction defined by Gardar rifting and the Grenville Front is extended in both directions (Fig. 6), two other agpaitic Precambrian alkaline complexes are encountered, both metamorphosed at about 1000 m.y. namely Kipawa in western Quebec, and Norra Karr in southern Sweden (von Eckermann, 1968). That the only four known Precambrian complexes of this character in the North Atlantic alkaline province should all lie along a single tectonic boundary and not be related, seems improbable.

If Ilimaussaq is accepted as displaying the clearest evidence of conditions of origin, it suggests that all four were emplaced under tensional conditions. This zone of tension must have very nearly paralleled the slightly later zone of compression. Perhaps some sort of "back arc rifting" (Karig, 1972) is involved. Militating against these speculative correlations is the obvious fact that the compositions of the Red Wine rocks cannot be directly compared with Ilimaussaq, despite a general similarity. Many of these differences can be attributed to the metamorphism, such as the pyroxene, nepheline and feldspar compositions. Although some of the chemical differences may be a feature of the primary magma (for instance the low aluminum content), others may be a result of remobilization and metasomatism during the metamorphism. The low volatile content (combined

Cl, F and H_2O) of the Red Wine complexes and the extensive metasomatic aureole surrounding them, suggest loss of volatiles during metamorphism. The suggestion by Floor (1974, p. 125) that the chemical compositions of alkaline gneisses "are identical to their unmetamorphic analogues" is disputed in this instance. The difference in oxidation ratio may reflect buffering of the rocks by ubiquitous highly ferrous arfvedsonite in the Red Wine Complex. The absence of sodalite in the Red Wine Complex is unusual, although this may be simply a metamorphic effect. However, the lack of significant amounts of either nepheline-rich or eudialyte-rich rocks similar to the kakortokites seems difficult to explain by this means. Further, the surroundings of the Red Wine rocks contain few dykes. In the metamorphosed rocks, this may perhaps be partially explained by transposition of the dykes into the gneissosity and subsequent metamorphism. Total obliteration of a substantial dyke swarm in this fashion seems very unlikely.

Acknowledgments

Dr. D.A. Brown, Australian National University, kindly provided a translation of Semenov's treatise "Mineralogy of the Ilimaussaq Massif". We have benefited greatly from informal discussions with participants in the "Friends of the Gardar Conference", Copenhagen in June 1974. Our first-hand knowledge of the Gardar province was acquired through the invaluable field guidance of Henning Bose, Lotte Melchior-Larsen, Brian J.G. Upton, and Henning Sorenson.

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81. MISCELLANEOUS DATA FROM VOLCANIC BELTS AT YELLOWKNIFE, WOLVERINE LAKE, AND JAMES RIVER, N.W.T.

W.R.A. Baragar
Regional and Economic Geology Division

Introduction

Approximately one month of the past season was devoted to examining drill core from the Yellowknife volcanic belt and in making brief reconnaissance surveys in volcanic belts at Wolverine Lake and along the James River. The purposes of the work were as follows: 1) examination of the drill core was to supplement existing data on the Yellowknife volcanic belt, particularly in regard to the constitution of pillow lavas, and 2) reconnaissance in the other two volcanic belts was to provide a basis for planning future volcanological studies.

I wish to express my appreciation to Giant Yellowknife Mines Limited for provision of drill core and to Mr. Brian Watson, Chief Geologist, for his part in making it available and for supplying background information. Grateful thanks are also due to R.W. Hornal and his staff of the Department of Indian Affairs and Northern Development for use of the Core Library at Yellowknife and for numerous courtesies. J.R. Hart performed the duties of assistant with distinction.

Yellowknife Volcanic Belt: Examination of Drill Core

Five drillholes spanning an important segment of the Yellowknife Supergroup at Yellowknife were examined The holes had been drilled by Giant Yellowknife Mines Limited over the past few years and the cores donated by the company to the core library of the Department of Indian Affairs and Northern Development. Four of the holes (S919, S1159, S1158 and S1157) are essentially in the plane of a single section bearing S 60°E and passing through a point about 1,200 feet S 30°W of the Giant Mine B-Shaft (Fig. 1). The fifth hole (S14115) is parallel to the section but lies about 800 feet northeast of it. Unlike the others it was drilled from underground workings. Between them the holes penetrate a stratigraphic thickness of about 5,400 feet including 1,900 feet of mafic lavas belonging to the upper part of the Kam Formation, the Jackson Lake Formation (1,700 feet), and 1,800 feet of silicic volcanics of the Banting Formation. The formational names are attributable to Henderson (1970).

A simplified section of the geology is given in Figure 2 and a stratigraphic column in a little more detail in Figure 3. The latter does not include information from the off-section hole (S14115) which can be integrated with less certainty into the geology of the section. The geology of the surface between S919 and S1158 at the shoreline of Yellowknife Bay is interpreted from the map of Henderson and Brown (1949).

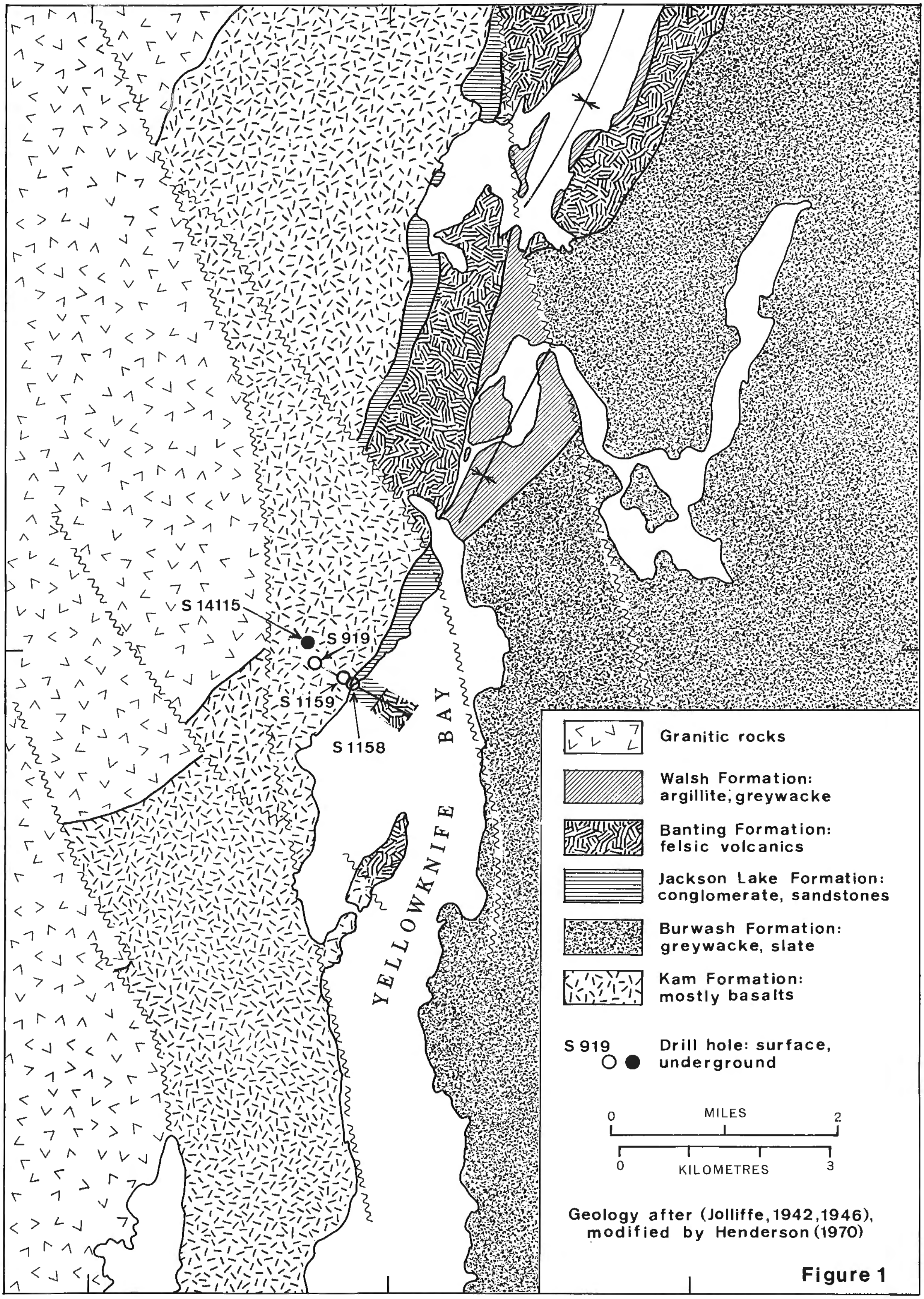
The surface and drillhole information in the western part of the section can be correlated reasonably well and indicates that flows of the upper part of the Kam Formation are overturned and dip steeply west. This is confirmed by correlation of distinctive units of the Jackson Lake Formation between drillholes S1158 and S1159 where an almost identical dip is obtained. Farther east felsic rocks of the Banting Formation are assumed to dip at the same angle and this dip is consistent throughout with the angle bedding makes with the core.

The segment of the Kam Formation examined comprises alternating pillowed and massive units as shown (Fig. 3). The pillowed units are continuously pillowed with no evidence of a possible hiatus in their course of accumulation. Presumably each belongs to a single eruption or several closely spaced eruptions. One cherty layer separating a massive and pillowed flow is the only evidence of a break in the eruptive sequence in this part of the section. Unfortunately schistosity does obscure some parts of the section. The variolitic flows are correlative with the Negus (lower) and Yellowrex (upper) flows respectively according to Henderson and Brown's (1966) map. They are not highly variolitic in the drill core. For the most part the variolites are confined to a zone, 1-2 inches wide, adjoining the pillow rim and coalescing rapidly inward to merge with the mass of lava forming the interior of the pillow. In drillholes S14115 the variolites are mostly small and inconspicuous. These flows may correlate with the Negus variolitic flows of hole S919, but if so, their variolites are much less well developed.

Schistosity is of variable intensity within the lavas but is generally not so severe as to obliterate the original nature of the rock. Even where it is prominent some of the original features, such as pillow rims and stretched variolites, can still be recognized.

The contact between lavas of the Kam Formation and sediments of the Jackson Lake Formation is not well-defined because of schistosity locally present. It is interpreted as a fault contact (Fig. 2) since its projected position on the surface falls well within the volcanic sequence. The faults in question are assumed to be the northerly-trending (sinistral) faults of Henderson and Brown (1949) each of which offsets the contact about 300 feet. If so, they must have moderate to shallow dips as shown in the section and very little of the Jackson Lake Formation can be assumed to be missing.

The Jackson Lake Formation in this section is composed mainly of light grey greywacke or subgreywacke, very little shale, and no conglomerate. In part it is composed of well-graded beds ranging in thickness from a few inches to a maximum of 25 feet (thickness of beds shown in Fig. 3 are diagrammatic) but for the



S 14115
S 919
S 1159
S 1158
YELLOWKNIFE BAY
Granitic rocks
Walsh Formation: argillite, greywacke
Banting Formation: felsic volcanics
Jackson Lake Formation: conglomerate, sandstones
Burwash Formation: greywacke, slate
Kam Formation: mostly basalts
S 919
Drill hole: surface, underground
0 MILES 2
0 KILOMETRES 3
Geology after (Jolliffe, 1942, 1946), modified by Henderson (1970)

Figure 1

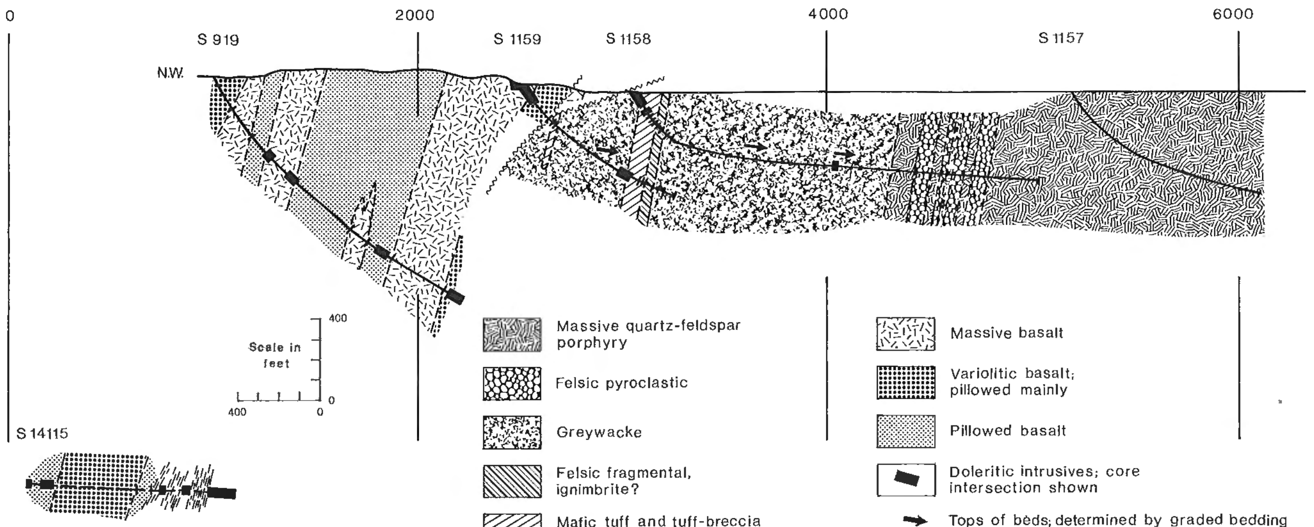


Figure 2

most part the greywackes are massive, monotonus units with inconspicuous bedding. Some mafic tuffs are interbedded with the greywackes in the lower part of the section but their generally light colour and sparsely scattered felsic fragments suggests that the greywackes are to a large degree the debris of a felsic volcanic source. One bed of felsic pyroclastics, low in the section, contains flattened yellowish fragments, 1-2 centimetres thick, with a delicate web-like texture reminiscent of pumice in welded tuff. It is, accordingly interpreted as an ignimbrite. The unit is distinctive and was readily recognized in both drillholes S1159 and S1158. The presence of a similar unit was reported on surface at about the same stratigraphic level (W.A. Padgham, pers. comm.).

Greywackes of the Jackson Lake Formation are abruptly overlain by felsic volcanics of the Banting Formation. The contact itself is somewhat obscured by a quartz-carbonate alteration that recurs intermittently throughout the Banting Formation, especially where schistosity is marked. The lower 500 feet of the formation consists of layers of massive pink or buff quartz and quartz-feldspar porphyry alternating with layers of fragmental rocks of similar material. One layer is essentially a greywacke containing fragments of felsic volcanic rocks indicating, perhaps, that the Jackson Lake and Banting formations interfinger. The upper part of the Banting Formation exposed in the drillhole is almost entirely massive quartz and quartz-feldspar porphyry. Narrow, fine-grained and breccia zones appearing intermittently through the mass may represent the contacts of individual flows or flow units. If so, they are much less prominent than might be expected for what must have been a highly viscous flow. Only one thin tuff layer can be attributed with confidence to a flow junction in the massive section.

Wolverine Lake

Volcanic rocks in the vicinity of Wolverine Lake (Fig. 4) are notable among volcanic belts of the Slave Province in that they contain iron-formation, comprise a high proportion of felsic volcanic rocks, and are only moderately deformed. Unlike the Superior Province where iron-formation is a characteristic component of the volcano-sedimentary assemblages, in the Slave Province it is rare. Its presence in this region was first reported to the writer a number of years ago by Cominco geologists.

The stratigraphic succession in the vicinity of Wolverine Lake embraces only part of the total volcanic succession of this region which is known from reconnaissance mapping to underlie an area some 20 miles in diameter (Barnes and Lord, 1954; Wright, 1957; Fraser, 1964; and Tremblay, 1971) and to comprise mainly felsic volcanic rocks.

The oldest rocks are a mixture of massive, aphanitic, light grey felsites - probably rhyolites - and related fragmental rocks. Rarely they are feldspar phyric. Fragments and groundmass of the fragmental rocks are generally of the same composition and may be in part auto - or flow breccias. Near the south of the observed area a thin wedge (± 200-300 feet) of greywacke interfingers with the felsic volcanics. Massive felsite passes into the greywacke wedge through a 10-foot-thick conglomeratic zone in which felsite fragments 2-3 inches in diameter, are embedded in a carbonate-rich, sandy matrix.

A greywacke member several hundred feet thick succeeds the lower felsic unit and is overlain in turn by iron-formation. The greywacke is thick-bedded, massive in hand specimen, and light grey in colour. With the heavy lichen cover that is characteristic of the region it can be very difficult to distinguish from massive felsites. Fragments of felsite ranging from a few millimetres to several centimetres in diameter are commonly present in the greywacke and are undoubtedly indicative of its highly felsitic composition.

The best exposure of iron-formation is in the river bed at the east end of Wolverine Lake where it succeeds greywacke with essentially no transitional zone between. Some 30 to 40 feet of iron-formation are exposed, all comprising thin-bedded (± 2-10 mm) jasper-hematite

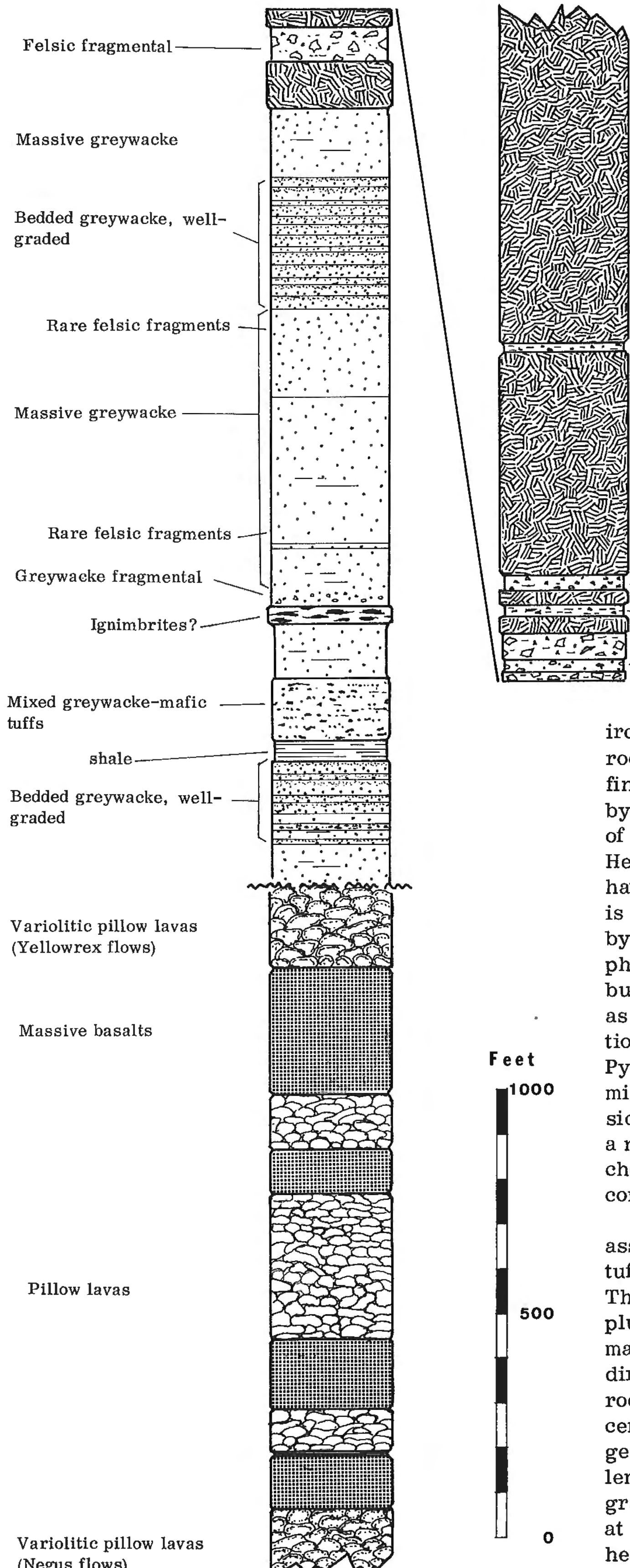
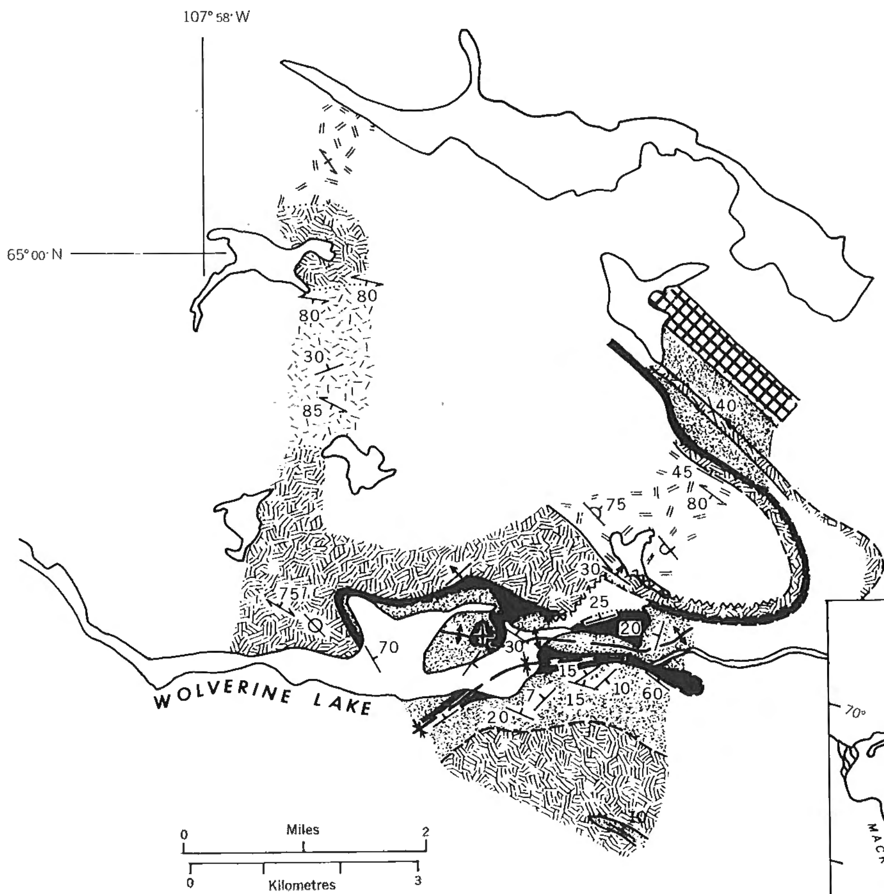
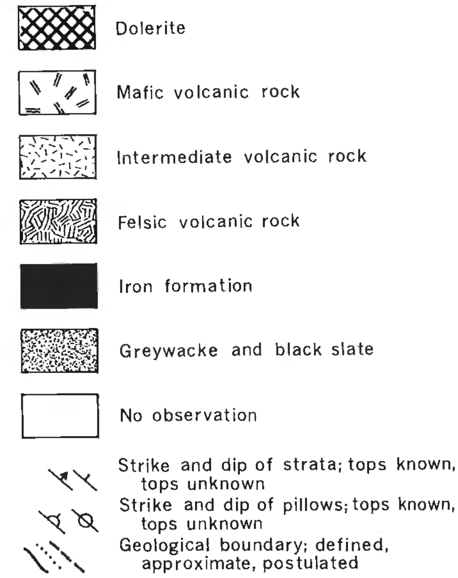


Figure 3

iron-formation. Recrystallization commonly gives the rock a finely sucrose texture. Disrupted beds confined to narrow stratigraphic intervals and truncated by undeformed overlying beds are common features of the sequence and probably reflect wave action. Hence at this locality the iron-formation appears to have been deposited in shallow waters. Elsewhere it is poorly exposed and its presence is commonly marked by surface gossans only. Much of it appears to be sulphide rather than oxide facies as exposed in the creek but the scarcity of good exposures makes it uncertain as to whether this is a function of stratigraphic position within the iron-formation or of lateral variation. Pyrite and lesser pyrrhotite are the only sulphide minerals recognized in the gossans. On the northeast side of the area where the iron-formation appears as a narrow (200-400 foot wide), rusty-weathering zone, chocolate brown-weathering carbonate appears as a constituent of the rock in addition to sulphide.

Above the iron-formation is a thick volcanic assemblage comprising felsitic (probably rhyolitic) tuff breccias, lapilli tuffs and flows and mafic flows. They appear to be folded into a gently northeast-plunging syncline with felsitic rocks on the flanks and mafic rocks in the centre. In the lowest exposures directly north of the peninsula of Wolverine Lake the rock contains rounded amygdaloidal bombs, 10 to 25 centimetres in diameter, in a lapilli-tuff matrix suggestive of subaerial eruption. One narrow-bedded lens in the same outcrop contains thin (3-4 cm), well-graded beds indicating tops to the north. Mafic rocks at the centre of the syncline are pillowed in part but heavy lichen cover makes an assessment of the proportion of pillowed lavas difficult. The pillows are





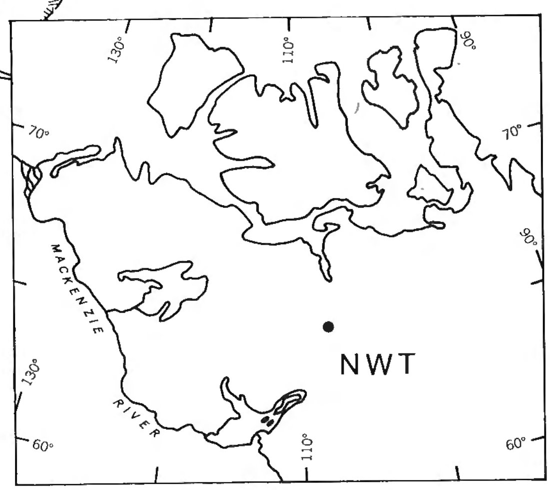


Figure 4

moderately thick-rimmed and markedly amygdaloidal indicating that they formed at shallow depth. Where the succession was crossed farther to the northwest mafic pillowed lavas were not encountered. Rather, the rocks are a mixed assemblage of intermediate to felsic volcanics most of which are feldspar phyric. Mafic rocks on the north end of that traverse are non-pillowed and feldspar phyric unlike the pillowed lavas to the south.

James River

The volcanic belt that crosses James River extends northward to the Arctic coast and includes the copper deposit of Kennarctic Explorations Limited at High Lake. It was outlined in the reconnaissance survey of the northeastern District of Mackenzie by Fraser (1964) and the High Lake quadrangle was mapped in detail by Padgham (1974).

A strip across the belt at James River is shown in Figure 5. At this point it is about 9 miles wide and is bounded on both sides by massive, intrusive granites. A granite plug intrudes its interior. The rocks are of moderate metamorphic grade and variably deformed but generally sufficiently well preserved that primary structures are recognizable. Unfortunately top-determination criteria are scarce (or because of heavy lichen cover not visible) and the structural interpretation is uncertain. The most reliable top-determinations made are shown and these permit a structural interpretation as follows. The belt is a tightly folded syncline with volcanic rocks composing the flanks, and slates and greywackes the core. A subsidiary anticline exposes volcanic rocks in the centre of the sedimentary core. The volcanic sequence consists of interlayered "mafic" and felsic flows topped by thick-bedded felsic fragmental rocks that interfinger with the overlying slates. The "mafic" rocks are probably mostly andesites. Pillows, recognized in a few places, are generally thick-rimmed and rarely useful for top determinations. A succession of dolerite-textured mafic rocks that may represent sills are interleaved with the volcanic rocks on the western flank of the belt. The felsic flows are massive, commonly quartz porphyries, and for the most part have a granular texture owing to metamorphic recrystallization. They are probably dacites. Felsic fragmental rocks at the top of the volcanic succession are composed of angular fragments of buff or cream-coloured rhyolite or dacite ranging from a few millimetres to more than 20 centimetres in diameter in a

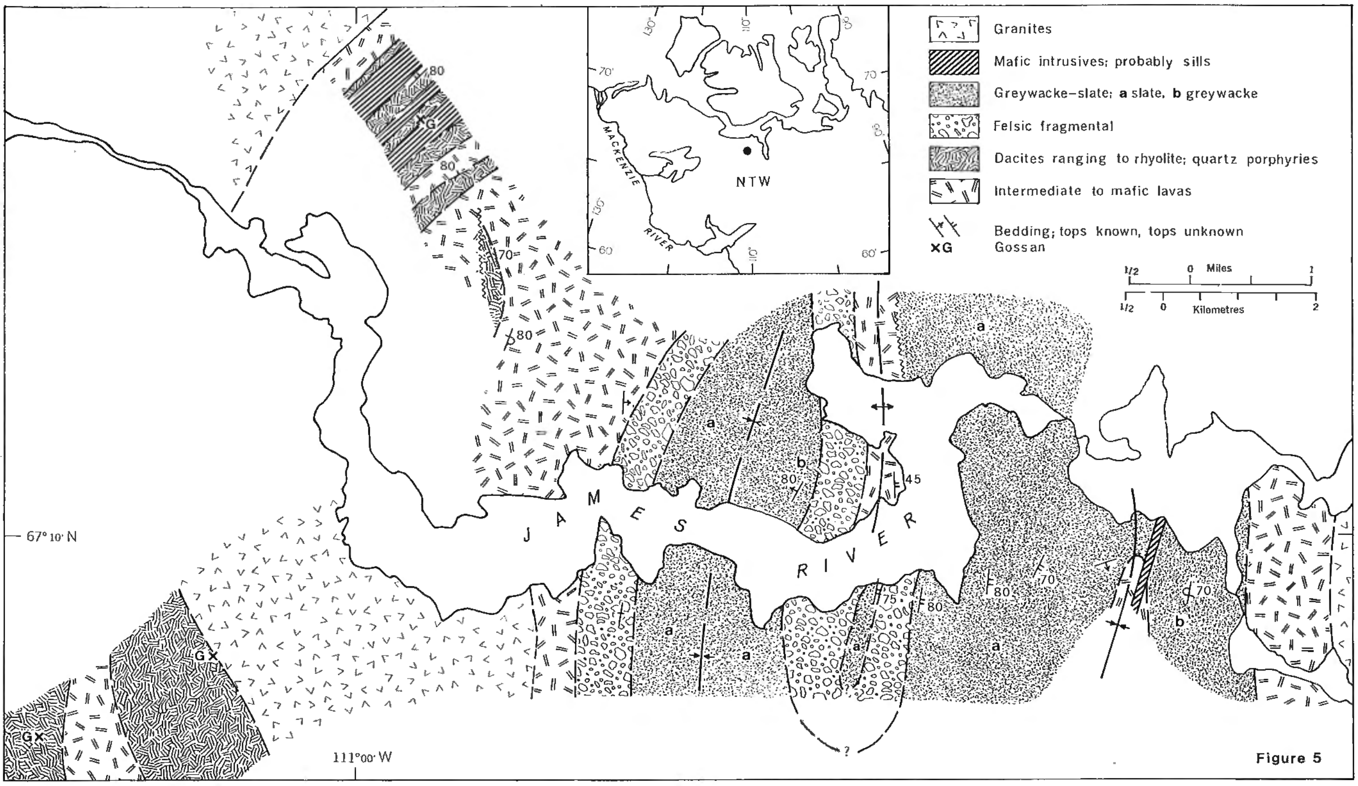


Figure 5

tuffaceous matrix of similar composition. A few fragments of black shales are present in places. Individual units of the felsic fragmental rocks appear to be thick. One well-exposed unit is 350 feet thick, and is bounded on both sides by black slates.

The sedimentary rocks are thin-bedded black shales and subordinate greywackes. Locally the greywackes are well-graded in beds ranging from about 10 centimetres to 5 metres in thickness.

Gossans associated with the felsic flows are numerous in the western half of the belt. Only a few were examined but others could be seen in the surrounding region. Those examined are patchy rather than linear in form and are sufficiently deep-weathered that sulphide minerals are rarely preserved. In two or three cases weathered blocks of massive pyrite in a sugary quartz matrix were found at the surface.

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FIELD CHARACTERS OF THE EARLY PRECAMBRIAN ROCKS FROM SAGLEK, COAST OF LABRADOR

D. Bridgwater[1], K.D. Collerson[2], R.W. Hurst[3] and C.W. Jesseau[2]

Introduction

A combined field program of geological mapping (Bridgwater, *et al.*) and collection for isotope studies (Hurst) was carried out in late July and August 1974, to establish a sequence of geological events in the gneiss complex of the Nain Province on the Labrador coast. This area forms the westernmost part of the disrupted North Atlantic Craton (Bridgwater *et al.*, 1973a) and is one of considerable interest, both in studies of the early evolution of the sialic crust and in studies of the boundary relations between areas of Archean rocks and areas affected by Proterozoic deformation and high grade metamorphism (Bridgwater *et al.*, 1973b).

Regional Setting

Previous work (*see* Taylor, 1969, 1970, 1971; Bridgwater, *et al.*, 1973a, b; Morgan, 1973 and in press; Knight, 1973, 1974) established the following main features in the Precambrian gneiss complex of northeast Labrador.

1. A major geological boundary trending northward in the inner part of Saglek Fiord (Fig. 1) separates Archean gneisses to the east (the Nain Province) from an area affected by Proterozoic high grade metamorphism and intense deformation to the west (the Churchill Province).

2. The Archean rocks are overlain by a north-trending belt of low-grade Aphebian sediments, the Ramah Group. Proterozoic deformation folded these cover rocks into a series of north-south flexures but apparently had little effect on the underlying Archean basement, apart from reactivation of pre-existing shear belts.

3. The Archean gneiss complex is made up of alternating units of quartzofeldspathic gneiss interlayered with belts of schists and gneiss of metasedimentary and metavolcanic origin. This is comparable to the regional distribution of rock units of different origin exposed in the Archean gneiss complex of Greenland.

4. The Archean gneisses north and west of Shuldham Island contain granulite facies assemblages which have been partly retrogressed during post-granulite facies deformation and granite injection.

5. The Archean gneiss complex is cut by basic dykes which are not seen to intrude the Aphebian cover rocks and which are affected by Proterozoic deformation.

6. Regional K-Ar age determinations (*see* Taylor, 1969, 1970, for summary) suggest that the gneiss complex became closed to argon loss about 2500 m.y. ago, comparable to other parts of the North Atlantic Craton. U-Pb age determinations on zircons separated from gneisses at Lost Channel (80 km south of Saglek) demonstrated the presence of sialic crust at least 3400 m.y. old on the Labrador coast (Hurst, 1974) suggesting that this area may preserve evidence of as complex a history as that recorded from West Greenland (McGregor, 1973; Moorbath *et al.*, 1972). However, the extent, regional setting and geological significance of the old rocks from Lost Channel is unknown.

Geological Summary

The Archean rocks of the Saglek area consist of strongly deformed high grade gneisses with a northerly strike. The major part of the complex consists of quartzofeldspathic gneisses interpreted by us as derived from granitic (*sensu lato*) plutonic igneous rocks interlayered with gneisses derived from supracrustal rocks and associated hypabyssal intrusives.

Many of the quartzofeldspathic gneisses contain remnants of basic dykes now recrystallized as amphibolites and rotated parallel to the regional foliation during subsequent episodes of intense deformation. The presence or absence of amphibolite dykes in a particular gneiss unit is used as the main criterion for separating a group of older gneisses from suites of younger gneisses in the complex (Fig. 2) and for establishing the sequence of events summarized in Table 1 (compare McGregor, 1973). As a working hypothesis, we suggest that the intercalation between quartzofeldspathic gneisses and supracrustal rocks is in part due to tectonic interleaving of the oldest gneisses with a cover sequence and in part due to the injection of younger granitic sheets into the interlayered gneiss-supracrustal complex.

A major fault (known as the Handy fault) trending northward through Handy Island in the sound between Shuldham Island and Big Island, and extending south through St. John's Harbour to Hebron Fiord, separates the gneiss complex into two structural and metamorphic domains. To the east of the fault zone the gneisses contain amphibolite facies assemblages. Granulite facies rocks are restricted to three or four scattered outcrops. West of the fault the majority of gneisses either contain granulite facies assemblages or are retrogressed from rocks which earlier contained granulite facies assemblages. On Shuldham Island in the transitional zone between the two areas the granulite facies rocks can be seen to have formed at the expense of

[1]The Geological Survey of Greenland, on an exchange visit to the Regional and Economic Geology Division, Ottawa.

[2]Memorial University of Newfoundland, St. John's, Newfoundland.

[3]University College of Los Angeles, California.

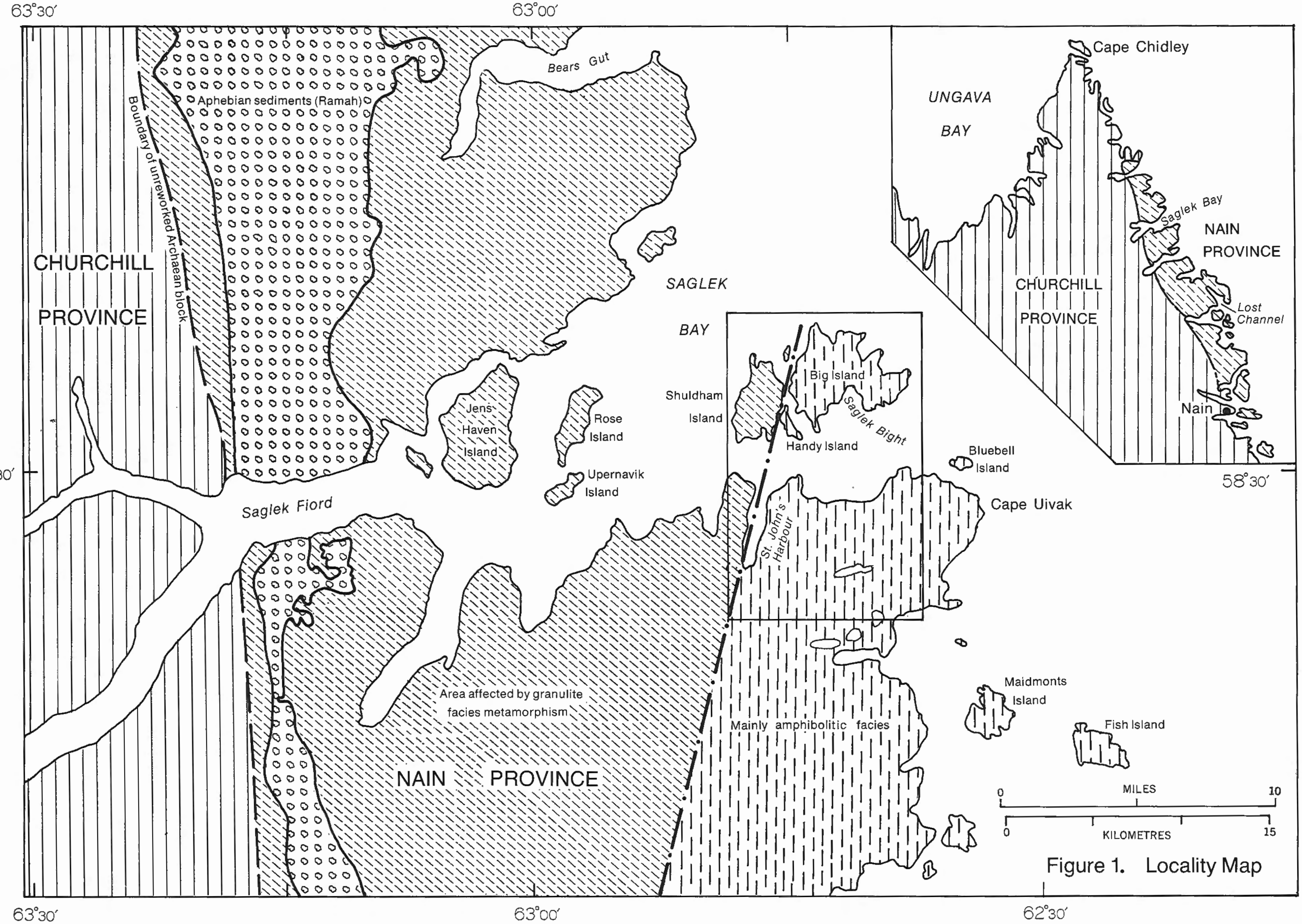
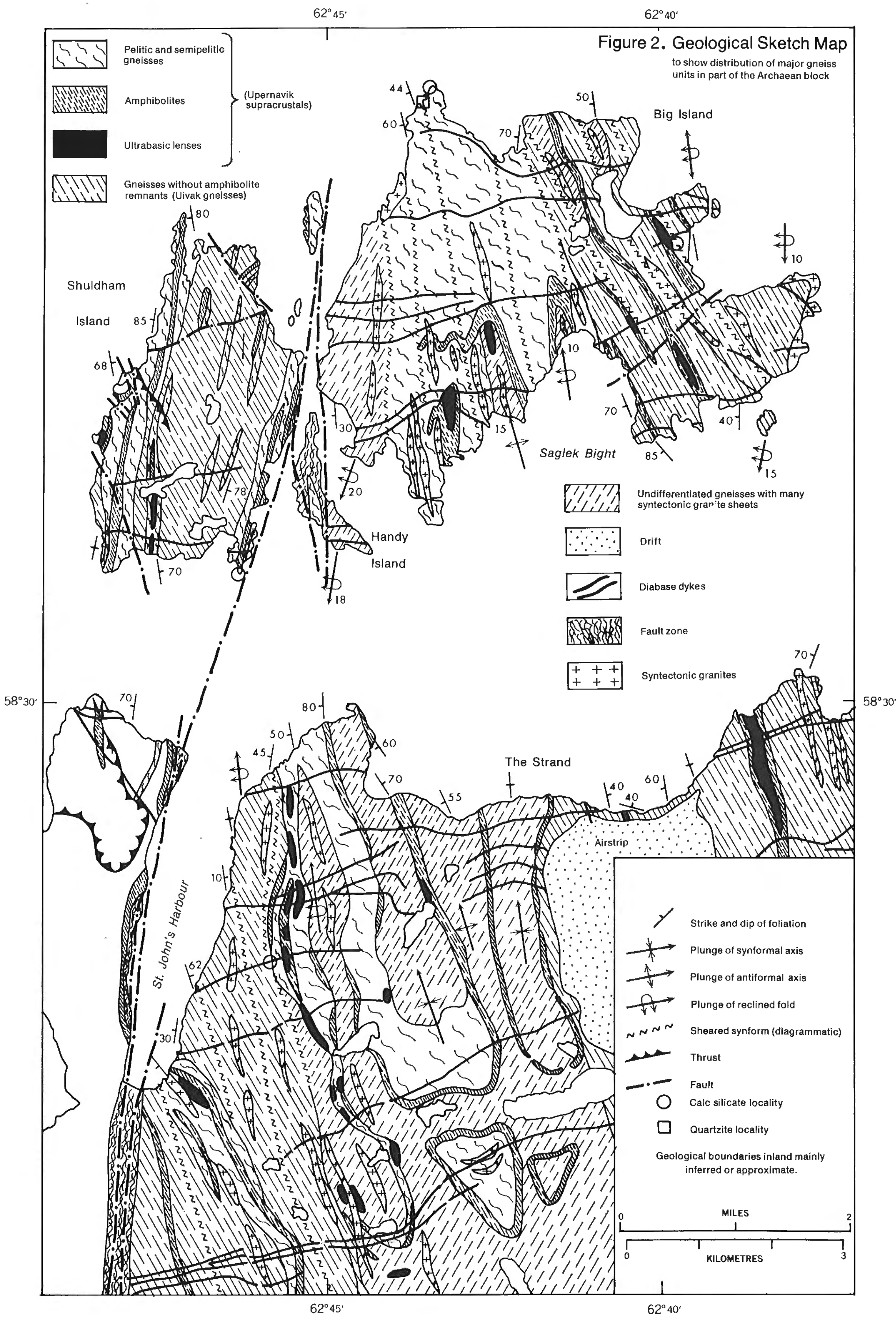


Figure 1. Locality Map



62°45′
62°40′
Figure 2. Geological Sketch Map
to show distribution of major gneiss units in part of the Archaean block
Pelitic and semipelitic gneisses
Amphibolites
Ultrabasic lenses
(Upernavik supracrustals)
Gneisses without amphibolite remnants (Uivak gneisses)
Big Island
Shuldham
Island
Saglek Bight
Handy
Island
Undifferentiated gneisses with many syntectonic granite sheets
Drift
Diabase dykes
Fault zone
Syntectonic granites
58°30′
58°30′
The Strand
Airstrip
St. John's Harbour
Strike and dip of foliation
Plunge of synformal axis
Plunge of antiformal axis
Plunge of reclined fold
Sheared synform (diagrammatic)
Thrust
Fault
Calc silicate locality
Quartzite locality
Geological boundaries inland mainly inferred or approximate.
MILES
0
2
0
KILOMETRES
3
62°45′
62°40′

earlier amphibolite facies rocks similar to those seen east of the fault. We regard the Handy fault as a major tectonic break in the area, probably developed in the boundary zone between granulite and amphibolite facies rocks which has remained active over a considerable time. We suggest that the rocks to the west of the fault may represent a lower level of the Archean crust than those to the east, and that the two areas responded differently to tectonic and magmatic events which occurred in the last stages of the development of the Archean gneiss complex.

Table 1

Simplified table of events

1. Deposition of early supracrustals
2. Intrusion of Uivak gneisses
3. Deposition, deformation and metamorphism of Upernavik supracrustals
4. Reactivation of earlier gneisses, intrusion of granitic suite
5. Granulite facies metamorphism
6. Intrusion of synkinematic granites along N-S axial planes
7. Intrusion of late granites in shear belts
8. Formation of major mylonite zones
9. Intrusion of at least 3 generations of basic dykes
10. Deposition of Ramah Group (Aphebian)
11. Proterozoic folding and high grade metamorphism, particularly in west, pseudotachylites in east

Major Rock Stratigraphic Units and Sequence of Events[1]

1. The Uivak gneisses are highly deformed quartzofeldspathic gneisses characterized throughout the area mapped by the presence of numerous relics of amphibolitic dykes (Saglek dykes, *see* below). The Uivak gneisses probably make up at least 50 per cent of the total outcrop in the Saglek area.

2. The Saglek dykes are a suite of metabasic amphibolite (or in granulite facies areas pyroxene granulite) intrusions which transgress earlier structures in the Uivak gneisses and which are interpreted as derived from diabase dykes which have been metamorphosed and strongly deformed by subsequent events.

3. The Upernavik supracrustal rocks are a variable group of schists and gneisses among which the metasediments range from pelites to quartzites and marbles. The metasediments are interlayered with a variety of meta-igneous rocks ranging from amphibolites possibly derived from lavas and sills, ultramafic pods and layered basic bodies. All the major outcrops of supracrustal rocks examined have the same general relations with the other rock units forming the gneiss complex; they are interlayered with the Uivak gneisses, but are not seen to be cut by Saglek dykes. They are migmatized and intruded by several generations of younger granitic gneiss. Individual supracrustal units vary considerably in thickness along the strike and occasionally contacts with adjacent Uivak gneiss units cut across lithological variations in the supracrustals, suggesting that the contacts are tectonic. No primary sedimentary contacts have been observed between the supracrustals and the Uivak gneisses, and no features such as conglomerates have been noted.

On the outer coast, as little as 5 per cent of the gneisses are regarded as derived directly from supracrustal rocks, while to the west, perhaps 30-40 per cent of the rocks are derived from sediments and lavas. On a regional scale about 80 to 85 per cent of the gneiss complex is thought to have been derived from plutonic igneous rocks. This is comparable to other parts of the North Atlantic Craton.

4. Quartzofeldspathic gneisses without amphibolite dyke remnants are deformed sheets of granitic gneiss that do not contain remnants of Saglek dykes, are locally seen to be intrusive into both the Upernavik supracrustals and the Uivak gneisses and are widespread. They rarely form major mappable units and appear to be mainly formed by the remobilization of earlier granitic gneisses such as the Uivak gneisses or partial mobilization and migmatization of the pelitic and semipelitic supracrustal rocks. Signs of remobilization are particularly widespread in the granulite facies rocks to the west of the Handy fault where there are major units of granitic hypersthene gneiss with abundant inclusions of the more resistant supracrustal units such as ultramafic and calcareous rocks. In areas of retrogressed granulite facies rocks, the remobilized quartzofeldspathic rocks show a distinct blotchy texture and partial loss of layering due to the concentation of the mafic minerals in aggregates.

5. Late syntectonic granites: The last major phase of deformation in the amphibolite facies area east of Handy fault produced a series of north-trending folds with axial planes varying from approximately vertical to shallow dips towards the west. The formation of the folds was accompanied by the injection of major swarms of syntectonic granite sheets varying from a few metres to several hundred metres in width. Major subconcordant bodies of granites believed to have been emplaced during the same phase of regional deformation occur on the outer coast of Big Island and Fish Island. On Fish Island the granites contain inclusions of granulite facies gneisses, suggesting that these granites postdate the regional granulite facies event.

West of the Handy fault, similar north-trending folds have not been observed in the granulite facies and it seems likely that they are represented by a series of subvertical zones of high deformation. These are intruded by granite sheets, some of which contain

[1] The stratigraphic names used in this account are informal and only apply to the area mapped.

hypersthene, others of which appear to have been emplaced after the main peak of granulite facies metamorphism.

6. Late granites emplaced along shear belts: The final plutonic episode in the area was the emplacement of pale grey granite sheets along shear belts (trending dominantly at 140°) which remained active after the end of regional penetrative deformation. Many of these bodies are composite intrusions with pegmatitic and aplitic phases or more mafic fine-grained margins surrounding leucocratic pegmatitic centres. Where these rocks are intruded into granulite facies gneisses, they are frequently accompanied by a zone of retrogression in which the granulites are bleached and hypersthene converted to amphibole.

7. Diabase dykes and other minor intrusions: At least three generations of diabase dykes have been identified from the area mapped; an early generation trending northerly and two later generations of east-trending dykes. All three generations are affected by faulting and are locally slightly metamorphosed. A few dykes contain highly foliated hornblende-rich centres and are thought to have been emplaced along active shear zones. Most of the dykes show well-developed ophitic or subophitic textures. One east-trending dyke on Fish Island contains aggregates of plagioclase megacrysts concentrated in a zone near the southern margin. A few olivine dolerites occur. Other minor intrusions noted from the area include a thin lamprophyre with hornblende phenocrysts from the mouth of Tigigakyuk Inlet and a series of flinty dark green intermediate or acidic dykes from the south coast of Handy Island. Locally the gneisses contain irregular masses of carbonate and diffuse areas in which the original minerals have been replaced by albite, carbonate and a bright green chloritic mineral. These are particularly well-developed along an east-trending fault zone east of Saglek Bight and at the mouth of Tigigakyuk. The carbonate mineralization post-dates the dykes.

8. Formation of mylonites and pseudotachylites: North-trending zones of mylonite and veins and irregular anastomosing sheets of pseudotachylite are common throughout the area. They are particularly abundant near the Handy fault where pseudotachylite veins break up a variety of granulite facies rocks. They have been reported from several other areas of Archean rocks on the Labrador coast (e.g. Coleman, 1921). Much of the movement associated with the regional formation of mylonite zones and possibly some of the pseudotachylites took place before the injection of the diabase dykes which cut across strongly sheared gneisses, for example, on the west coast of Shuldham Island. However, the main phase of pseudotachylite formation is post-dyke and is regarded as related to the major movements along the boundary of the Churchill Province to the west.

Field Characters of the Major Rock Units

The Uivak gneisses are a composite group of quartzofeldspathic rocks which may not all belong to the same igneous suite. They are described as a single lithological unit because of their relation with the Saglek dykes. They can be described under two main headings: (a) Early grey gneisses; (b) Porphyritic granite gneiss and associated calc-alkaline intrusions.

The early grey gneisses are by far the most abundant rock unit in the area mapped; most of the rather nondescript outcrops of quartzofeldspathic gneiss in the Archean complex are either composed of this rock or at least contain a large percentage of early grey gneiss, migmatized and included in younger granitic rocks. Where comparatively little affected by post-Saglek dyke tectonism and migmatization, the early gneisses are typically leucocratic medium- to fine-grained biotite-bearing layered rocks with septa of grey "tonalitic" grey gneiss interlayered with coarser-grained concordant pegmatites 1-2 cm across, composed of a more potash feldspar-rich phase. The concordant pegmatite layers form 5-10 per cent of the total rock. Most were formed at an early stage in the history of the gneisses predating the Saglek dykes and (locally) the intrusion of the early granite suite described below. However, in any one outcrop there are commonly several generations of pegmatitic layers and unless clear-cut intrusive relations are seen with later units such as the Saglek dykes, it is impossible to decide when a particular pegmatitic layer was formed. The early grey gneisses locally contain inclusions of quartzitic gneiss with garnet-sillimanite layers and some graphite. These are interpreted as derived from remnants of even earlier supracrustal rocks into which the grey gneisses were emplaced. The general character of the early grey gneisses in the field suggests that they are derived from a suite of dominantly granodioritic rocks which were emplaced during active deformation, and which acquired a very early layering by the segregation of slightly more potash-rich phases.

The porphyritic granitic gneisses (Figs. 3 and 4) and related rocks are concentrated in a belt extending from the west coast of Maidmont Island through White Point to Saglek Bight. Their relation with the early grey gneisses is not seen over much of the area. Outcrops with well-developed potash feldspar augen and a moderately high mafic mineral content pass laterally into strongly foliated gneisses that only differ from the normal grey gneisses in a slight increase in the amount of potash pegmatite veining and higher biotite content. On the east shore of Saglek Bight sheets of coarse-grained gneiss with well-preserved potash feldspar augen and copious biotite are seen to be intrusive into grey gneisses which already possessed a marked foliation and pegmatitic layering when the granitic sheets were emplaced. At the same locality, the grey gneisses are intruded by deformed sheets of hornblendite and by pods of diorite and quartz-diorite, all of which are themselves intruded by Saglek dykes. At many other localities the grey gneisses contain "inclusions" of hornblendite which pre-date the Saglek dykes. These

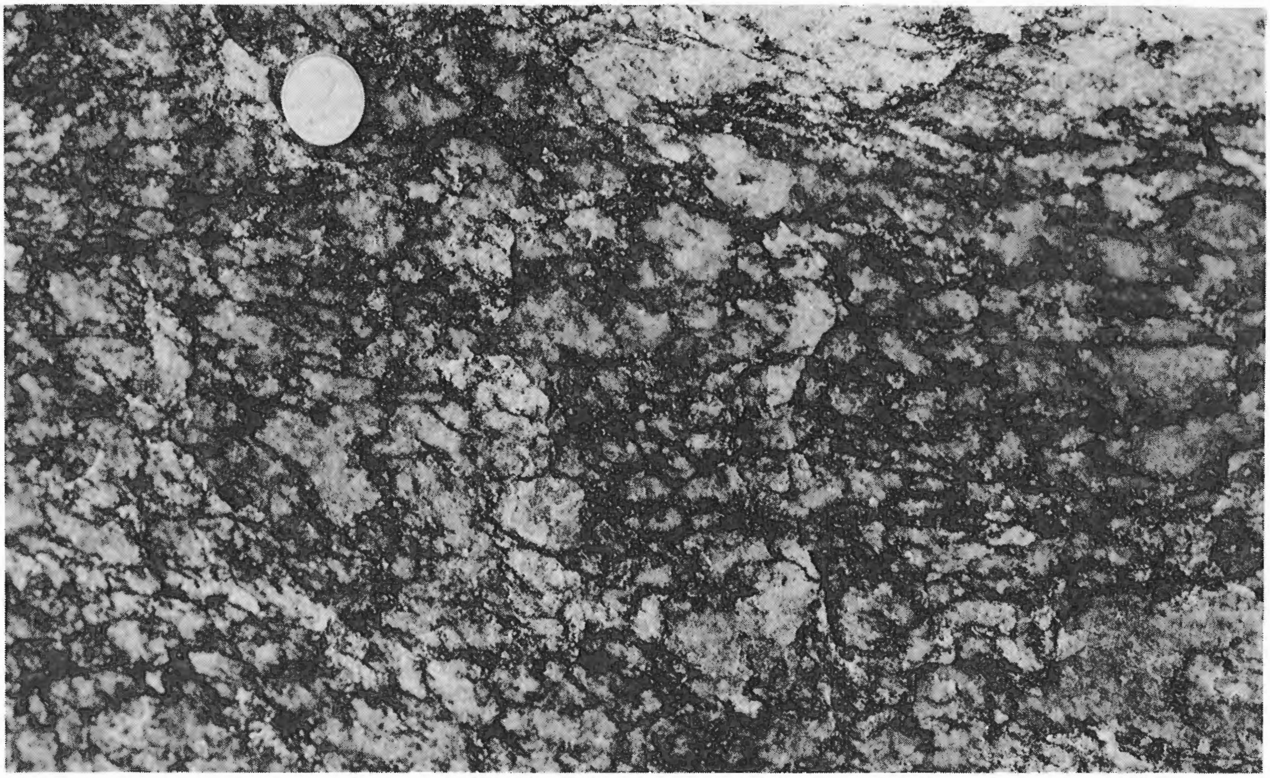


Figure 3. Porphyritic granitic gneiss viewed on the surface showing least strain. Note the relic feldspar megacrysts, Maidmont Island.

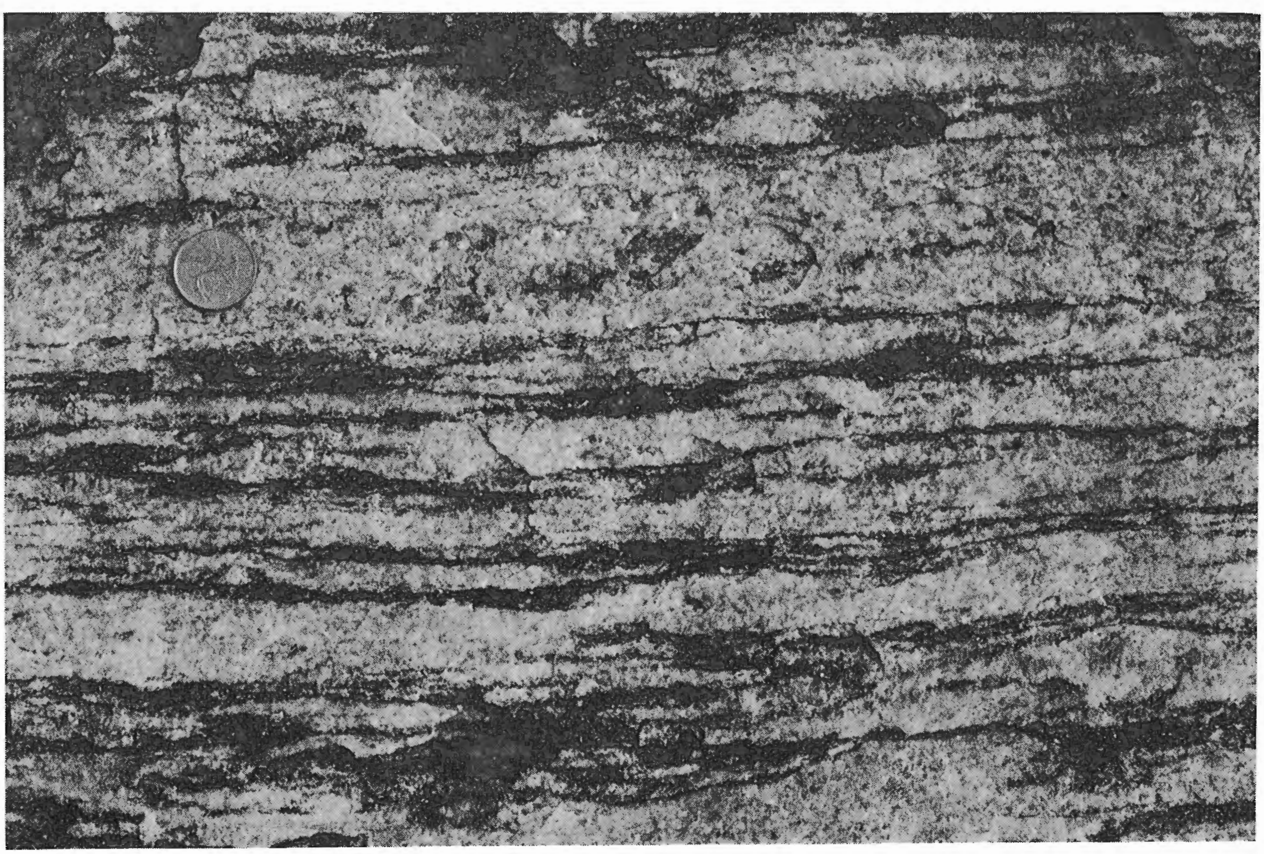


Figure 4. Same outcrop as Figure 3, seen on plane, showing maximum extension of the original texture. The light layers are in part derived from single feldspar megacrysts, and in part represent sheared pegmatites.

are interpreted by us as broken-up sheets of ultramafic rock which were emplaced into the grey gneisses, the intrusive relations of which have now been destroyed.

The Saglek dykes generally occur as concordant layers and disrupted pods within the Uivak gneisses (Fig. 5). Their original discordant nature is only locally preserved where they have partially escaped later deformation. Fortunately, the Saglek dykes show several distinctive petrological features in the field, which enables them to be distinguished from other amphibolitic remnants within the gneisses with a fair amount of confidence. Nearly all the dykes still showing original discordant contacts contain plagioclase megacrysts or aggregates of plagioclase replacing earlier megacrysts (Fig. 6). These survive as white lenses and rods even in the most heavily deformed dykes. Similar textures have not been seen in other amphibolitic rock units in the gneiss units (for example, amphibolitic rocks in the supracrustal sequences).

Where well-preserved, the Saglek dykes can be seen to have been slightly sinuous bodies which sent out numerous apophyses into the surrounding country rocks. Distribution of the plagioclase megacrysts was highly irregular, commonly occurring along one margin of the dykes or concentrated in pockets in which up to 60 per cent of the total rock is made up of megacryst. The groundmass of the dykes is generally an even, fine-grained, granoblastic amphibolite. In areas affected by granulite facies metamorphism, some orthopyroxene is found in the dykes and they are generally coarser-grained than those seen east of the Handy fault. Nearly all the dykes have been broken up and mechanically rotated parallel to the regional foliation. The original feldspar megacrysts are frequently elongated to at least 10-20 times their original length. There is little evidence that this intense deformation was accompanied by significant metasomatism and only the marginal 2-3 cm of amphibolite adjacent to pegmatite veins contains biotite suggesting introduction of potash.

The Upernavik supracrustals are dominated by metasedimentary schists and gneisses which form major units between Saglek Bight and Upernavik Island. Amphibolites of presumed metavolcanic origin, together with layered amphibolites with local feldspar rock units alternating with more mafic layers and ultrabasic lenses, are found within the metasedimentary successions and the suite is regarded as a mixed group of sediments and volcanic rocks intruded by basic and ultrabasic sills. The basic rocks form a higher proportion of the successions found to the east of Saglek Bight and on the outer coast farther to the south.

The main metasedimentary unit preserved is a biotite-garnet schist commonly with cordierite or altered cordierite and sillimanite. The composition varies considerably from biotite-rich units (sometimes with graphite) quartz and feldspar-rich units and impure psammites. Calc-silicate-rich layers (diopside-amphibole rocks) forsterite marbles, and occasionally carbonate-rich lenses are widespread within the successions although they only locally form coherent layers. The calc-silicate-rich units are commonly associated with distinctive garnet-quartzites.

The amount and character of migmatization varies from area to area and from one lithology to another. Most of the supracrustal gneisses in the amphibolite facies areas are schists with concordant or semiconcordant veins and stringers of quartz and feldspar, many of which have been deformed and broken up during deformation to form eyes and streaks surrounded by biotite, sillimanite and garnet-rich material. West of the Handy fault the textures in the migmatized supracrustal rocks are more irregular and the rocks should be more properly called gneisses.

No primary depositional features have been recorded from these rocks, apart from the rapid variation in lithology, which is probably the best evidence that these rocks represent an original sedimentary succession. Evidence on the primary sedimentary environment is restricted to the present chemical and mineralogical assemblages. The abundance of semipelitic gneisses and impure psammites in the successions suggest the presence of earlier sialic source rocks and deposition in fairly shallow water. Similar successions both in the Archean of Greenland and in high grade areas of the southern African Shield locally contain pyroclastic rocks and are interpreted as containing a large percentage of volcanogenic material.

The basic rocks within the supracrustal successions can be divided into two groups: amphibolitic units thought to represent part of the original sequence and layered rocks clearly derived from stratified basic igneous bodies. The first group are fine-grained, rather nondescript amphibolites. A number of field characters strongly suggest that they were formed in a sub-aqueous environment as part of a mixed sedimentary and volcanic supracrustal suite. Many of the amphibolites contain lenses or thin discontinuous layers of pale green calc-silicate rock, comparable to the diopside-epidote-scapolite-sphene-garnet layers in the Malene supracrustals of West Greenland (McGregor, 1973). These layers and lenses are interpreted as possibly formed by hydration of basaltic material accompanied by leaching of sodium in a submarine hydrothermal system. Other amphibolitic units show small-scale layering with alternating dark amphibole-rich units grading into more felsic andesitic or even locally dacitic rocks, and possibly represent graded volcanic ash units. Layered units of this type locally contain homogeneous basic amphibolitic layers possibly derived either from massive flows or sills intrusive into the sequence.

Layered igneous bodies are found at many localities within the supracrustal sequence, particularly west of the Handy fault. These locally cut across earlier layering in the metasediments, but are not otherwise separable from the supracrustal rocks in the sequence of events. The layered bodies vary from a few metres to 30-50 m in width, they show an overall variation in the relative amount of feldspar and mafic material from top to bottom and local rhythmic variations internally. Some contain distinctive units within the layered sequences; garnet-bearing leuco-norites occur near to the presumed upper contacts, while layers very rich in ilmenite occur locally lower in the sequence. The

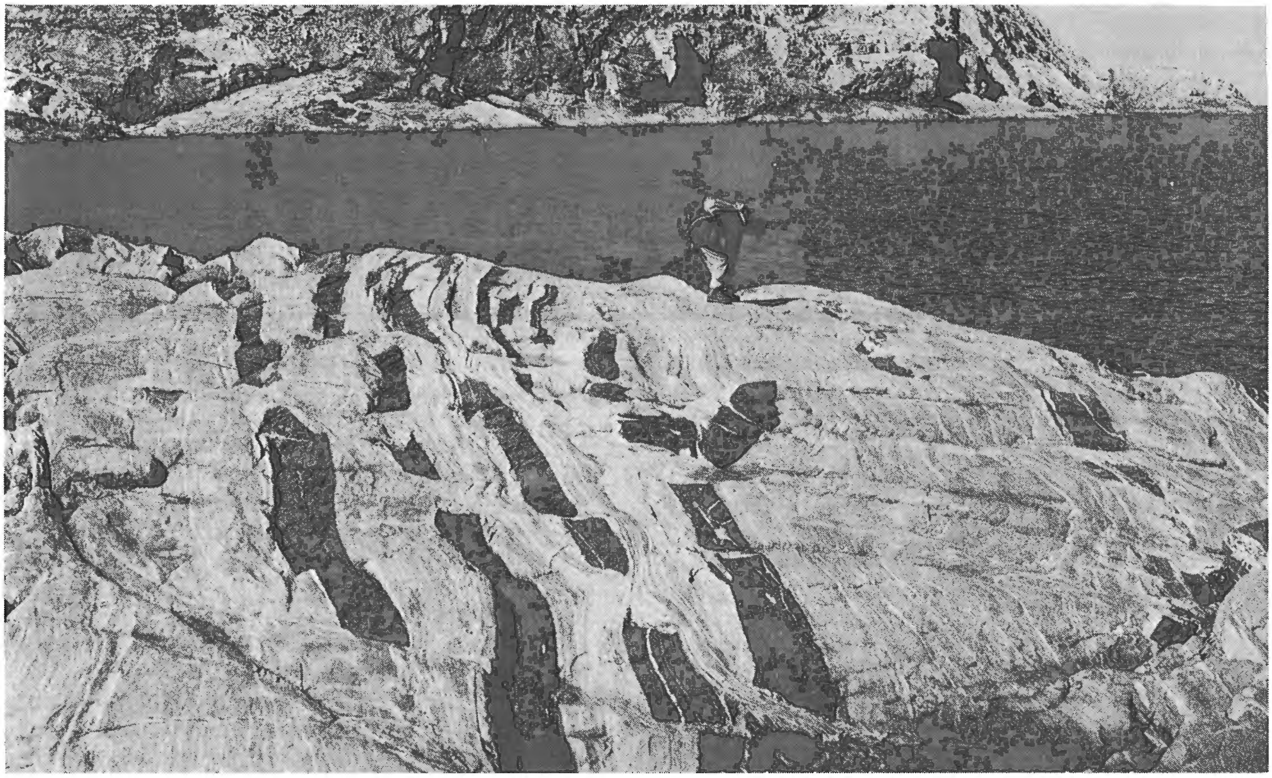


Figure 5. Outcrop of Uivak gneisses containing Saglek dykes which have been rotated parallel to the regional foliation, Saglek Bight.

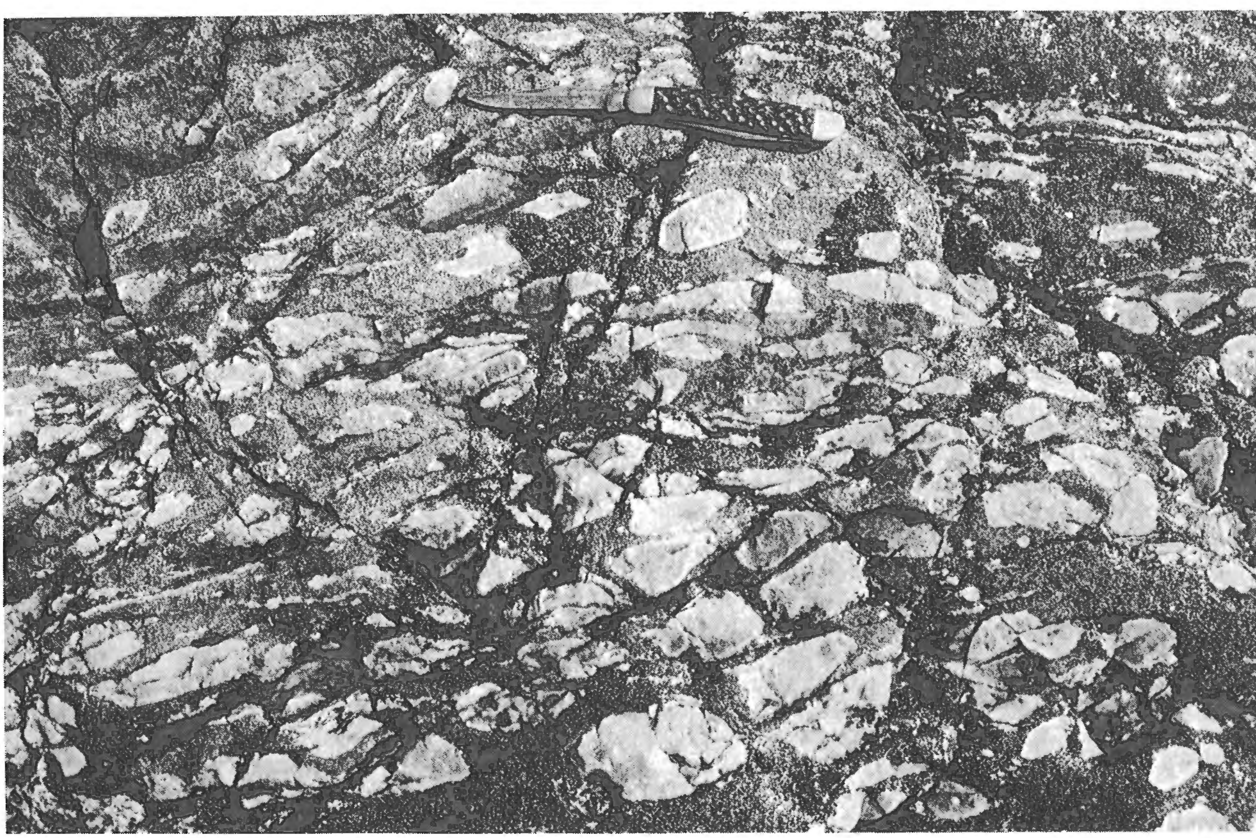


Figure 6. Local accumulation of plagioclase phenocrysts in a Saglek dyke, Saglek Bight.

bulk composition of the layered bodies in the Upernavik supracrustals is basaltic.

Ultramafic masses occur as pods and strings in the gneiss complex up to several hundred metres in width and a kilometre along strike. The main bodies are associated with amphibolites and metasediments and must be regarded as part of the supracrustal suite, although some may have moved tectonically since their original formation. The ultramafic rocks include olivine and enstatite-rich varieties and their metamorphic equivalents. Very few show any trace of original igneous textures or primary layering. On the west coast of Shuldham Island one body contains a spectacular network of olivine blades, individual crystals which locally measure over 50 cm in length. The texture resembles spinifex structures seen in quenched ultramafic lavas (Pyke *et al.*, 1973) although in these particular outcrops we interpret the olivines as metamorphic. Many bodies show a reaction with the adjacent quartzofeldspathic gneisses: they are zoned and frequently potash has been introduced into the outer parts of the bodies, resulting in the formation of biotite and phlogopite-bearing pegmatitic veins.

The younger quartzofeldspathic gneiss is a rather heterogeneous group of rocks which intrudes or migmatizes the supracrustal suites, but which was formed before the main granulite facies event in the west of the area and before the last major folding in the east. Athough they occupy a similar position in the sequence of events in the Saglek area, as the Nuk gneisses do in Godthaabsfiord, West Greenland (McGregor 1973), they do not form such a well-defined calc-alkaline suite. Locally the younger gneisses form discrete sheets which are concordant to the regional structures, but which locally transgress earlier fabrics in the supracrustals and the Uivak gneisses, and raft off fragments of the earlier rocks. Generally, however, the younger quartzofeldspath gneisses occur as migmatitic veins and stringers breaking up the earlier gneisses and supracrustals. Many are apparently formed by local remobilization of the earlier rocks and there is a gradation between older gneisses with well-preserved structures cut by Saglek dykes and areas of migmatites in which the neosome becomes dominant leaving scattered remnants of older gneiss and Saglek dyke. The major unit of gneisses without dykes shown in Figure 2 from Handy Island to east of St. John's Harbour is regarded as mainly remobilized older material.

The late syntectonic granites differ from all earlier granitic gneisses in the area in that they possess a relatively simple fabric which shows evidence of only one main phase of deformation. Most outcrops of the late syntectonic granites have a sugary, commonly slightly pink appearance in the field. Mafic minerals occur as anastomosing networks within the rock (rather than as the distinct layers found in the earlier gneisses). Larger bodies (such as those exposed on the outer coast of Big Island) show a slightly pegmatitic border zone with many inclusions of country rocks aligned parallel to the contact passing inwards to a more homogeneous rock away from the contact.

Structural Development

The structural development of the area is complex and only two of the major phases of deformation can be treated here.

The earliest major regional structures preserved are those which resulted in the interleaving of the Uivak gneisses and the Upernavik supracrustal suite. The actual mechanism by which this occurred is unknown, but thrusting accompanied or followed by the formation of major isoclinal folds both appear to have played major roles in the formation of the regional layering in the gneiss complex. The interleaving of the Uivak gneisses and the supracrustal rocks was accompanied by intense strain, rotating the Saglek dykes parallel to the regional structures and destroying sedimentary features in the supracrustal rocks. Wherever estimates of the amount and type of strain can be made, the rocks generally show evidence of both flattening and intense rotational shear. Intrafolial folds are common in all gneiss units older than the late syntectonic granites.

The layered gneisses were affected by several phases of later deformation, the last major one of which produced the north-trending structural grain in the area shown in Figure 2. The folds formed during this phase are generally asymmetrical with axial planes dipping to the west and either vertical or overturned eastern limbs. In the easternmost parts of the area the axial planes are flat-lying and the folds become eastward-facing nappes. The form of individual folds varies markedly in a vertical section. Synforms exposed at 1000 m as gentle shallow structures become attenuated downwards so that at sea level they are commonly sheared out in belts of extreme deformation.

Conclusions

The Archean gneiss complex of the Saglek area is composed of at least four major gneiss groups, each of which represents a distinct period of plutonic activity separable by periods of relative quiescence or by marked changes in regional metamorphic conditions. By analogy with other well-preserved parts of the North Atlantic Craton, we suggest that this implies a long history of development and that the earliest rocks in the Saglek area (the Uivak gneisses) are at least as old as any rocks so far discovered in the Canadian Shield.

Acknowledgments

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REPORT ON THE GEOLOGY OF THE KILOHIGOK BASIN, GOULBURN GROUP, BATHURST INLET, N.W.T.

Project 740092

F.H.A. Campbell and M.P. Cecile[1]
Regional and Economic Geology Division

Introduction

Approximately one-half of map-areas NTS 76J (W) and 76K (E) were mapped at a scale of 1: 250,000, as part of the study of the Bathurst Inlet area. Detailed stratigraphic and sedimentological data were collected from the west in the vicinity of Contwoyto Lake, and from outliers east of Bathurst Inlet. On the basis of these data, additions to the stratigraphic terminology have been made and an intracratonic basin, the Kilohigok[2] Basin, is defined here.

The Western River, Burnside River, Peacock Hills, and Kuuvik formations were defined by Tremblay (1967). The Brown Sound Formation was defined by Tremblay (1968) and the Tinney Cove and Ellice formations by Tremblay (1971). The mapping of these units in the area was done principally by Fraser (1964) and Tremblay (1967, 1968, 1971).

These formations are retained here, and two new formations are introduced, a number of subdivisions of most of the formations are made, and the Tinney Cove and Ellice formations are redefined.

F.H.A. Campbell and M.P. Cecile are jointly responsible for the mapping and general definition of the Kilohigok Basin (*see* Fig. 2). F.H.A. Campbell is principally responsible for the detailed description and definitions of the Western River to Quadyuk formations. M.P. Cecile is principally responsible for detailed descriptions and definitions of the units above the Quadyuk Formation up to and including the Ellice Formation, which are the subject of his Ph.D. dissertation.

The Kilohigok Basin

Based on stratigraphic detail and sedimentological factors, the Goulburn Group sediments formed part of a large extensive intracratonic basin encompassing an area in excess of the outcrop area of the Goulburn sediments (i.e. 7,000 sq. m). Figure 3 give the approximate general limits and shape of the basin based on generalized paleocurrent trends.

The major evidence indicating that the Kilohigok Basin is intracratonic is as follows:

1. Geographic position of the basin with respect to correlative units of the Coronation Geosyncline;

2. The small number of sediment cycles in Goulburn units in comparison to those of the correlative miogeosynclinal sediments of the Epworth Group;

3. Absence of overstepping at the basin margins, and thinning of all units westward towards the Epworth Group;

4. Lateral continuity of very thin units and a lack of abrupt facies change;

5. Nature of the sediments (sediments of the Kilohigok Basin are predominantly shallow water or fluviatile with significant input of continental clastic material);

6. Regional paleocurrent trends are variable with a westerly sense of sediment transport (in detail each stratigraphic unit differs considerably in its paleocurrent vectors, indicating local changes in basin configuration with various emergences and submergences of the basin).

Western River Formation

The Western River Formation has been subdivided into eight members east of Bathurst Inlet and four west of the inlet (*see* Fig. 1). The W_1 member everywhere consists of basal transgressive quartzite and quartz-pebble conglomerate.

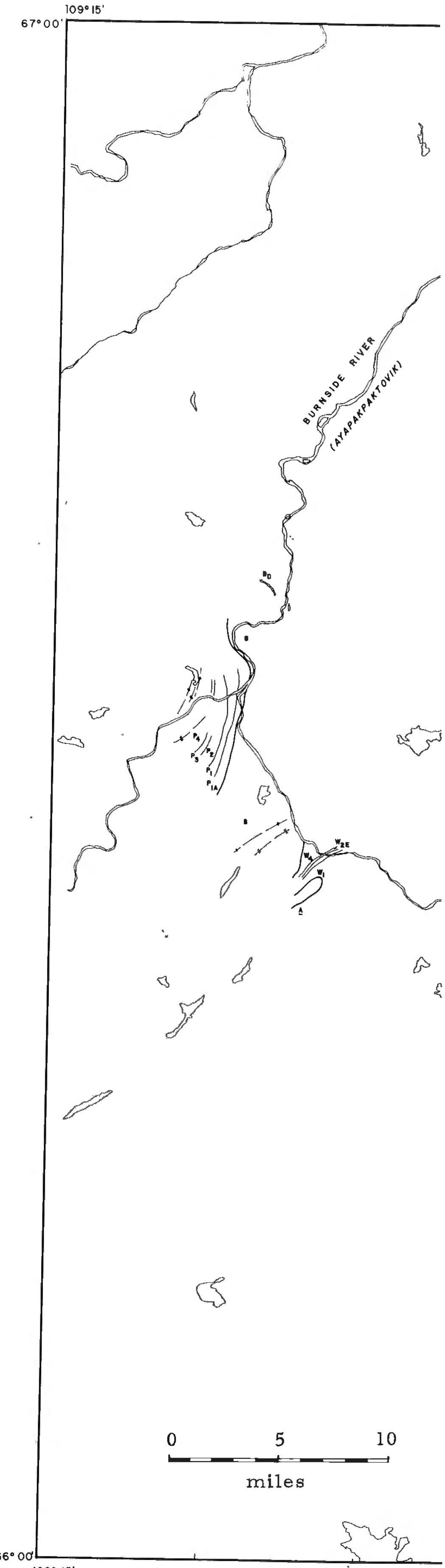
East of Bathurst Inlet the W_1 member is overlain by and in part laterally equivalent to, the W_{1A} member, which is dominated by quartzite and siltstone in the north, and quartzose turbidites in the south. The W_{1A} member contains W_{2A}, a sequence of thin-bedded limestone, dolomite and shale, interpreted as the deep-water lateral equivalent of the stromatolitic dolomite of W_{2B}. The lateral facies relations between the various members of this part of the Western River are shown in Figure 4. Northeast of the inlet, these lower members are overlain by alternating red mudstone, argillite, quartzite and dolomitic quartzite, with local biohermal stromatolites (units W_{2C}, $_{2D}$, $_{3B}$, $_{3C}$, $_{3D}$), interpreted as a repetition of shelf-mud flat conditions locally developing paltformal carbonates. The main stromatolitic unit (W_{2B}) thins and pinches out to the north, as does the entire Western River Formation. The Archean basement is overlain by a thick stable shelf quartzite with minor stromatolites (W_{2D}), interpreted as a back-platform facies equivalent to the platform-edge carbonates of W_{2B}. The W_{2B} member of the Western River is dominated by branching, columnar stromatolites which form elongate ellipsoidal mounds up to 100 feet long and 70 feet thick (*see* Fig. 5). The upper surface of these mounds is undulating, with relief up to 5 feet between the mounds. They are elongate in a northward direction, as are the individual stromatolites. The lower one-third of the W_{2B} member is dominated by dolo-arenite, quartzite, and dolomitic

[1] Carleton University.

[2] Inuit name for Bathurst Inlet.

		DIABASE DYKES
INTRUSIVE CONTACT		
		GRANITE, GRANODIORITE (INTRUDES W_1 ONLY, MAY PREDATE T_1)
GOULBURN GROUP — ELLICE FM.	E_2	KAOLINITIC QUARTZITE
	E_1	QUARTZ PEBBLE CONGLOMERATE; KAOLINITIC QUARTZITE
MINOR UNCONFORMITY		
TINNEY COVE FM.	T_2	ARKOSE, PEBBLY ARKOSE
	T_1	POLYMICTIC CONGLOMERATE; COARSE ARKOSE
ANGULAR UNCONFORMITY		
AMAGOK FM.	A	MODERATELY INDURATED ARKOSE
BROWN SOUND FM.	B_3	FERRUGINOUS MED.-FINE GRAINED ARKOSE
	B_2	FERRUGINOUS-SILTY-CALCAREOUS MUDSTONE
OMINGMAKTOOK	(breccia symbol)	CHAOTIC INTRAFORMATIONAL SLUMP BRECCIA AS THIN UNIT IN MID.-B_1, AND AS CHANNELS THROUGH D, B_1, K, P_4
LOCAL REGOLITH		
	D	DIABASE SILL IN LOWER-MIDDLE B_1
INTRUSIVE CONTACT		
MEMBER	B_0	FERRUGINOUS-CALCEROUS MUDSTONE
KUUVIK FM.	K_3	STROMATOLITIC DOLOMITE; DOLO-ARENITE, SILTITE, LUTITE; INTRAFORMATIONAL BRECCIA; MINOR MUDSTONE
	K_2	DOLOMITIC MUDSTONE (RED); MINOR STROMATOLITES
	K_1	DOLOMITIC MUDSTONE; MINOR STROMATOLITES AND THIN-BEDDED TURBIDITES (DOM. C-E BEDS)
PEACOCK HILLS FM.	P_5	LAMINATED RED CONCRETIONARY MUDSTONE-DOLOMITE (EQUIVALENT TO P_1-P_4 WEST OF INLET)
	P_4	MUDSTONE-DOLOMITE - VERY THIN-BEDDED TURBIDITES
	$P_{2,3}$	RED AND GREY MUDSTONE
	P_3	GREY MUDSTONE - VERY THIN-BEDDED TURBIDITES (A-E BEDS)
	P_2	RED CONCRETIONARY MUDSTONE
	P_1	MUDSTONE-DOLOMITE TURBIDITES; P_{1A}-MUDSTONE TURBIDITES IN P_1
QUADYUK FM.	Q	STROMATOLITIC DOLOMITE AND LIMESTONE; DOLO-ARENITE, SILTITE, LUTITE; INTRAFORMATIONAL BRECCIA; MINOR MUDSTONE
BURNSIDE RIVER FM.	B_1	RED SILTSTONE; FINE GRAINED SUBARKOSE
	B_P	PEBBLY AND BOULDERY PROTOQUARTZITE; QUARTZ PEBBLE CONGLOMERATE (EQUIVALENT TO B WEST OF INLET)
	B	PINK, WHITE, RED SUBARKOSE; MINOR QUARTZITE; FEW SHALY PARTINGS; QUARTZ PEBBLE CONGLOMERATE
	B_M	RED MUDSTONE; MINOR DOLOMITE
	B_D	ARNACEOUS DOLOMITE; DOLO-ARENITE; MINOR STROMATOLITIC DOLO-ARENITE; DOLOMITIC QUARTZ-PEBBLE CONGLOMERATE
WESTERN RIVER FM.	W_4	GREY, BUFF, RED SILTSTONE AND MUDSTONE; MINOR QUARTZITE
	W_{3D}	RED MUDSTONE AND ARGILLITE
	W_{3C}	FINE-GRAINED RED AND PINK QUARTZITE AND ARKOSE
	W_{3B}	RED MUDSTONE AND ARGILLITE; MINOR TURBIDITES (A-E BEDS)
	W_{3A}	GREY-GREEN COARSE-GRAINED TURBIDITES (A-E BEDS)
	W_3	WHITE, PINK PROTOQUARTZITE; MINOR ARENACEOUS DOLOMITE
	W_{2E}	GREY CONCRETIONARY MUDSTONE; MINOR DOLOMITE
	W_{2D}	QUARTZITE; MINOR DOLOMITE AND MUDSTONE
	W_{2C}	RED SILTSTONE; MINOR QUARTZITE
	W_{2B}	STROMATOLITIC DOLOMITE; DOLO-ARENITE, SILTITE, LUTITE; MINOR QUARTZITE AND DOLOMITIC QUARTZITE
	W_{2A}	THIN-BEDDED LIMESTONE, DOLOMITE AND SILTSTONE
	W_{1A}	INTERBEDDED SILTSTONE, QUARTZITE; THICK-BEDDED QUARTZOSE TURBIDITES (A-E BEDS)
	W_1	QUARTZITE, ARGILLITE, QUARTZ-PEBBLE CONGLOMERATE; MINOR DOLOMITE; REGOLITH
ANGULAR UNCONFORMITY		
	A	GNEISS, SCHIST, METASEDIMENTS, GRANODIORITE

Figure 1. Stratigraphy of the Kilohigok Basin.



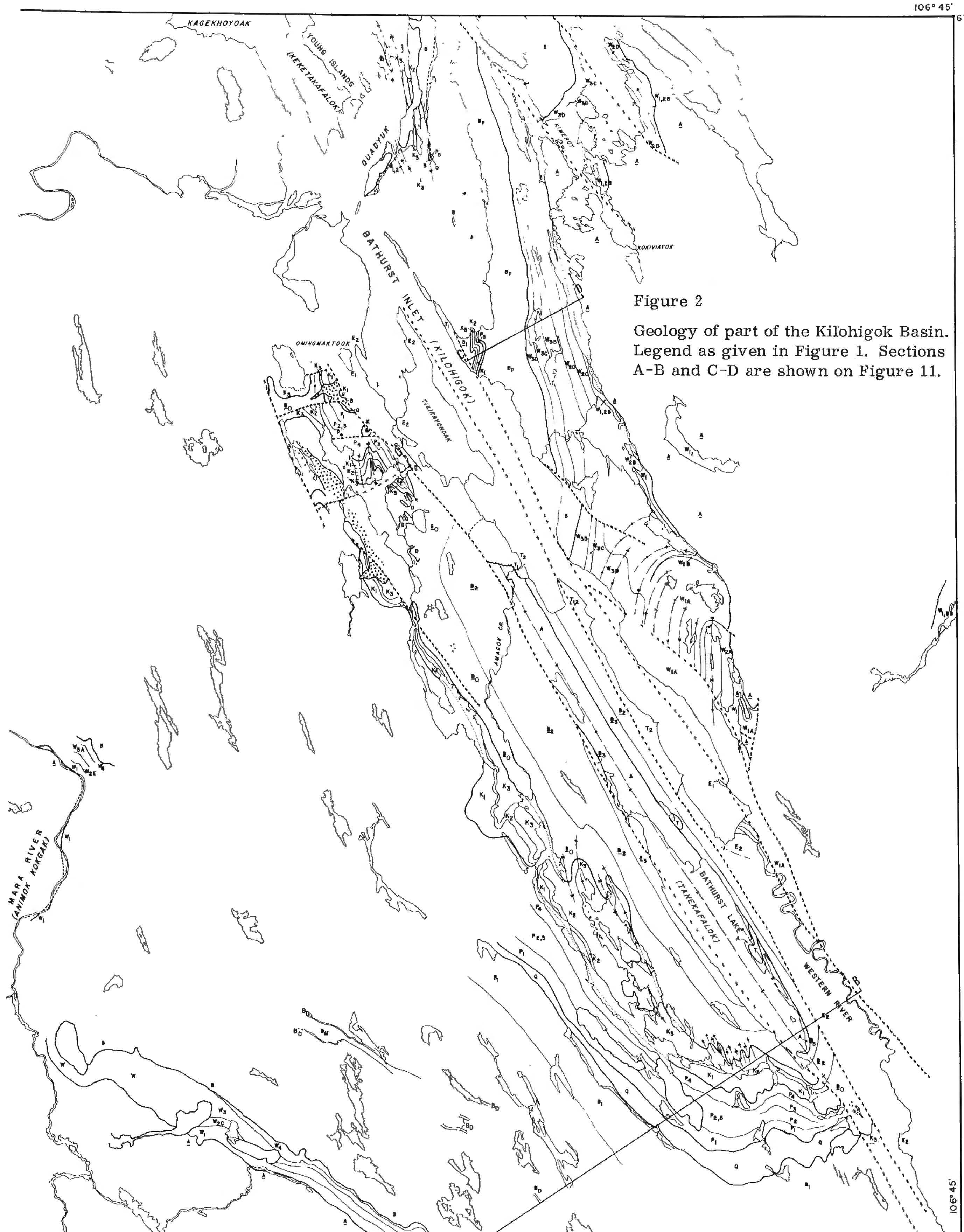


Figure 2

Geology of part of the Kilohigok Basin. Legend as given in Figure 1. Sections A-B and C-D are shown on Figure 11.

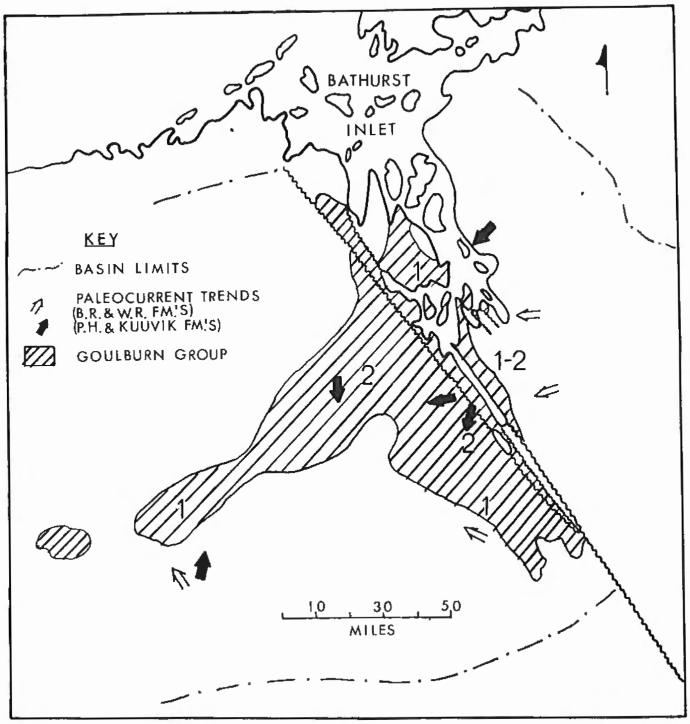


Figure 3. Distribution of known Goulburn Group rocks of the Kilohigok Basin and approximate basin boundaries.

quartz-pebble conglomerate, with small isolated biscuit stromatolites with no internal structure. Locally, near the top of this member, the mounds are separated by crossbedded quartzite and quartz-pebble conglomerate, while dolo-arenite and mud-chip or -flake intraformational conglomerate is the dominant inter-stromatolite sediment in the remainder of the member. Possible pseudomorphs of gypsum were noted at two locations near the top of this member in the southern part of the area, east of Bathurst Inlet.

Southwest of the inlet the Western River Formation, though thinner, contains a succession identical to that reported by Tremblay (1971) for the Beechey Lake area. The entire formation in this area is less than 1,000 feet thick, but the depositional sequence of events recorded is the same as that east of the inlet. The lowermost member in this area, W_1, contains very little quartz-pebble conglomerate and is dominated by argillite and siltstone, with minor quartzite. This member locally contains a dolo-siltite up to 12 feet thick near the top, with isolated biscuit stromatolites; this is interpreted as equivalent to the W_{2B} member east of the inlet. It is overlain by the red siltstone with minor quartzite of W_{2C}. The W_3 member overlies the W_{2C} member in this area, and consists of quartzite with minor thin dolomitic quartzite and dolo-siltite near the top.

Along the Mara River, the formation becomes thinner still, and the members present in the south are replaced by a sequence beginning with quartz-pebble conglomerate and quartzite (W_1), overlain by concretionary mudstone with thin dolo-siltite beds at the top (W_{2E}). These in turn are overlain by thin-bedded turbidites (W_{3A}).

The uppermost member in both of these areas is a sequence of varicoloured siltstones and mudstones and minor quartzite, characterized by the presence of mudcracks and mud-chip conglomerate (W_4).

Paleocurrent data indicate that the dominant transport directions in the Western River were southwesterly and westerly (*see* Fig. 6).

Burnside River Formation

The Burnside River Formation (Tremblay, 1969) has been subdivided into two major members with three minor members (*see* Figs. 1 and 7). The formation is dominantly composed of subarkose and quartzite in the western part of the area, and by pebbly and boulderly subarkose and quartzite in the east (Bp). Red siltstone and fine-grained arkose are developed both east and west of the inlet (B_1). Figure 7 shows a typical section of the Burnside River west of the inlet.

The Bp member east of the inlet locally contains quartzite clasts with diameters up to 3 feet in large channels cut into the more common pebbly and bouldery subarkose.

The mudstone and sandy dolomite units (B_M, B_D) occur only in the southern part of the area, west of the inlet. The mudstone unit records a coarsening-upward cycle, and the uppermost part of the member is a dolomitic quartz-pebble conglomerate with abundant planar crossbedding. The thin dolomitic units are locally stromatolitic, but also contain abundant small quartz pebbles, and some rare jasper clasts, presumably derived from the exhumed regolith beneath the Western River Formation.

The uppermost member of the Burnside River is the B_1 member, which consists of red siltstone and fine-grained arkose west of the inlet, and is the equivalent of a fine-grained red quartzite in the inlet itself and on the islands.

Paleocurrent data from trough-crossbedding (*see* Fig. 6) show that the dominant transport direction was northwest in the eastern part of the area, and southwest in the south and central part of the area. The formation attains a maximum thickness of about 14,000 feet in the eastern part of the area, east of the inlet. It thins markedly to the west, and is approximately 600 feet thick in the Contwoyto Lake area.

The abundant trough-crossbedding, uniform grain size and bed thickness, together with the isolated quartz-pebble conglomerate beds and the east to west thinning, suggests a shallow fluvio-deltaic sequence deposited on a broad stable shelf.

Quadyuk Formation

The Burnside River is conformably overlain by a sequence of dolo-siltites and dolo-arenite with minor mudstone which grades upward into a sequence of large, elongate stromatolite mounds. The unit is conformably overlain by the Peacock Hills Formation (*see* Fig. 3). These rocks are here named the Quadyuk Formation for the large island in Bathurst Inlet.

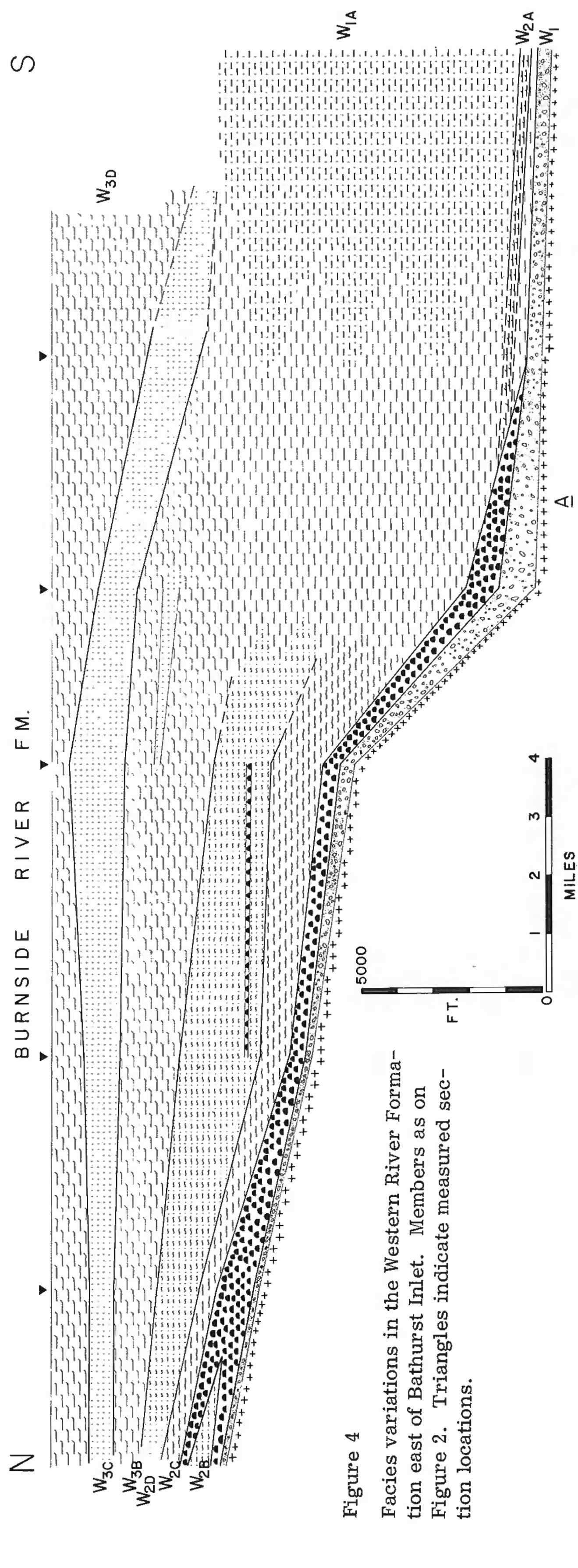


Figure 4

Facies variations in the Western River Formation east of Bathurst Inlet. Members as on Figure 2. Triangles indicate measured section locations.

The Quadyuk is approximately 600 feet thick at its maximum in the type area, west of Bathurst Lake, at 66°05'N, 107°20'W. It thins gradually to the north where it is non-stromatolitic and less than 10 feet thick at Quadyuk Island, and absent in the Mara-Burnside rivers area, where a pisolitic dolomite near the top of the Burnside River Formation may be its lateral equivalent. In the type area, the formation can be subdivided into two parts. The lower one-third consists of alternating dolo-siltite, dolo-arenite and calcareous mudstone, with isolated small biscuit stromatolites. The lower part grades upward into large, elongate stromatolite mounds with reddish or cream-coloured dolo-siltite and mud-chip conglomerate between the mounds. The uppermost portion is characteristically reddish or pink, with minor thin, red, shaly partings within the mounds. The mounds are up to 120 feet long, 30 feet wide, and 10 to 15 feet high. They are elongate in an easterly direction but the individuals are commonly oriented north-south, perpendicular to the large, possibly tidal, channels which locally separate groups of mounds. Individual small columnar stromatolites locally grow into these channels, directly underlying the P_1 member of the Peacock Hills Formation.

The Quadyik Formation caps the red siltstone sequence in the Burnside River and represents the first shallow water platformal carbonate sequence above that in the Western River east of the inlet. The Quadyuk is the first formation which thins to the north, and thus records a major change in the depositional history of the basin, which is reflected in each of the overlying formations.

Peacock Hills Formation

The Peacock Hills Formation is here subdivided into four members west of the Bathurst Inlet area which are correlative with a single basin-edge member east of the inlet and in the Contwoyto Lake area (*see* Fig. 8). The members P_1, P_2 and P_4 are sequences of very thin beds comprised of tan dolo-siltites grading into grey, green and red mudstones (the mudstones comprise more than 50 per cent, by volume, of the sequence). These three members are interpreted as basinal equivalents of the Kuuvik Formation. The member P_{1A} and P_3 are sequences of very thin A-E turbidite beds composed mainly of mudstones and representing major influxes of terrigenous material into the basin. P_5, the basin-edge equivalent of the first four members, is a ferruginous sequence of very thin beds composed of dolo-siltites grading to mudstones and units of very thin beds of ferruginous mudstone. In the Contwoyto Lake area the dolo-siltites are replaced by calcareous siltstones.

The Peacock Hills Formation thickens basinwards from a few hundred feet to approximately 1,500 feet. Paleocurrents, deduced from climbing ripples (*see* Fig. 6), are southwesterly in the Bathurst Inlet area and southward-directed in the area near the junction of the Burnside and Mara rivers.

Kuuvik Formation

The Kuuvik Formation is here subdivided into four members. The members K_1, K_2 and K_3 are a continuous shoaling-upwards sequence of terrigenous clastic dolomites and stromatolitic dolomites which, together, are equivalent to K_4, a basin-edge equivalent found in the Contwoyto Lake area (*see* Fig. 9).

K_1 is a sequence of very thin beds comprised of dolo-siltites, grading to mudstones with greater than 50 per cent, by volume, of dolomite. K_1 is a proximal basin equivalent of the upper members of the Kuuvik Formation. K_2 is a sequence of thick units of alternating red to grey dolomitic mudstone or mudstone and clastic dolomite (including intradolo-arenite) ribbed with very thin beds of mudstone. K_3 is a sequence of, first, clastic dolomite (with intradolo-arenite) overlain by a continuous succession of elongate and nested stromatolite domes, which is succeeded by units of laterally-linked elongate stromatolite biscuits, clastic dolomite and minor mudstone. K_4, a basin-edge facies laterally equivalent to $K_{1, 2, 3}$ is a sequence of thick clastic dolomites (including intradolo-arenite and edgewise conglomerate) red, grey and green mudstones, siltstones and units of laterally-linked elongate stromatolite biscuits, isolated stromatolite biscuits and oncoliths.

Stromatolite elongations are generally parallel to current flow, and perpendicular to strand lines, due to wave refraction (Hoffman, 1969). The thickest laminations and "leaning" direction are toward the basin in the Bathurst area (*see* Fig. 10). Kuuvik stromatolite elongations (*see* Fig. 10) vary from west to southwesterly, with thickening of laminations and "leaning" direction

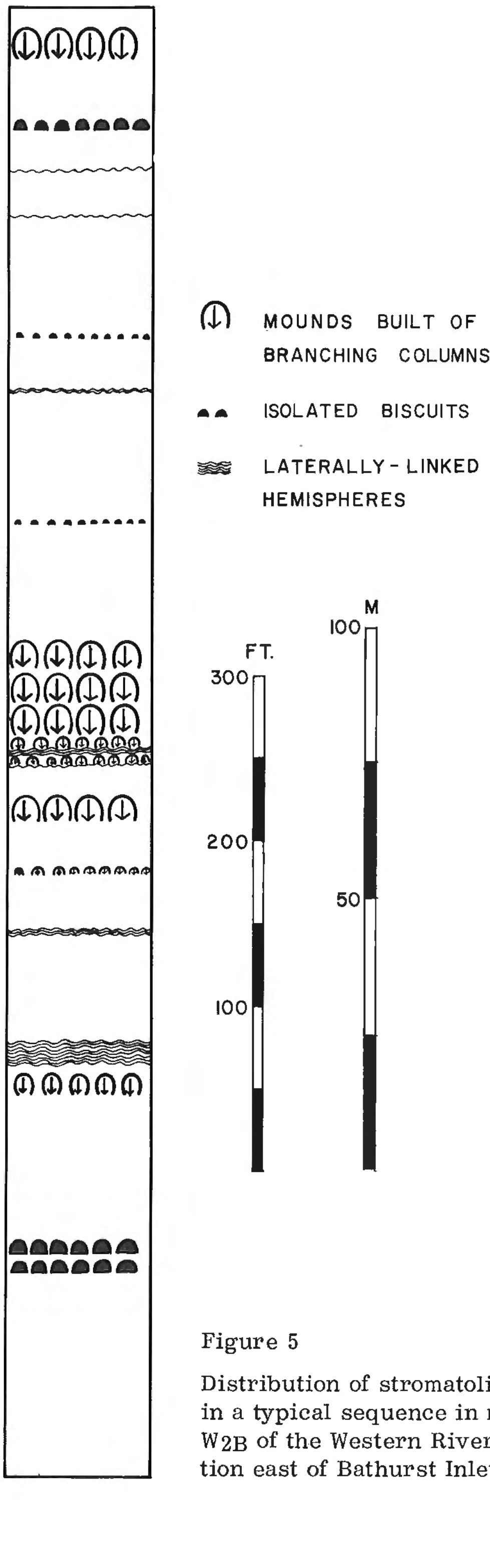


Figure 5

Distribution of stromatolite types in a typical sequence in member W_{2B} of the Western River Formation east of Bathurst Inlet.

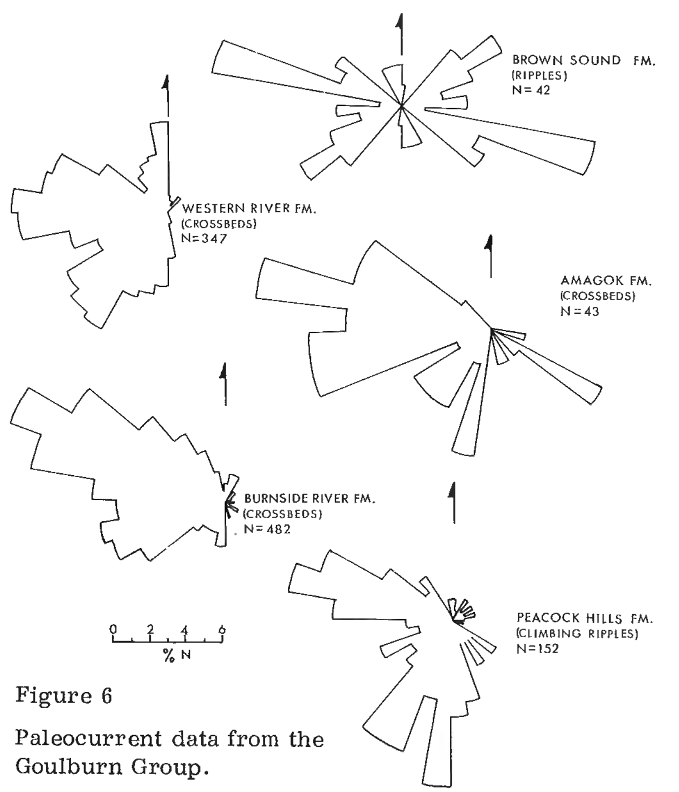


Figure 6

Paleocurrent data from the Goulburn Group.

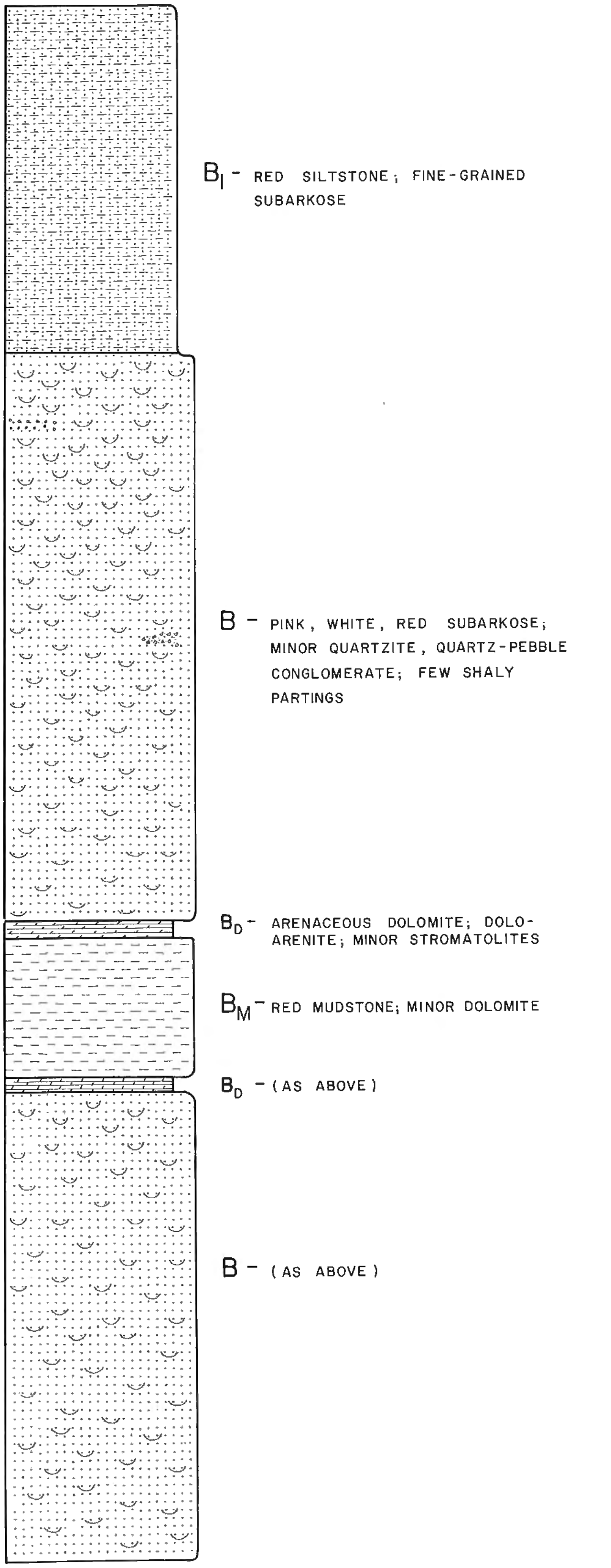


Figure 7. Diagrammatic section of the Burnside River Formation, west of Bathurst Inlet. Members as shown on Figure 1.

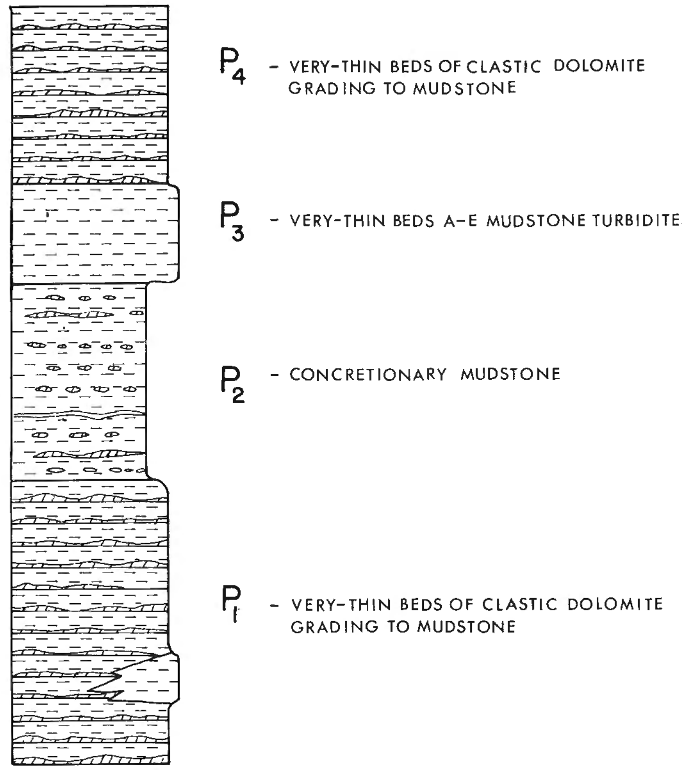


Figure 8. Diagrammatic section of the Peacock Hills Formation, west of Bathurst Inlet. Members as shown on Figure 1.

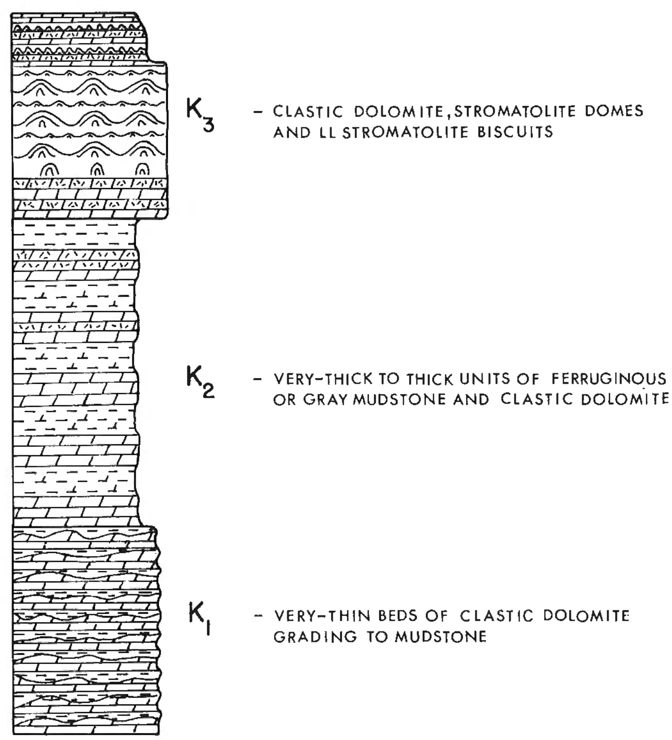


Figure 9. Diagrammatic section of the Kuuvik Formation, west of Bathurst Inlet. Members as shown on Figure 1.

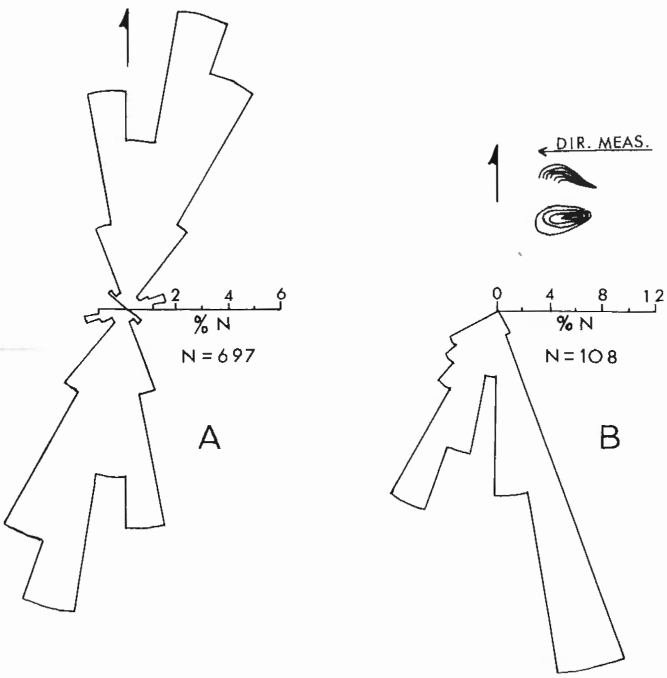


Figure 10. Stromatolite elongation directions and asymmetric stromatolite orientations in the Kuuvik Formation.

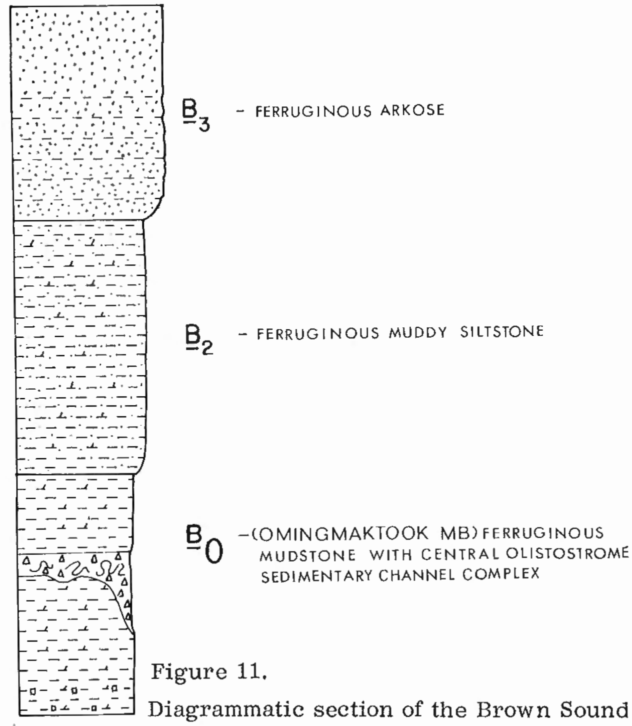


Figure 11.
Diagrammatic section of the Brown Sound Formation, west of Bathurst Inlet. Members as shown on Figure 1.

to the southwest in the eastern Bathurst Inlet area; south to southwesterly with thickest laminations on the south and southwest sides in the western Bathurst Inlet area; and southwesterly, with thickest laminations on the northeast side in the Contwoyto Lake area. The Kuuvik Formation varies in thickness from 700-1,000 feet over the entire inlet area, but only 260 feet of the Kuuvik Formation remains in the Contwoyto Lake area after erosion.

Brown Sound Formation

The Brown Sound Formation is here subdivided into three members: a lower ferruginous mudstone with an associated olistostrome (Omingmaktook member), a middle ferruginous muddy-siltstone, and an upper ferruginous arkose (*see* Figs. 1 and 11). The Omingmaktook member contains salt casts, ripples, mud-chips etc., and can be subdivided into lower and upper mudstone units, underlying and overlying respectively, an olistostrome with an erosional base. The olistostrome is a complex of intraformational breccia with some channels cutting as far down as the upper Peacock Hills Formation and containing large exotic olistoliths up to several hundred feet long. The olistoliths are a clastic carbonate and laminated mudstone. Development of the olistostrome is accompanied by local minor syndepositional east-trending normal faults.

The B_2 member is a homogeneous, ferruginous, muddy siltstone with ripples and mud-chip conglomerates. The upper member, B_3, is a fine- to medium-grained arkose, consisting of well-indurated sandstones, frequently interbedded with very thin mudstone beds.

The lower part of the Brown Sound Formation has been intruded by a thin diabase sill (D) apparently contemporaneous with the development of the olistostrome. The sill outcrops sporadically throughout the lower member west of the inlet. It intrudes the red siltstones and mudstones of the Brown Sound, and locally has a regolith developed on its upper surface which consists of blocks and subrounded fragments of diabase in a ferruginous mudstone matrix. At several localities, the olistostrome is closely associated with the diabase, but nowhere does the olistostrome appear to cut completely through the sill.

Paleocurrents (*see* Fig. 6) from ripple-marks, give northwest-southeast to east-west directed wave surge and/or current flow. A small number of asymmetric ripples give westerly transport vectors. The approximate thickness of the Brown Sound Formation is 5,000 feet.

Amagok Formation

The Amagok Formation is here proposed for a sequence of coarse-grained medium- to poorly-indurated cream-coloured to deep red, often mottled arkoses, consisting of alternations of large trough-crossbed sets, planar-bedded sandstones, and muddy, ferruginous planar-bedded sandstones. The Amagok Formation is in conformable and gradational contact with the Brown Sound Formation and is overlain with angular unconformity by the Tinney Cove Formation. The type section of this formation is located along Amagok Creek where it flows into Bathurst Inlet. At the type locality about 1,700 feet of its total known thickness of 3,000 feet

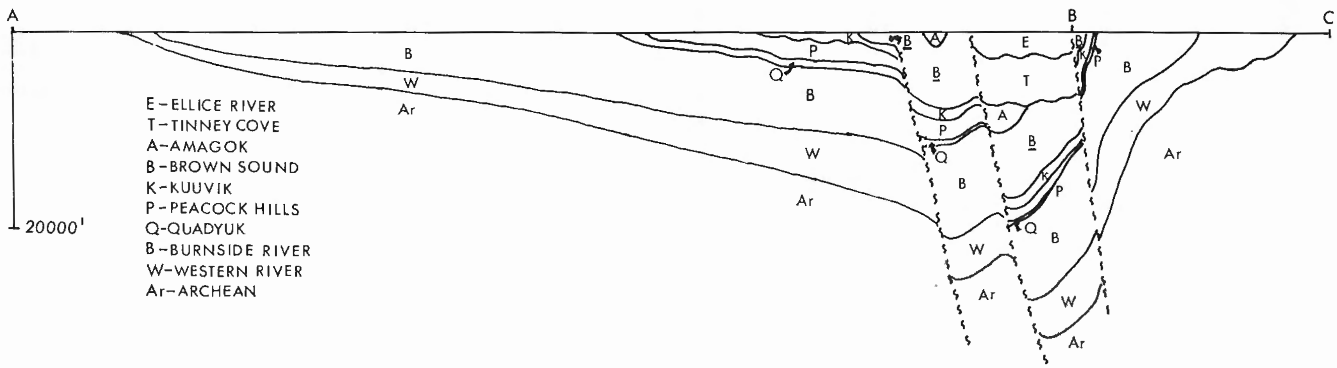


Figure 12. Diagrammatic cross-section through the Kilohigok Basin. Location of section shown on Figure 2.

is exposed. Complete but discontinuous sections outcrop in the core of the syncline between Bathurst Lake and Amagok Creek.

The Amagok Formation is equivalent to map-unit 15 of Fraser (1964) which Tremblay (1968) included with the Brown Sound Formation.

Paleocurrents from this unit are southwesterly (*see* Fig. 6).

Tinney Cove - Ellice Formations

It is proposed here that the Tinney Cove Formation, first defined by Tremblay (1971), be redefined as the arkoses and polymictic conglomerates in the Bathurst Inlet area which unconformably overlie the Goulburn Group. Bathurst Inlet will be the type area of the Tinney Cove Formation, due to the absence of any thick continuously exposed sections elsewhere.

The Tinney Cove Formation includes two units of very different compositions in the Bathurst Inlet area. Both are relatively flat-lying and are characterized by prominent trough-crossbeds, moderate induration, slabby to flaggy partings, and cream to red colours. The lower unit is a sequence of cream to red, medium- to poorly-indurated, trough-crossbedded and planar-bedded arkose with polymictic orthoconglomerates. The upper unit is a sequence of kaolinitic orthoquartzites and quartz-pebble conglomerates, with trough-crossbeds and sequences of more massive, parallel-bedded, cream to red sandstones.

Tremblay (1971) defined the Ellice Formation as a sequence of kaolinitic orthoquartzites stratigraphically above a polymictic conglomerate, which overlies a sequence of sandstones, mudstones and dolomites, with unknown affinities to the sediments in the rest of the basin. The orthoquartzites above the Tinney Cove in the Bathurst Inlet area are mapped as equivalent to the Ellice Formation.

Paleocurrents from both the Ellice and Tinney Cove formations are southwesterly.

Structure and Metamorphism

The Goulburn sediments underwent at least one phase of 'low-grade' metamorphism and/or diagenesis which has produced locally abundant muscovite and chlorite in the Western River, Burnside River, Brown Sound, and parts of the Peacock Hills formations. The Brown Sound and parts of the Peacock Hills also contain abundant specular hematite.

The Goulburn sediments also underwent open concentric flexure-slip folding about a northeast-trending axis, followed by block faulting (*see* Fig. 12) producing open concentric flexure-slip folds paralleling their trend, and small, tight, flexure-slip folds, with steep axial planes, adjacent to fault zones. The sediments were later cut by transcurrent sinistral faults, with movement mainly along the main "Bathurst fault", with a possible total displacement of up to thirty miles (using offsets in older structural domains as mapped by Fraser, 1964).

Economic Geology

No mineralization of economic significance was found in the Proterozoic sediments of the area. Minor local secondary chalcopyrite is present in the Ellice and Western River formations, adjacent to a large diabase dyke near a major fault, in the southeastern part of Bathurst Inlet. Minor chalcopyrite was observed in other parts of the basin.

Total-count scintillometers were carried on approximately 50 per cent of the traverses and measurements were taken at one-quarter to 1-mile spacings. Readings from four to six times background were obtained from mudstones of the Brown Sound and Peacock Hills formations. The high readings in the Peacock Hills Formation were obtained under a diabase sill.

Regional Considerations

The Kilohigok Basin, although not directly connected to the Coronation Geosyncline, forms a major marginal intracratonic basin spatially linked to the Epworth Group and tectonically linked to the Athapuscow Aulacogen (Hoffman, 1973). Fraser and Tremblay (1969) and Hoffman (1969, 1973) proposed that all three were lithologically correlatable. Our recent investigations strongly support this contention, not only on a lithologic basis, but also on the basis of major tectonic cycles which are reflected in both the character of the sediments and their sequence.

The Goulburn and Epworth goups can be correlated across the Archean west of "Rockinghorse Lake" (Bostock, 1967) where the westernmost outlier of the Goulburn Group is at "Rockinghorse Lake", west of Contwoyto Lake (Bostock, 1967). The Epworth Group is separated from the Goulburn Group by some twelve miles of Archean basement rocks. We propose to term this zone where the Proterozoic rocks are absent the Rockinghorse Arch, as both groups thin towards this area, and preliminary paleocurrent data indicate that some detritus was supplied from this zone. For example, the Burnside River Formation is only 600 feet thick in the Contwoyto Lake area and is absent in the "Rockinghorse Lake" area (Bostock, 1967).

The Stark Formation (Athapuscow Aulacogen) and the Omingmaktook member (Kilohigok Basin) are units which record a major regional tectonic event, and the two are correlated for the following reasons:

1. Both occur within or are associated with identical red bed sequences, above the platform carbonates the Tochatwi Formation in the Athapuscow, and the Brown Sound in the Kilohigok.

2. Both are characterized by carbonate slump blocks (exotic olistoliths) up to one-half mile long.

3. Both red bed sequences have associated intrusive rocks, quartz diorite lacoliths in the Athapuscow and a diabase sill in the Kilohigok.

4. The intrusive rocks may have initiated or been intruded synchronous with the uplift associated with the olistostromes.

The presence of relatively rare olistostromes in spatially separated sedimentary sequences, together with the nearly identical stratigraphic sequences, indicates that the entire area was affected by the same major tectonic events.

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BEDROCK GEOLOGY (THE DALY LAKE GROUP), NORTH WOLLASTON LAKE, SASKATCHEWAN (64L/6, Parts of 64L/5 and 7)

Project 740015

F.W. Chandler and K.K. Mukherji[1]
Regional and Economic Geology Division

The Wollaston Lake Fold Belt (Money *et al.*, 1970) is made up of Precambrian chiefly supracrustal rocks which strike northeast across northern Saskatchewan. The rocks of the belt are of high metamorphic grade and their present economic potential lies in base metals and uranium.

Money *et al.* (1970) divided the belt into three stratigraphic groups. The Daly Lake Group consists of sedimentary rocks of intermediate maturity and occupies most of the belt. The Meyers Lake Group, consisting of mature sediments and the Sandfly Lake Group of immature sediments and probable volcanics, lie along the eastern margin of the main fold belt and are present in a satellitic belt, the Compulsion River Fold Belt, that branches northeastward on the southeast side of the main belt (Møller, 1970).

The writers remapped part of Wollaston Lake map-area (Fahrig, 1958) to familiarize themselves with a section across the Daly Lake Group. The rocks of the area mapped are divided into four units: (a) the Athabasca Formation, (b) the western migmatites (c) the central migmatites and (d) the eastern migmatites (Fig. 1).

The Athabasca Formation forms the western part of the map-area and is not described here (*see* Fahrig, 1961). It is bounded on the east by the western migmatites and this boundary is defined by the easternmost drift fragments of Athabasca as the most recent ice flow was from the northeast. Just east of this boundary, hematite-stained fragments of the western migmatite (sub-Athabasca regolith) are abundant in the drift.

The western migmatites are commonly nebulitic with a restite consisting of fine-grained compositionally layered granodioritic gneiss. Rounded zircons are present in this rock type. Subordinate rock types are fine-grained layered amphibolite, calc-silicates and rare trondhjemitic rocks with wisps bearing biotite, cordierite and amphibole. The restite occurs as usually disoriented blocks and rafts in, and impregnated by, pink granite and granitic pegmatite.

The fresher central migmatites were probably derived from greywacke and lesser impure interbedded carbonate (possibly turbidites) and from minor quartzose sandstone. There is weaker evidence of a similar origin for the western and eastern migmatites. The impure carbonates, now calc silicates, are widespread through the central and eastern migmatites and are particularly abundant in an area coinciding with unit 2 of Fahrig (1958) between Gillies and Grant islands. This unit is not on strike with Wallis' (1971) carbonate-rich Hidden Bay Group. Trondhjemitic mobilizate characterizes the central migmatites which are particularly abundant and pegmatitic in their western part.

The eastern migmatites are chiefly layered biotite-bearing metasandstones interlayered with much granite and granitic pegmatite. The meta-sandstone is less biotitic than that of the central migmatites and in places has been converted to a layered granodioritic gneiss similar to that of the western migmatites. The rock is pink because of the presence of abundant potassium feldspar, some in the form of porphyroblasts, in contrast to the drab grey and brown of the metasandstone of the central migmatites. Subordinate coarse calc-silicate outcrops, strung out along strike, may represent carbonate-rich sedimentary horizons. Several outcrops of fine-grained granite and granite pegmatite were observed in the southeast part of the eastern migmatites.

The central and eastern migmatites are more or less coextensive, across strike, with the Daly Lake Group of Money *et al.* (1970).

Bedding, the only sedimentary structure unequivocally identified in the area, was seen in the better preserved inner parts of the central migmatites. It was not possible to decipher a stratigraphy for the metasediments; however, differentiation of the gabbroic body exposed on the Sandy Islands (Fig. 1) established the local stratigraphic top to be to the northwest. Compositional layering, with much interlayered coplanar mobilizate in the non-resistant lithologies, is widespread. Drag folds on a scale of several inches to several feet may reflect folding on a larger scale. In the central part of the area there appears to be a crude northeastward lithological continuity. For example, quartz arenite and quartz-pebble conglomerate with associated amphibolite might be used in attempts to define structure. Dips of planar structures are generally greater than 45 degrees. A north-striking fault with a sinistral offset of about a mile is present at the centre of the northern margin of the area.

In the western migmatites, foliation is weak and poorly oriented. Passage from the western to the central migmatites is marked by an abrupt change in lithology and acquisition of a strong northeast structural trend. The abruptness of the transition suggests a dislocation between the western and the central migmatites. Transition from the central to the eastern migmatites is by a gradual increase in the proportion of granitic mobilizate and by absence of trondhjemitic mobilizate in the sedimentary rocks. The strong northeast structural trend is also present in this part of the area.

Metamorphic indicator minerals are rare except in the central migmatites. Here, garnet is abundant in metagreywackes but absent in amphibolites. Cord-

[1]Concordia University.

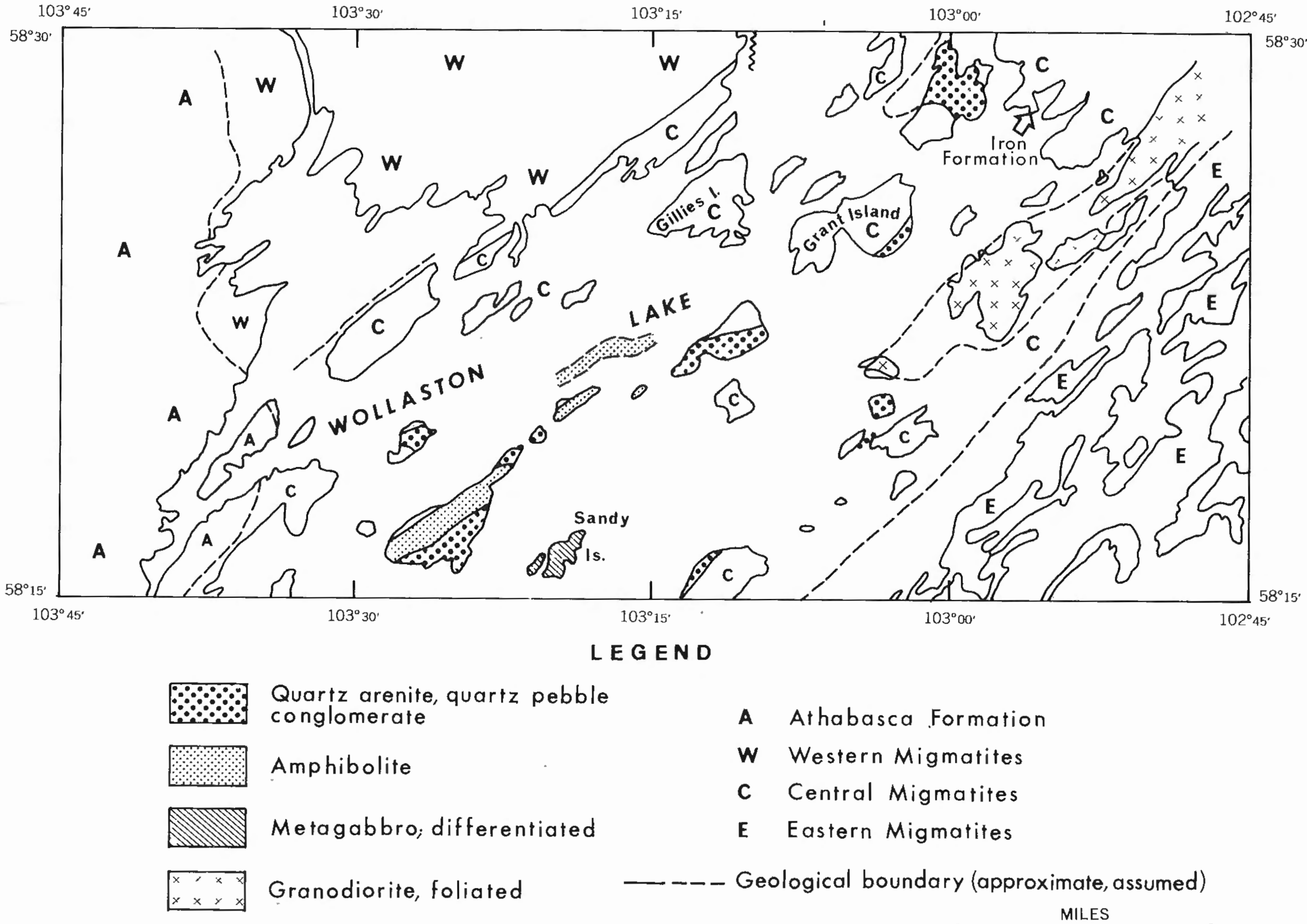

Figure 1. Bedrock geology, northern Wollaston Lake, Saskatchewan.

ierite is abundant in pelitic rocks. Muscovite is rare or absent and there appears to be fibrolite in quartz-rich sandstone. Regional metamorphism probably reached the top of the amphibolite facies at low pressure (Winkler, 1967).

Igneous rocks are confined to the central migmatites. Homogeneous amphibolite (possible sills) is associated with quartz arenite in many places. A foliated granodiorite pluton was traced 15 miles southwest from the northeast corner of the map-area. In the south-central part of the map-area a locally foliated and weakly metamorphosed differentiated metagabbro strikes northeast across the Sandy Islands for at least 8 miles. All three rock types postdate the migmatized metasediment.

Perhaps due to growth of magnetite, the western and eastern migmatites are more magnetic than the central ones. Magnetic highs coincide with both the Sandy Islands gabbroic body and some outcrops of quartz-magnetite-garnet iron-formation (Fig. 1).

Present economic interest in the Wollaston Lake Fold Belt lies in disseminated base metals in the metasediments (Sangster and Kirkham, 1974) and in uranium (Knipping, 1971; Wallis, 1971). Disseminated sulphides were not recognized in the map-area by the writers. Samples of the rock types of the area have been collected for a rock geochemical survey to discover which rock types are most likely to contain mineralization. The uranium deposit at Rabbit Lake lies in highly altered (weathered?) rocks of Wallis' (1971) unit 2. These biotitic sandstones are included in Fahrig's (1958) unit 3 and are on strike with similar rocks mapped by the writers to the northeast. An 18-inch radioactive pod in trondhjemitic pegmatite in these rocks was largely removed during exploration.

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GEOLOGY OF ISLAND LAKE MAP-AREA (53E), MANITOBA AND ONTARIO

Project 740016

Ingo Ermanovics, Graham Park[1], John Hill[2], Peter Goetz[3]
Regional and Economic Geology Division

New data, suitable for publication on a scale of 1 inch to 1 mile, was obtained for three areas underlain by Archean supracrustal rocks in the Island Lake map-area. The three areas are as follows: Stevenson Lake to Collins Bay on Island Lake; Bigstone, Wass and Knight lakes; and the belt of rocks extending from Cobham River to Gorman and Azure lakes (an extension of the Favourable Lake belt in Ontario).

Bigstone Lake Greenstone Belt

Basement

The margin of the greenstone belt rocks is generally an intrusive junction with granitic rocks, commonly quartz-diorite. However, in many places there are outcrops of banded tonalite gneiss near or at the margin. This banded gneiss is deformed by folding which affected the metasediments of the greenstone belt, and is also intruded by the quartz-diorite of the post-greenstone plutons. The effects of the deformation have typically produced parallelism or near-parallelism between the banding in the gneiss and the bedding of the metasediments; however, at some localities an original discordance can be inferred by reconstructing the relationships prior to folding - i.e., the banding in the gneiss appears to be cut by the bedding of the greenstone belt. This interpretation is supported by the absence within the greenstone belt of intrusive sheets similar to those making up the banding in the gneiss. The granitic intrusions within the greenstone belt invariably match the marginal plutons. These banded tonalitic gneisses are therefore regarded as remnants of the original sialic basement on which the greenstone belt supracrustal series was deposited unconformably.

Stratigraphic sequence

There is considerable lateral variation in both lithology and thickness within the greenstone belt. Estimates of thickness are subject to uncertainty owing to the effects of variable strain and possible undetected major folds or faults. However, top evidence is sufficiently frequent for the general picture to be reasonably clear. The sequence appears to consist of a mainly volcanic lower part and an upper part with approximately equal proportions of volcanics and sediments. The lower part at its maximum apparent thickness (12,000 feet), on the northwest side of the lake, consists of basalt and andesite pillow lavas. (By 'apparent thickness' is meant thickness without allowing for the effects of bulk strain. All thicknesses given here are apparent.) When traced north-eastwards, these thin rapidly and several flows of dacite and some greywacke horizons appear. At the southwest end of the lake, the volcanics are missing completely, due probably to removal by erosion prior to the deposition of the upper series. Along the southeast side of the lake the series gradually thickens again to a maximum of around 9,000 feet. It consists here of alternating acid and intermediate flows and intercalated sediments in the southwest which give way to a more uniform sequence of basalts and andesites in the northeast.

The base of the upper series is marked by a conglomerate or breccia which contains fragments of volcanics and metasediments similar to those found in the lower series. In the southwest where the volcanics disappear, the conglomerate contains blocks of foliated and metamorphosed sediments which are thought to have been derived from the basement. It is in this area that the lower series may have been completely removed by erosion leaving the upper series lying unconformably on the tonalite gneisses of the basement. At the northeast end of the lake, this horizon is represented by a quartz conglomerate and sandstone. Above the conglomerate is a series of greywackes and finely laminated sandstone, siltstone and mudstone beds. The greywackes are thickest and coarsest, in general, in the southwest and mudstone is more typical in the northeast. However, much of the outcrop is obscured by water. The maximum apparent thickness of this sedimentary unit is about 5,000 feet; it is overlain by a mainly volcanic sequence of pyroclastics followed by basaltic and andesitic lavas. The andesites are markedly pale coloured and highly schistose. There are some pyroclastic and sedimentary beds towards the top of the succession. This volcanic unit reaches a maximum apparent thickness of about 5,000 feet. Again there is a considerable lateral variation in the volcanics.

Structure

The large-scale structure is dominated by a northeast-southwest-trending upright syncline which appears to occupy the whole outcrop width of the greenstone belt (i.e., about 7 miles at maximum). Satellite folds which seem to be associated with this major structure possess a prominent penetrative axial-planar foliation which is the first obvious small-scale structure seen on outcrop and is the dominant foliation of the area. This foliation and associated folds are refolded by a set of asymmetric folds with an east-west to east-northeast trend which possess a strain-slip type of foliation developed only locally. A major fold of this generation

[1]Keele University, Newcastle, Staffordshire, England.

[2]University of Western Ontario, London, Ontario.

[3]Carleton University, Ottawa, Ontario.

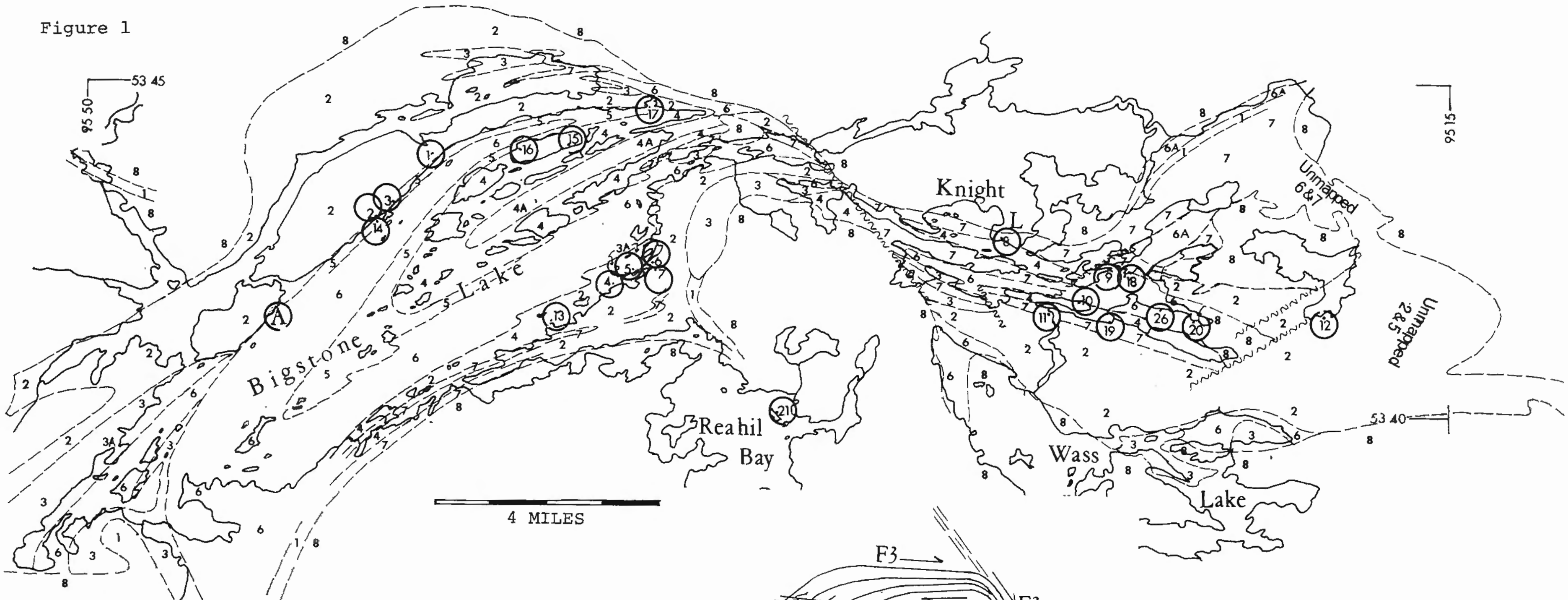
Table 1

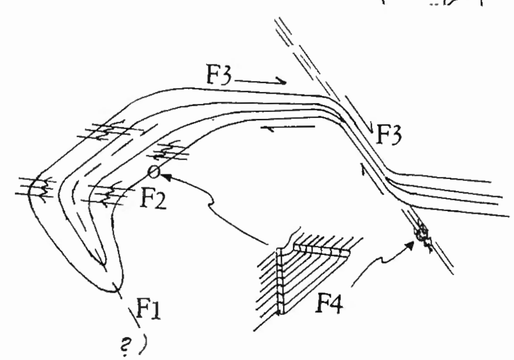
ASSAYS OF ROCK SAMPLES CONTAINING VISIBLE CONTENT OF ONE OR MORE OF THE FOLLOWING MINERALS: PYRITE, CHALCOPYRITE AND PYRRHOTITE

Locality	oz/ton Au	oz/ton Ag	% Pb	% Zn	% Ni	% Cu	Remarks
1	trace	nil	trace	0.24	0.07	0.09	Agglomerate in pillowed basalt
2	trace	nil	trace	trace	0.01	trace	Agglomerate in pillowed basalt
3	trace	nil	trace	0.01	0.01	0.02	Agglomerate in pillowed basalt
4	trace	nil	trace	0.01	trace	trace	As for locality number 13
5	nil	nil	0.27	0.56	0.06	0.04	Disseminated coarse crystals in mudstone
6	trace	nil	trace	0.02	trace	trace	Dissemination in siliceous greywacke
7	trace	nil	0.04	0.54	0.02	trace	As for locality 6
8	0.010	0.08	trace	trace	trace	2.55	Stratabound in schisted dacite; ½ inch thick
8	trace	nil	trace	0.02	0.02	0.04	Disseminated in porphyritic dacite
9	trace	0.04	trace	0.02	0.02	0.68	Vein in andesitic dyke and siltstone
10	trace	nil	0.01	0.06	0.01	0.05	Stratabound in siltstone
11	trace	nil	0.02	0.02	0.06	0.12	Bornite in mudstone
12	trace	nil	trace	trace	0.03	0.08	Porphyritic quartz eye rhyodacite
	ppm Au	ppm Ag		ppm Zn	ppm Ni	ppm Cu	
13	NA	NA	NA	NA	NA	29	Stratabound massive pyrite in siltstone between basalt and andesite
14	<.005	NA	NA	130	164	4220	Veined networks in agglomerate near basalt
15	NA	NA	NA	NA	91	158	Veins in greywacke agglomerate in basalt
16	.015	NA	NA	NA	63	1800	Greywacke near pyroxenite intrusion
17	.015	1.6	NA	NA	NA	1550	Disseminated in dacite; zone 2 to 4' wide in same horizon as 14 and locality A
18	NA	NA	NA	NA	NA	4110	Stratabound in siltstone in greywacke; zone 3' wide
19	.115	NA	NA	NA	NA	830	Disseminated in mudstone
20	12.4	NA	NA	NA	NA	88	Quartz veins in mudstone
21	.030	2.0	NA	100	NA	64	Garnetiferous greywacke with quartz veins
22	.020	3.8	NA	NA	NA	345	Veins in black chert in rhyodacite
23	NA	NA	NA	NA	NA	52	Disseminated in quartz diorite near gabbro
24	NA	NA	NA	NA	NA	1600	In greywacke intruded by gabbro
25	<.005	0.5	NA	NA	NA	380	Quartz veins in dacite in basalt
26	.010	NA	NA	NA	NA	265	Porphyritic quartz eye dacite
Samples of	NA	NA	NA	NA	200	8860	Mafic lava
scattered drill	.020	2.0	NA	328	175	600	Intermediate lava
core from locality	.060	2.4	NA	1420	NA	500	Mudstone facies
(A) on Bigstone	.030	2.0	NA	112	NA	490	Quartz veins in mudstone facies
Lake	NA	NA	NA	NA	231	900	Feldspar-quartz veins

Localities 1 to 12 assay analyses; localities 13 to 26 geochemical methods (HNO_3-HCl extraction)
Analysis by Bondar-Clegg & Company Ltd.
Trace = less than 0.010 oz/ton Au; less than 0.01% Pb, Zn, Ni, Cu
NA = not analyzed

Figure 1





1 Hybrid tonalite gneiss and hornblende gneiss

2 Basalt; minor andesite and agglomerate

3 Gabbroic rocks; 3A ultramafic rocks

4 Andesite; 4A andesite tuff

5 Andesitic and dacitic agglomerate, tuff and minor greywacke

6 Laminated greywacke, siltstone, mudstone and quartzite; 6A greywacke gneiss

7 Dacite and rhyodacite; minor greywacke and tuff

8 Undivided 'granitic rocks' and gneiss

∿∿∿∿ Fault

—·—·— Lithologic boundary

(4) Locality of mineral assay in Table 1

(A) Locality of mineral assay in Table 1

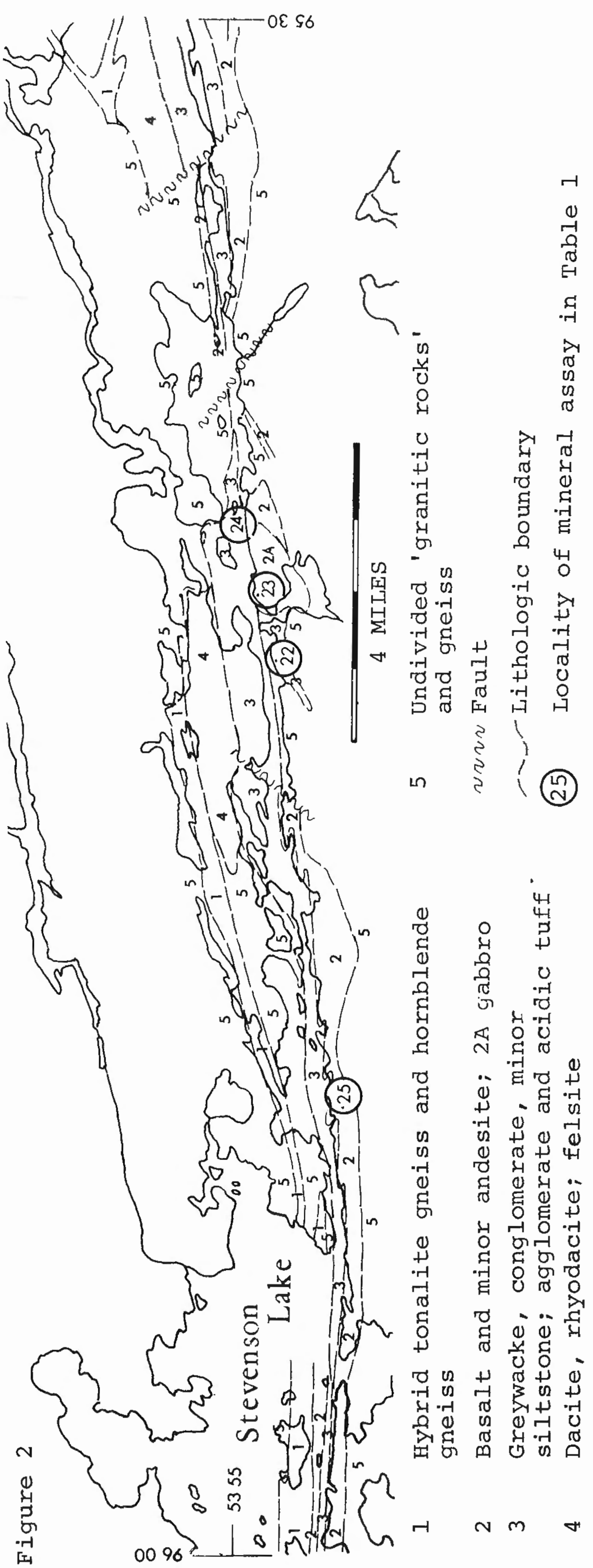


Figure 2

is responsible for the abrupt change in strike from northeast to northwest at the southwest end of the lake. Subsequent minor structures, also developed locally, are of the chevron or kink-band type.

The belt has also suffered large-scale horizontal simple shear movements in east-west and northwest-southeast directions resulting in rotation and displacement of the belt in a dextral (right-lateral) sense. Provisionally these deformation episodes may be classified as follows (Fig. 2).

- F1 - northeast-southwest major fold and main foliation
- F2 - east-west asymmetric folds with local strain-slip foliation
- F3 - east-west then northeast-southwest shear movements
- F4 - Chevron and kink-band folds

However, fabric study of thin sections may reveal the presence of a pre-F1 deformation (pers. comm. W.K. Fyson, 1974).

Igneous intrusions

(a) Pre-tectonic - The sediments of the upper supracrustal series are cut by numerous thin diabase dykes which are metamorphosed, folded and foliated together with the sediments; they may represent feeder bodies for the volcanics above. The lower volcanic series is cut by a large number of gabbro sills (the largest is nearly 3,000 feet thick), which are also deformed and metamorphosed.

(b) Syn-tectonic - The large quartz-diorite to quartz-monzonite plutons which surround the greenstone belt and the associated small sheet-like bodies within the belt cut and therefore post-date the main F1 folding and foliation of the supracrustals but are deformed and affected by retrogressive metamorphism, particularly along the large shear zones. Near the margins of the plutons, the foliation is typically parallel to the contacts which show considerable variation in trend across the area. Much of the deformation of these bodies is probably due to stresses associated with their emplacement.

(c) Late or post-tectonic - Numerous dykes of dacite, andesite and diabase occur throughout the area. They are easily distinguished from the pre- and syn-tectonic intrusions by their unmetamorphosed and undeformed nature. Several larger bodies of gabbroic and dioritic rock probably also belong to this category. Some of the diabase dykes are probably Proterozoic in age.

Metamorphism

The grade of metamorphism is rather variable - from low greenschist facies to middle amphibolite facies, the higher grade rocks being found near the margins of the belt. In the central part of the belt the sediments appear to be in middle to upper greenschist facies. The higher grade rocks are probably due to contact metamorphism - several of them have a hornfels-like appearance and occur near the thick gabbro sheets.

Sulphide concentrations

These were found in five types of environment (Fig. 1, Table 1): (a) in the thick pyroclastic beds below and above the main sedimentary unit (8 occurrences; pyrrhotite, pyrite and chalcopyrite); (b) within sedimentary beds either between or immediately above flows of dacite or andesite (10 occurrences; mainly pyrite); (c) within the basal conglomerate of the upper series (3 occurrences; pyrite and chalcopyrite); (d) at or near the margins of quartz-diorite plutons or sheets (5 occurrences; pyrite and chalcopyrite); and (e) in fault or shear zones (2 occurrences; pyrite). Although some Zn values in Table 1 are reasonably high, sphalerite was not recognized in the field. This distribution suggests that the sulphides were derived from the acid and intermediate volcanics and became concentrated by sedimentation processes and to a lesser extent by subsequent magmatic activity. Generally speaking, sulphide concentrations on the north side of Bigstone Lake are richer than those on the south side. This could be related to the thickness of individual flows which are thicker (80 to 100 feet) on the north side, compared to the south side (30 to 60 feet).

Stevenson Lake Greenstone Belt

Basement

Rocks considered to be basement to the greenstones are particularly well exposed at the north margin of the belt. Here they appear to overlie the top of the stratigraphic sequence but are separated from metasediments by intrusive granodiorite and microcline-bearing granitic rocks. Within these rocks late deformation episodes F3 and F4 effectively mask earlier textures so that orthogneiss and paragneiss and distinguished only with difficulty. However, one estimate of orthogneiss to paragneiss is in the proportion of 8 to 2. A regional discordance of strike direction of 20 degrees exists between basement rocks and supracrustal rocks.

Stratigraphic sequence

Estimates of thickness are subject to the uncertainty of measurements owing to intense effects of strain and its variableness. Rounded pebbles of unknown original shape are generally elongated more in the vertical than in the horizontal directtion, although elongations 1: 20 in the horizontal direction in mylonite are also common. A conservative estimate of horizontal contraction and concomitant vertical extension is placed at 300 to 400 per cent. "Way-up" evidence in the sequence is confined to pillows of a basaltic lower part (2,500 feet) which faces north. Andesite and agglomerate (100 feet) overlie the basalt locally. Acid tuffs and sediments (200 feet) have great lateral extent and overlie the basalt or andesitic agglomerate; these are overlain by greywacke, conglomerate, and agglomerate. Locally basalt is overlain by 10 feet of siltstone and mudstone followed by tonalite boulder conglomerate (80 feet) which is overlain by the greywacke sequence. In the area marked locality 22 (Fig. 2) acid, porphyritic flows and agglomerate constitute an unusual thickness of rock with little lateral extent and may represent a volcanic centre. The area just north of locality 22, north of the greywacke unit, is felsite of unknown origin. In this area are recognized both mylonitized granitic rocks and acidic volcanic rocks, although this distinction is not everywhere possible.

Structure

The large-scale structure is dominated by an east-west-trending upright syncline of which only the southern limb is exposed. Evidence for a northern limb is afforded by inclusions of basalt in granitic rocks which occupy the northern limb. Faults parallel to the axis of the major syncline are probably responsible for exposing tonalitic gneiss which occupies a position adjacent to the upper greywackes of the sedimentary series. Fold styles are similar to those of Bigstone Lake but the belt has been sheared (mylonitized) along its entire length.

Igneous intrusion

These are similar to those described for the Bigstone Lake area. The southern contact is intruded by leucocratic, white, granodiorite and quartz diorite; this contact is commonly cataclastic. Igneous rocks along the northern contact include quartz monzonite which becomes mylonitized at the belt-margin. Here such rocks have been mapped as felsite and may be mixed with acidic volcanic rocks. Similarly, at locality 22 granodioritic intrusive rocks are difficult to divide from acidic volcanic porphyries.

Metamorphism

The grade of metamorphism is upper amphibolite facies but is locally upper greenschist in cataclastic zones. The grain size of all rocks increases toward belt margins, suggesting contact metamorphism. However, the granites themselves are metamorphosed and the apparent reduction of grain size in the central axis of the belt is probably due to intense mylonitization of acid rocks (F3) where grain reconstitution has not kept pace with strain.

Sulphide concentrations

Although grab samples from sulphide concentrations in sedimentary environments are generally of higher sulphide content, their size and distribution is limited (e.g. locality 24, where one lense of pyrite and chalcopyrite is 7 inches thick). On the other hand, vein and disseminated sulphides in acid volcanic sections have greater lateral distribution, but the assay at any one place gives lower values. Thus, within the area shown on Figure 2, site 22, either within the acid pile or at the greywacke boundary (under water) seems to be the most favourable locality for exploration for sulphides.

Cobham River Paragneiss Belt

Basement

The southern margin of the belt contains medium-grained, granoblastic quartzofeldspathic gneiss which may be of igneous or sedimentary origin. The relationship of these rocks to the paragneiss is as yet unknown. Elsewhere, layered tonalite gneiss is interfolded with paragneiss.

Stratigraphic sequence

No volcanic flow rocks were recognized, although a thickness of 450 feet of acidic tuffs and grey felsite generally constitute the northern portion of the belt. Adjacent to these are siliceous greywackes which attain a mapped thickness of 5,000 feet. This thickness is reduced to 2,500 feet when doubling due to folding is considered. Mafic schists (100 feet) lies adjacent to the greywackes on the south side. Quartzofeldspathic greywackes, conglomerate, siltstone, agglomerate, calc-silicate gneiss and biotite gneiss on Azure Lake constitute the southernmost exposures of the paragneiss belt. No top determinations are available, although bedding commonly dips south at 55 to 80 degrees. Paragneiss of the Cobham River type outcrops intermittently for a distance of 8 miles at Warrington Lake, 5 miles south of the Cobham River belt.

Structure

The large-scale structure is indeterminable, but folds with east-west axes attain wave lengths of 500 feet. Refolded folds, and chevron and kink-band folds are common in zones of intense strain. F3 folds have shallow plunges, commonly with reversing plunge directions. The southern boundary of the Cobham River paragneiss and the accompanying cataclasis which continues northwestward into the Norway House map-sheet is taken as the northern boundary of the Berens batholithic block. The boundary separates mainly massive quartz monzonite to quartz diorite to the south, from mainly foliated quartz dioritic rocks and relatively abundant hybrid granitic gneisses to the north.

Metamorphism

The grade of metamorphism is uniformly upper amphibolite facies. Calc-silicate rocks on Gorman Lake contain diopside, scapolite, epidote and tremolite. Garnet is common in greywackes, and biotite and hornblende common in orthogneiss.

Sulphide concentrations

Except for small concentrations of pyrite in greywackes, no significant mineral showings were found. However, it should be recognized that rock exposure is less than one per cent and access to outcrops is difficult. Pegmatites in greywacke and calc-silicate rocks (e.g. at Azure and Gorman lakes) carry tourmaline and tantalite-columbite minerals. The pegmatites seem to be related to the late-tectonic (post-metamorphism) quartz monzonites.

PRELIMINARY REPORT OF THE GEOLOGY OF THE ARSENO LAKE MAP-AREA (86B/12), DISTRICT OF MACKENZIE

Project 720052

R.A. Frith and R. Leatherbarrow
Regional and Economic Geology Division

General

During the course of regional 1:250,000 mapping in the Indin Lake map-area in 1972, several gneiss domes were discovered (Frith, 1973). These seemed of particular interest so the part of the area which contains them (Arseno Lake W½) was mapped in greater detail during the 1973-74 field seasons. This resultant detailed map was then combined with the one mile to the inch Arseno Lake E½ map by McGlynn and Ross (1963) to produce a 1:50,000 compilation of the whole Arseno Lake area (86 B/12). Most of the work was carried out by foot traverse on lines one half mile apart or less, except for the area occupied by the batholithic granodiorite in the northwestern part of the area, which was mapped by helicopter.

The map-area straddles the Bear-Slave structural province boundary. The southeastern quarter of the area (Fig. 1) consists chiefly of Archean granodioritic gneiss but varies from granitic to dioritic (unit 3). These gneisses are in fault contact with metamorphosed greenstones of the Yellowknife Supergroup which consists of subaqueous pillow basalt, andesite, paraconglomerate and greywacke. The contact is not only faulted but obscured by migmatization. Some nearly vertical pillow elongations and lineations (slickensides, minerals, vesicules) along the contact suggest that the movement was vertical with the granitic gneiss moving up relative to the volcanic rocks. McGlynn and Ross (1963) report that the volcanic rocks face west or southwest with an estimated thickness of 18,000 feet. Overlying the volcanic rocks are paraconglomerates (unit 2a) up to 1,500 feet thick with subangular clasts of volcanic and sedimentary rock presumably of older Yellowknife rocks. The upper paraconglomerate contains clasts of quartz, granitic gneiss, diorite (tonalite) and volcanic fragments along with conformable hornblende gneiss, probably volcanogenic. Overlying the paraconglomerate are metamorphosed porphyroblastic beds of turbidite greywacke and argillite (unit 2). Kenoran granitic rocks were intruded into and have formed a migmatite or granitized gneiss (M2) from the greywacke and argillite metasediments.

As previously noted the Bear-Slave boundary in the map-area is in most places a fault, separating the Archean rocks from the Proterozoic sediments of the Snare Group. However at one locality, east of Arseno Lake and in the Basler Lake region south of the map-area, the Snare Group unconformably overlies the Archean Yellowknife rocks (Lord, 1942).

The Snare Group in the map-area consists of basal dolomite (unit 4) or quartzite (unit 5) overlain by a thick sequence of argillite, arkose and subgreywacke (unit 7). Interstratified with unit 7 are near-basal calcareous argillites (not shown) quartz-pebble conglomerate (unit 6) and quartzite (unit 5). Dolomite is also interstratified with unit 4 and is probably quite high in the stratigraphic sequence. Intruded into the metasediments are diabasic or gabbroic sills or dykes that have been folded with the metasediments (McGlynn and Ross, 1963).

Granitic gneiss domes make up a small but significant part of the map-area. The cores (unit 3) are Archean in age (Frith *et al.*, 1974) and are bordered along most of the contacts by a migmatitic zone (M7) formed from the Snare Group rocks. Some diabase dykes of uncertain age intrude the cores of the gneiss domes. The south portion of a granodiorite batholith (unit 9) characterized by potash feldspar phenocrysts 2-5 cm long occurs in the northwestern part of the area. The boundary of this intrusion is mylonitized in places and the host Snare rocks show a narrow, generally 25 m wide, aureole of garnetiferous rock. The intrusion is probably epizonal (Buddington, 1959).

Structure and Metamorphism

Archean granitic rocks within the Slave province show a moderate to faint alignment of biotite that trends in an easterly or northeasterly direction. A second fabric or crenulation cleavage with orientation 020° occurs locally. In places this second fabric is expressed as closely spaced parallel joint sets. Within the Yellowknife Supergroup the rocks show bedding or pillow flattening in a similar 020° direction but vertical extension is also well marked, particularly in the central part of the volcanic band. The volcanic rocks are invariably uralitized to produce a blue-green hornblende mixed with variable proportions of actinolite, saussuritized plagioclase, sphene, chlorite epidote and accessory ores. Near the margins the volcanic rocks are generally coarser due to hornblende recrystallization, a texture described by Lord (1942) as "dioritic" and attributed to the intrusion of granitic rocks. However, it is probable, that the texture is caused by a contact aureole effect not from intrusion, but by the latent heat of a more deeply derived domal emplacement of granitic gneiss. McGlynn and Ross (1963) show the upper conglomerate beds to be highly sheared with stretching along a northwest cleavage direction. In addition, the cleavage is folded around axes that may be correlated with the first deformation of the Snare Group.

Where the composition of the Yellowknife metagreywackes and meta-argillites was suitable, porphyroblasts of one or more of andalusite, cordierite or staurolite were formed. They now appear as skeletal growths with abundant inclusions of quartz and biotite.

LEGEND

PROTEROZOIC

9	Porphyritic granodiorite
M7	Migmatite derived principally from Unit 7

Snare Group

8	Diabase and gabbro
7	7a Metamorphosed argillite, arkose, subgreywacke 7b Porphyroblastic schist and gneiss derived from 5a.
6	Quartz pebble conglomerate
5	Quartzite impure quartzite, 5a interstratified with Unit 4.
4	Dolomite, argillaceous dolomite Basal and intraformational.

ARCHEAN

3	Granitic gneiss of granodiorite composition with lesser granite, monzonite and diorite commonly with alaskitic pegmatite. Minor diabase dykes.
M2	Migmatite derived from Unit 2. In places the rock is homogenous and granitic in appearance.

Yellowknife Supergroup

2	Metamorphosed porphyroblastic greywacke trubidite, argillite underlain by paraconglomerate 2a.
1	Metamorphosed pillow basalt, andesite with less abundant tuff and breccia intruded by minor amounts of rhyolitic porphyry and diorite.
	Fault
	Igneous lineation, dip unknown.
	Bedding dip unknown, minor transposition of beds
	Axial planar feature inclined, vertical
	Axial planar feature related to last deformation inclined, vertical
	Anticline, syncline
	Anticline, syncline related to last deformation
	Linear feature
	Linear feature related to the last deformation
	Biotite isograd, prograding to the west

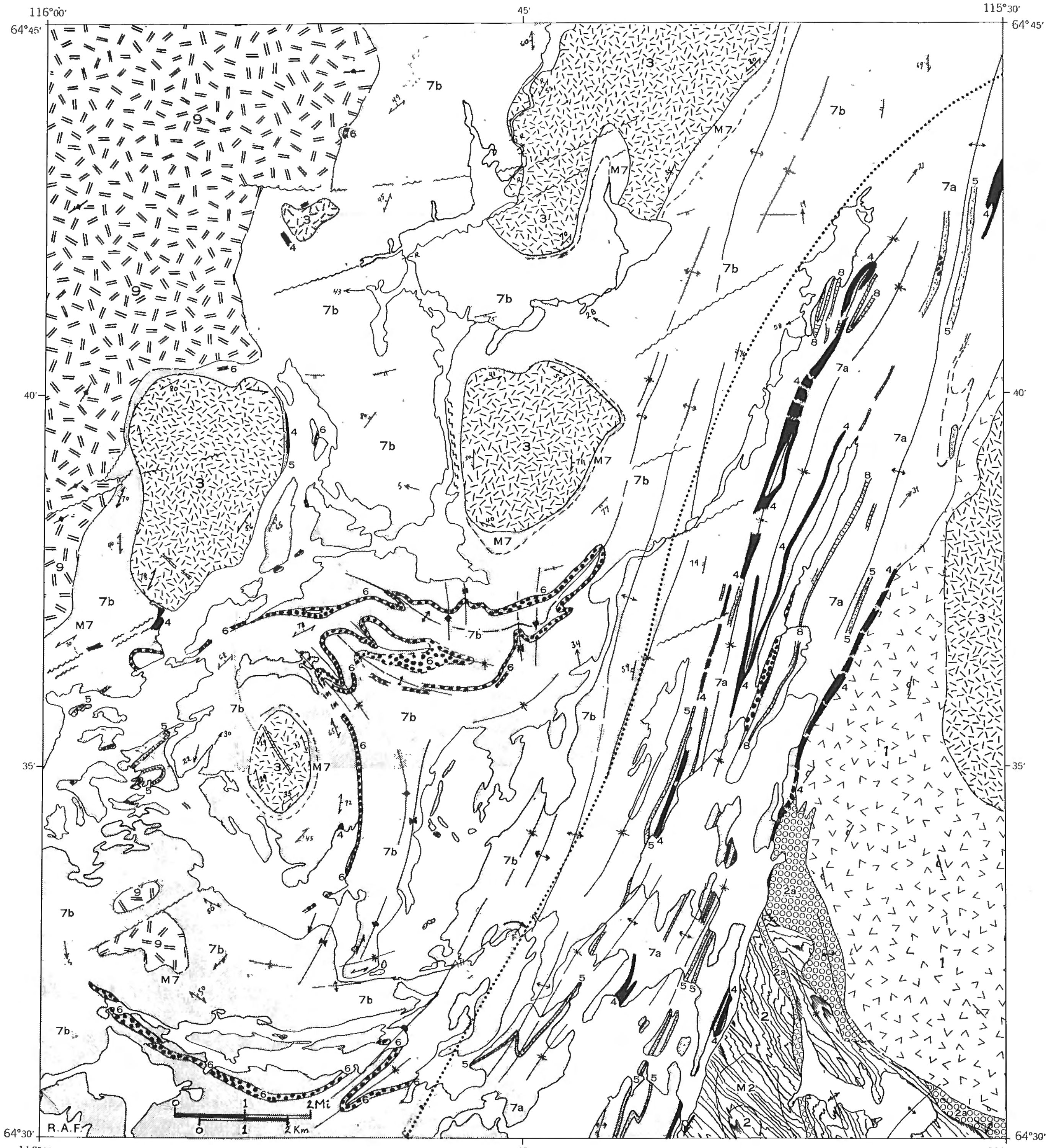


Figure 1. Sketch map of the Arseno Lake map-area (86 B/12). Geology of the east half was done by McGlynn and Ross (1963) and the west half by Frith, Leatherbarrow and co-workers.

The granitic contact southwest of the metasediments is gradational from a layered migmatite to a heterogenous schlieren-textured granitic gneiss. The dominant schistosity is northerly which conforms to that observed in the volcanic rocks.

Along the Bear-Slave boundary, low-grade dolomitic rocks of the Snare Group are in contact with Yellowknife Supergroup rocks. The contact is usually faulted and talc is locally present along slip planes. The dolomite on and near the contact contains rosettes of tremolite so metamorphism apparently did not exceed greenschist facies.

Deformation and metamorphism of the Snare belt differs from one side of the belt to the other. On the east, fold axes trend approximately 020° and form a zone of closely spaced upright to westerly dipping, mostly isoclinal folds that have formed according to Ross and McGlynn (1965) by simple or pure shear. The fold axes plunge consistently to the north. The metamorphism is generally low, but increases over a short distance to sillimanite grade in the vicinity of the gneiss domes or the porphyritic granodiorite. The west side of the Snare belt was affected by two phases of deformation. A biotite isograd approximated the boundary between the two domains (Fig. 1). The first phase (D_1) of the folding was similar to that in the east half of the belt and where the second phase (D_2) of deformation was not too intense, the fold axes strike approximately 080°. The D_1 was the more penetrative with biotite schistosity, grain flattening and elongation, and the development of porphyroblasts along the axial planar structures. The folding was mainly isoclinal with transposed bedding resulting in the schistosity being parallel to the bedding. The second phase of folding (F_2) has axial traces that are generally north-south but the associated deformation is not as penetrative F_2 is visible on the airphotos as open concentric folds and ground observations indicate that they have hinge lines generally plunging in a southerly or southwesterly direction. On outcrop scale the D_2 is present as gentle warps or as fracture cleavages which are in places quartz-filled. D_2 has displaced the D_1 structure particularly in the vicinity of the domes. It is common to observe around the southern parts of the domes gentle south to southwesterly plunging F_1 lineations which contrast with steeper F_1 lineations around the northern parts of the domes suggesting that D_2 was two-phase involving first the F_2 folding and then the uplift of the domal areas. Similar relationships hold for the deformation around the porphyritic granodiorite batholith and the smaller stocks associated with it. The batholith contacts however, are vertical to overturned and emplacement is thought to have involved considerable vertical movement. Faulting of all rock types in a 060° direction is considered to be associated with the late phases of granitic uplift.

The Mantled Gneiss Domes

The domes in the map-area are similar in many respects to those described by Eskola (1949). These domes characteristically contain an ancient core of basement rock enveloped by younger beds. The basement rocks appear to have been mobile during the dome formation. Within the present study area, the domes range from 2 to 12 km across and consist of a slightly foliated granitic gneiss that is in sharp contact with mantling clastic subgreywacke and argillite. The boundary of the core zone is characterized by biotite enrichment and contains xenoliths of biotite gneiss and schist that were possibly derived from the mantling gneisses. The gneissosity is faint for the most part, but well developed at the peripheries and entirely concentric for all bodies except the far western dome (which shows less consistent gneiss dome characteristics). The mantling gneisses are tightly folded with shallow to steeply dipping quaquaversal axial planes. The gneisses are migmatized around the margins, the mobilizate being derived locally by metamorphic segregation or diffusive transfer as in the model described by Olsen and Fisher (1974). The age of metamorphism has been determined by Rb-Sr whole rock isochron techniques at 1808 ± 43 with an initial Sr^{87}/Sr^{86} ratio of 0.7142 (Frith *et al.*, 1974) suggesting an *in situ* mode of development. The segregation veins are folded by D_2 and it is assumed that the metamorphism that produced them had a significant role to play in the subsequent rheomorphism of the core.

No unconformities were found between the core and mantling gneisses, but basal dolomite or quartzite forms the adjacent mantle gneiss in a number of localities, suggesting that unconformable relationships may be present but have been obscured by movement along the core-mantle boundary.

There are 5 major centriclinal structures in the study-area and several smaller structures of either porphyritic granodiorite or basement gneiss. The major structures vary in size and the size and zoning of the domes suggest that several levels of emplacement are represented. The northernmost dome is the largest and is considered to be the most deeply eroded, whereas the smaller domes are eroded to a lesser extent. A hidden dome may be present a few miles east of the southernmost dome and is expressed at the surface by a pegmatite rich region of concentrically planar migmatitic and gneissic Snare Group rocks.

The Porphyritic Granodiorite

The porphyritic granodiorite is part of the Hepburn batholith belt (Hoffman, 1973) of epizonal intrusions characterized by steep to inclined contacts generally with inclusion-free margins, and narrow sillimanite - garnet metamorphic aureoles with generally discordant boundary relationship. The granodiorite contains phenocrysts that show good Carlsbad twinned K-feldspar indicating a probable magmatic crystallization. However, in some localities rapakivi textures (Terzaghi, 1940) are observed suggesting that metasonatism may have played a role in the formation of the body. The megacrysts vary in shape from euhedral to rounded and in some places they are so abundant as to form a continuous framework similar to the case cited by Dawes (1966, 1970). The K-feldspars of the rapakivi are perthitic and the exsolution may be associated with the mantling plagioclase. It is conceivable that the granodiorite formed in two stages: the magmatic semi-crystalline intrusive stage which resulted in its ethmolithic shape and a metasomatic stage that resulted in the development of the rapakivi texture to bring the feldspars into equilibrium. Field studies of a similar body in the southwestern part of the Indin Lake map-area show that those porphyritic rocks grade into augen gneisses that form the unconformable basement to the Snare Group rocks. The augen foliation planes also penetrate the sediments. From this it is concluded that the porphyritic variety was formed by mobilization of the augen type possibly accompanied by partial anatexis. Isotopic Rb-Sr data of both the Arseno Lake and the Southwest Indin Lake porphyritic bodies show marked scatter with upper age limits of at least 2300 m.y., some 500 m.y. older than the rocks they intrude (Rosaline Frith, 1974). The origin of the batholith appears to be linked principally to the basement gneisses and not to the mantle.

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GEOLOGICAL STUDIES IN WESTERN MELVILLE PENINSULA, DISTRICT OF FRANKLIN

Project 720070

T. Frisch and N. Goulet[1]
Regional and Economic Geology Division

Mapping on a 1:125,000 scale completed the field component of this project. The area covered comprises the Prince Albert Hills south of 68°30'N and the coastal region at the head of Committee Bay east of 87°20'W (parts of 47B, 46M and 46N). The previous year's field work was summarized by Frisch (1974).

Prince Albert Group

This group of rocks was divided into seven mappable units: amphibolite, biotite schists, iron-formation, acidic metavolcanics, ultramafics, metaconglomerate and quartzite; the latter two units occur only in minor amounts. Due to a common absence of top indicators, the stratigraphic sequence of these units is not known. However, at one locality on the western margin of the Prince Albert belt east of Selkirk Bay, structures and textures (including spinifex) characteristic of Archean ultramafic flows (Pyke *et al.*, 1973) are well preserved in metaperidotites (Fig. 1) and indicate that these ultramafics underlie amphibolites and acidic metavolcanics, which, if this stratigraphic order can be extended, are in turn overlain by iron-formation. Pillows found in amphibolite at other localities are too deformed to be of use in top determination.

The significance of acidic volcanism in the Prince Albert Group was confirmed by the recognition of additional occurrences of metarhyolitic and metadacitic (?) rocks.

The rocks of the Prince Albert Group have been affected by two periods of folding. The earliest folds (F_1) trend northwest-southeast, are steeply plunging, and range in size from the microscopic to at least the outcrop scale. A penetrative axial planar schistosity (S_1) associated with the F_1 folds is very well developed throughout the belt. S_1 is parallel to the planes of flattening of pillows in metavolcanic rocks and clasts in metaconglomerates. The younger folds (F_2) dominate the map pattern and are outlined by the northeast-trending units of the Prince Albert Group. On both a mesoscopic and a map scale they are tight to isoclinal and moderately to steeply plunging, with almost vertical axial planes. A penetrative schistosity (S_2) is parallel to the axial planes of F_2 folds and is particularly marked in hinge zones of major folds. Locally, in the metavolcanics the planes of flattening of pillows are folded about S_2.

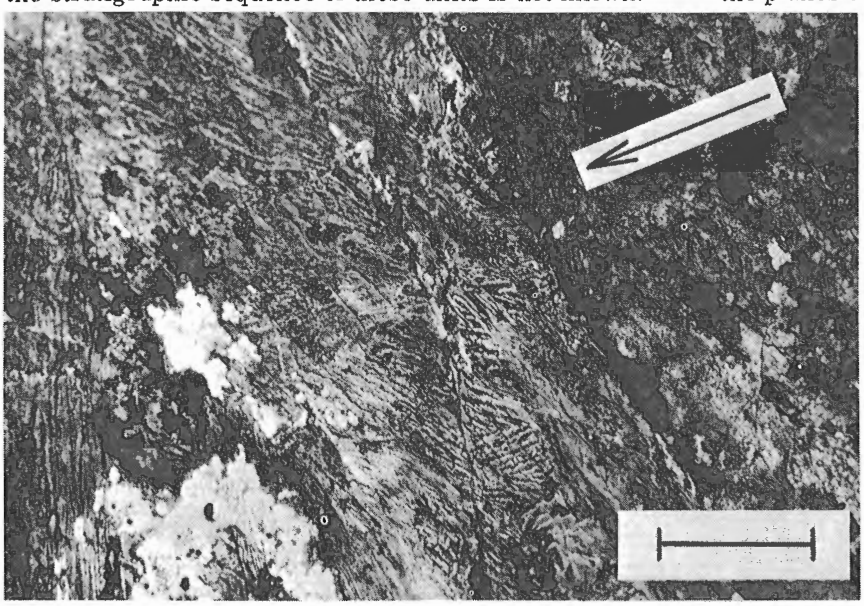

Figure 1

Spinifex texture in an ultramafic flow of the Prince Albert Group, western Melville Peninsula. The main spinifex zone is bordered by a poorly-preserved foliated spinifex zone (arrow); to the right lies massive metaperidotite of the "cumulate zone". Flow top is to the left. Bar scale represents 10 cm. GSC 202654-A.

A very complex interference pattern results from the superposition of the two fold systems. The scarcity of facing indicators makes it difficult to outline the complete character of the structures.

A belt up to 4 km wide of amphibolite and metagabbro, running from Mackar Inlet northeast for at least 17 km, is undoubtedly correlative with the Prince Albert Group.

Minor showings of chalcopyrite and pyrrhotite were noted, chiefly in metamafic rocks, bornite in acidic metavolcanics, and galena in biotite-amphibole schist of the Prince Albert Group and its correlatives.

Farther south, near the Matheson River, a layered gneiss-schist belt (unit 9a of Heywood, 1967) includes amphibolite and minor meta-ultramafic rock, which are characteristic of the Prince Albert Group, suggesting an affinity with the latter.

[1]Queen's University, Kingston.

Gneisses and Granites

Poorly- to non-foliated granitoid rocks of "plutonic" aspect predominate in the northern half of the area mapped and well-developed foliation is generally confined to the margins of the Prince Albert belt but well-foliated and -layered granitic to granodioritic gneisses and migmatite abound in the southern half. The gneisses show evidence of two superposed deformations, which are probably those that also affected the Prince Albert Group. In the noses of many folds, an axial-plane foliation, usually marked by alignment of biotite flakes, clearly cuts across an earlier foliation.

Other major rock types include a variably deformed augen-gneiss, consisting of pink K-feldspar porphyroblasts in a biotite-rich matrix, extending from Ross Inlet eastwards along the southern margin of the map-area; a foliated, homogeneous, pink granite, probably syntectonic, forming a concordant mass in layered gneisses on the south coast of Committee Bay; a generally non-foliated, pink quartz monzonite with large K-feldspar crystals comprising a major unit on the east coast of Committee Bay; and agmatite, particularly common east of the south end of Wales Island.

The only clearly post-tectonic granitic rocks are pegmatite and aplite dykes and veins, which are best observed in coastal exposures.

Metadykes

Amphibolite metadykes were found throughout the area, trending east, northeast and northwest, but are most abundant in the terrain east of Selkirk Bay. Some northeast-striking dykes are tightly folded about northeast-trending axes. As the dykes of the other two sets are much less deformed, at least some of the northeast dykes probably pre-date them. Dykes were found in all the major granitic units, as well as in the Prince Albert Group.

Late(?) Precambrian Metasediments (unit 16 of Heywood, 1967)

Eight sections in the basal part (described by Frisch, 1974) and one in the thickest unbroken sequence of this unit were measured near and northeast of Folster Lake. The latter section is 850 m thick; as the top of the unit is not exposed, this is a minimum thickness. The basal conglomerates, marbles, hematite-rich quartzites, and schists typically total 30 m (maximum 52 m). The overlying quartzite, in the thickest section measured, is more or less calcareous throughout, though only the lower 140 m conspicuously so, as shown by a pronounced carious weathering surface.

Approximtely 100 measurements of crossbed and slump fold orientations indicate a general transport direction from the northeast, i.e. from the granitoid and Prince Albert Group terrane.

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88. SEDIMENTOLOGICAL STUDIES OF THE YELLOWKNIFE SUPERGROUP IN THE SLAVE STRUCTURAL PROVINCE

Project 740018

John B. Henderson
Regional and Economic Geology Division

Several areas in the Slave Structural Province that are particularaly well preserved and exposed were examined. The stratigraphic and structural relations of various members of the Yellowknife Supergroup were established with particular interest in the transition from dominantly volcanism to dominantly sedimentation in these areas during the Archean. The relationship of certain mineral deposits to the sediments and volcanics was investigated in order to better appreciate the resource potential of these rocks. Models previously developed regarding the sedimentological volcanological and tectonic evolution of the Province

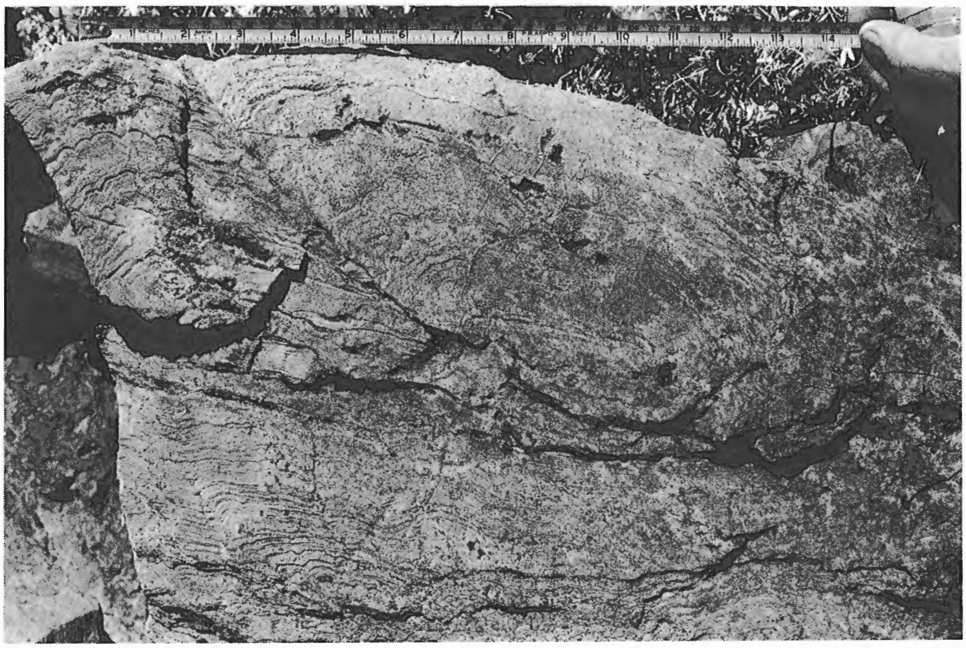

Figure 1

Archean stromatolite in dolomitic carbonate, High Lake area, District of Mackenzie. GSC 162966

Figure 2

Archean stromatolite in dolomitic carbonate, High Lake area, District of Mackenzie. GSC 162973.

are being reviewed as is the direction further sedimentological work in the Yellowknife Supergroup should take.

To this end visits were made to the Back River area, High Lake area, Point Lake area, Winter Lake area and the Beechey Lake area. In addition, a brief visit was made in the Hearne Lake area in connection with the regional mapping of that area (Project 700014).

Back River

One of the largest areas of felsic volcanic rocks in the Slave Province is found in the eastern part of the province north of the headwaters of the Back River (76 B/13) (*see* also Baragar, this publication, report). The dominantly felsic volcanic terrain, occupying a more or less rectangular area about 40 km long and 20 km across, is surrounded by the typical greywacke mudstone turbidites of the Yellowknife Supergroup. The sediments on the eastern and western sides of the volcanic terrain are in the greenschist facies of metamorphism. The contact area between the volcanic rocks and the sediments on the eastern side of the volcanic terrain is easily accessible from the Black River (64°50'N, 107°45'W).

In this area the felsic volcanics outcrop very well although the particularly luxuriant lichen growth largely obscures flow contacts and textures on weathered surfaces. Fresh surfaces indicate the predominantly fragmental felsic volcanics have undergone only minimal deformation. Few or no sedimentary units other than local minor volcanogenic beds occur within the main volcanic pile.

On the flanks of the main volcanic pile in the vicinity of Back River thick bedded units of coarse-grained greywacke turbidites and felsic fragmental volcanic units occur in about equal proportion. Thick units of dominantly argillite are present in this area as well. The turbidites are among the coarsest grained and thickest bedded seen anywhere in the Slave Province. To the east away from the main volcanic area and to the south the proportion of felsic volcanics decreases and the sediments in general become thinner bedded and finer grained. In the most coarsest grained material (up to 1 cm) it is evident that the sediments had a dominantly felsic volcanic provenance. In this area the sediments and volcanics dip at relatively shallow angles (35 degrees) although commonly the most prominent structural feature visible is the very steep fracture cleavage. In addition the metamorphic grade of the sediments is as low as seen anywhere in the Slave Province.

At the margin between the main volcanic pile and the flanking area of mixed sediments and volcanics is a zone of sediments dominated by carbonaceous mudstone and iron-formation. This zone was traced more or less continuously for 20 km. The most complete sequence is located on the Back River (64°55'N, 107°40'W) where the zone changes from a generally northerly striking unit to one with a generally westerly strike. In this area the intermediate to felsic volcanics are capped by a felsic volcanic breccia. An iron-formation consisting of thin bedded siderite and chert with very minor magnetite overlies the breccia and is followed by a massive unit of dolomite. At the top of the sequence is a massive black carbonaceous mudstone commonly containing finely disseminated pyrite to spectacular pyrite concretions. This sequence is followed by the normal siltstone to greywacke turbidites typical of the Yellowknife Supergroup. Along strike the zone is quite variable, commonly with parts of the sequence missing. The most persistent facies is the carbonaceous mudstone that in places has small but locally quite spectacular frost boil gossans developed over it. The only sulphide identified was pyrite. The iron-formation is variable in composition. In the north and central part of the zone it consists dominantly of thin bedded to laminated siderite with variable amounts of chert layers and locally minor magnetite concentrations. In the southern part of the zone near the south end of the island filled lake the Back River flows through, the iron-formation is the chert magnetite type and at the southernmost point observed, consists of silicate iron-formation overlain by siderite magnetite iron-formation. The black carbonaceous mudstone is everywhere closely associated with the iron-formation or is in close proximity to it, commonly separating areas of iron-formation. At several localities along the zone carbonate cemented felsic volcanic breccias occur immediately below the zone that in one instance has associated extensive pyrite mineralization. As well carbonate lenses and irregular veins are common in the felsic volcanics below the zone of chemical sedimentation.

High Lake Area

The High Lake area (76 M/7) has been recently mapped by Padgem (1973). The area is underlain in part by Archean volcanics of which felsic fragmental volcanics greatly predominate over both intermediate and mafic volcanics. Typical Yellowknife Supergroup greywacke turbidites occur in the southeastern part of the area. The remainder of the area is underlain by intrusive Archean granitic rocks and extensive sheets of diabase. The contact area between the volcanics and sediments is well exposed in the area about Snofield Lake (67°17', 110°47').

In the Snofield Lake region south of High Lake mafic and intermediate volcanic rock as well as extensive argillaceous units are more common in the volcanic pile than in the Back River area. At two localities within the volcanic sequence iron-formations similar to those described at Back River were found associated with these argillaceous units. The largest such sequence is located on the west side of an elongate lake 3 km west of the south end of Snofield Lake where siderite-chert-iron-formation is overlain by black carbonaceous mudstone followed by normal shales. These are followed abruptly by very coarse thick bedded volcanogenic turbidites of very proximal aspect that are overlain by a massive white carbonate unit. This sequence occurs about ½ km north along strike of a large gossan in which traces of sphalerite were seen.

It was not possible to trace this sequence any distance to the north or south. A much smaller occurrence of iron-formation occurs a few hundred metres north of the northeast shore of Snofield Lake and consists of thin-bedded siderite associated with dolomite and black carbonaceous mudstone. Chert nodules are common in both the siderite and mudstone. Pyrite mineralization is associated with the siderite layers. The similarity of these sediments to those seen at Back River is striking.

The sediments to the east of the volcanic sequence are similar to the typical greywacke mudstone turbidites of the Yellowknife Supergroup that are so common throughout most of the Slave Province.

Of particular interest is the occurrence of Archean stromatolites in the discontinuous dolomite unit that occurs along the contact between the volcanics and the normal Yellowknife sediments east of Snofield Lake. The unit in most places is highly deformed due to extensive shearing along the volcanic sediment contact. In a few places, however, there has been only minimal deformation and the stromatolites are very well preserved (Fig. 1, 2). The stromatolites have two forms at the two localities at which they are found. At the first locality ($67^{O}17\frac{1}{2}'$, $110^{O}45'$) the stromatolites occur as wavy to corrugated laminations with local nodular convexities with relief of about 1 cm. Rare intraformational breccia layers are present in which the clasts are coated with thin laminations. At the second locality ($67^{O}19'$, $110^{O}46'$) the stromatolites are much larger and more coarsely laminated forming flattened domes made up of even to corrugated laminae with relief of several centimetres (Figs. 1 and 2).

A thin tuffaceous layer within the carbonate unit at one locality ($67^{O}17'$, $110^{O}45'$) contained small amounts of sphalerite.

Point Lake Area

The contact between a major sequence of Archean mafic volcanics and sediments of the Yellowknife Supergroup occurs near the central part of Point Lake ($65^{O}15'$, $113^{O}00'$) (Bostock, 1967). It was in this area that the occurrence of granitic basement to Archean supracrustal rocks was first indicated in the Slave Province (Stockwell, 1932).

In the area of interest (Fig. 3) the volcanic rocks consist of a thick sequence of mainly mafic pillowed and massive flows with locally abundant mafic tuffs and other fragmental mafic rocks of volcanic origin. Felsic volcanics are a very minor component of the volcanic sequence. In most cases the volcanic rocks are strongly deformed, particularly those of fragmental origin. In many places however, the more massive pillowed flows are well enough preserved to provide useful top indicators. The main sedimentary unit consists primarily of the typical Yellowknife greywacke mudstone turbidites but in this region has associated within it elongate lenses to discontinuous units of silicate magnetite chert iron-formation (Bostock, 1966).

In this contact area also occurs a conglomerate-sandstone unit (Bostock, 1967) that is of considerable interest. The conglomeratic unit unconformably overlies a highly deformed altered granitic rock. Contact relations are clearly exposed over a length in excess of 1 km at locality A (Fig. 3). In Figure 4 the nature of the contact can be clearly seen where the fractured granitic surface is overlain by the conglomerate. In places erosional depressions on the unconformity surface are up to 15 metres deep and 35 metres wide. The conglomerate is very massive with only rare beds or lenses of volcanic lithic sandstone. It is locally variable but in general consists of coarse well rounded granitic cobbles similar to the granitic rock it overlies, smaller more deformed mafic volcanic clasts and minor amounts of intermediate and felsic volcanic clasts. The volcanic clasts in most cases are a more abundant if less spectacular component than the granitic cobbles. An important member of the formation is an extensively crossbedded sandstone composed of silicic volcanic rock fragments and quartz that occurs southwest of the granite and on the peninsula south of point B (Fig. 3). This member bears a very close resemblance to the Jackson Lake Formation at Yellowknife which is thought to represent terrestrial sedimentation (Henderson, in press). Wherever contact relations were observed the conglomerate - sandstone formation appeared to conformably overlie both the mafic volcanics and the greywacke turbidites.

This together with the fact that the turbidites were never seen in contact with the granite and the volcanics are only found in fault contact with it and since the major component of the conglomerate are mafic volcanic clasts, would support the suggestion that the granite may not be the "fundamental" basement to the Archean supracrustal succession in the area but may be younger than at least some of the volcanics as first suggested by Bostock (in prep.). Material has been collected for radiometric dating in order to help resolve this question.

At several localities mineralized zones and chemical sediments occur at or near the contact with the conglomerate-sandstone formation. The most interesting of these occurs at locality B (Fig. 3) where one metre of massive sulphides (pyrite, sphalerite, chert and chalcopyrite) occurs in a layer within the mafic volcanics about 20 metres west of the contact with the conglomerate. The sulphide layer is well exposed on the shoreline as a slightly lower weathering rusty zone one metre wide. The deformed mafic volcanics (pillowed?) on either side are not altered. The sulphide layer can be traced for about 40 metres but once away from the immediate shoreline appears as a minor rusty rubble zone that otherwise might easily be overlooked. Table 1 consists of analyses of 9 reasonably representative grab samples from the shoreline outcrop. Several smaller rusty zones in the volcanics along this shoreline contain traces of sphalerite. At localities C and D (Fig. 3) again at the contact between the volcanics and the conglomerate is a black carbonaceous mudstone unit with extensive pyrite mineralization. Localities E and F (Fig. 3) are at or near the contact between the conglomerate and the greywacke turbidites. In these areas again is found a major unit of black carbonaceous

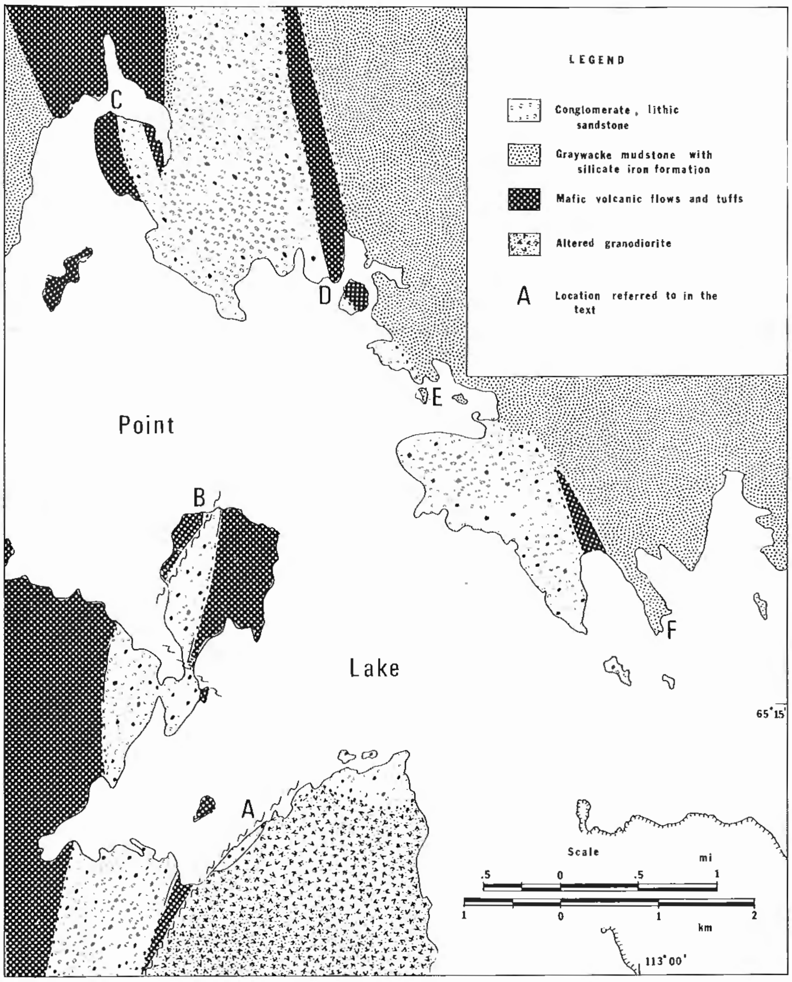

Figure 3 (above). Geological maps of central Point Lake, District of Mackenzie. Geology modified after Bostock (in prep.).

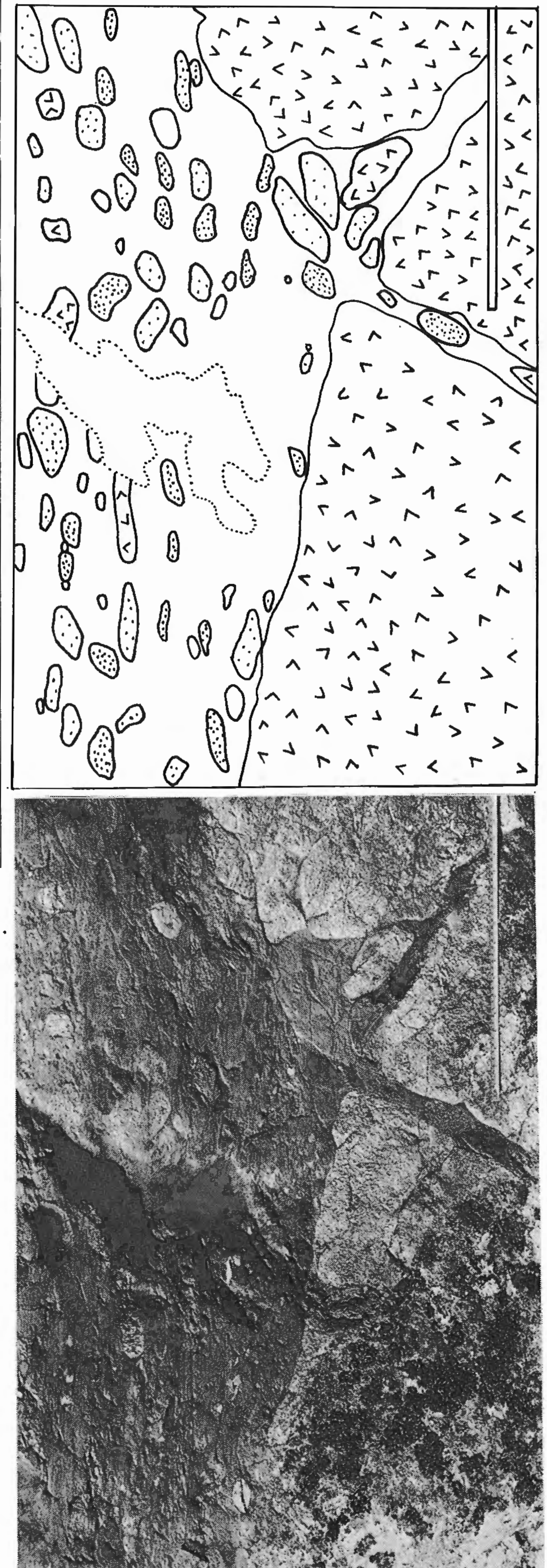

Figure 4 (right). Unconformity at Point Lake, between granitic basement and overlying Archean conglomerate here composed mainly of mafic volcanic clasts with minor granitic and felsic volcanic cobbles. Note fractures in the unconformity surface containing cobbles of the conglomerate. Scale extended 43 cm or 17 inches. GSC 163013.

mudstone that also contains siderite. The siderite iron-formation at locality E is the larger, is complexly folded but consists of the same package of lithologies as described at Back River and High Lake areas - i.e. black carbonaceous locally pyritiferous mudstone and thin-bedded to laminated siderite iron-formation with minor chert layers and local magnetite concentrations. Chert nodules occur in both the mudstone and iron-formation.

If these localities of chemical sediments are related as seems to be reasonable if a volcanic exhalative model is invoked, then they may provide a useful time horizon in the immediate Point Lake area — a rare commodity in the Archean. If indeed these deposits are time-equivalent then it is further evidence for the conformity of the conglomerate with other members of the supracrustal succession.

Table 1

Locality B — Sulphide Layer Analyses

Sample	Au oz/ton	Ag oz/ton	Cu %	Pb %	Zn %
HBA-1	trace	1.94	2.52	0.17	5.60
HBA-2	trace	0.52	0.10	0.25	9.84
HBA-3	trace	1.10	1.36	0.44	10.4
HBA-4	trace	1.02	1.14	0.13	3.84
HBA-5	trace	1.04	1.44	0.60	12.9
HBA-6	trace	1.72	1.76	0.53	15.6
HBA-7	trace	1.04	0.33	0.21	5.12
HBA-8	trace	1.60	0.31	0.50	14.4
HBA-9	trace	0.94	0.93	0.39	8.92

trace: less than 0.010 oz/ton Au

Analyses are of representative grab samples taken from the shoreline exposure of the sulphide layer.

Beechey Lake Area

A narrow belt of volcanic rocks occurs at the western margin of the extensive area of Yellowknife Supergroup rocks that underlie much of the Beechey Lake area. A prominent gossan occurs in this belt (65°36', 107°55') and is the locus of a prominent geochemical anomaly (Agricola Lake, Cameron and Durham, (1973), *see* also Cameron this publication report).

Approximately 2,300 metres of volcanic rocks are in intrusive contact with granitic rocks to the west-southwest of the belt. They form a steeply dipping monoclinal succession topping east with a prominent quartz feldspar porphyry sill 200 metres thick and 4,500 metres long at the top. The lower part of the sequence consists of thick massive units of probable andesitic composition dominantly of fragmental origin. Some pillowed flows are also present in the section. In the lower part of the section are abundant irregular quartz feldspar porphyry intrusions. In the central part of the sequence is a thick intrusive mafic sill. Andesitic and dacitic fragmentals make up the upper part of the sequence that becomes increasingly felsic and thinner bedded towards the top. Minor thin carbonate units also occur in this section of the sequence. It is in this part of the section that the main gossan occurs (*see* Cameron, this publication, report).

Above the volcanic sequence is a 200-metre thick lens of black highly deformed carbonaceous mudstone locally containing finely disseminated to concretionary pyrite. This lens has its maximum thickness above the alteration zone in the volcanic sequence and thins to both north and south over a distance of several kilometres. The mudstones are followed abruptly by thin-bedded volcanogenic siltstones that become increasingly coarser grained and thicker bedded to the east where they are similar to the typical greywacke mudstone turbidites of the Yellowknife Supergroup.

Five hundred metres east of the contact with the mudstones is a series of thin discontinuous layers to lenses of silicate chert magnetite iron-formation similar in many respects to the silicate iron-formation associated with the greywackes in the Point Lake-Contwoyto Lake area. A few metres east of the silicate iron-formation is a 50-metre unit of oxide iron-formation interlayered with argillite and locally with chert. This is the major iron-formation that causes the prominent anomaly on the aeromagnetic map of the region.

Both the volcanics and the sediments in the region are steeply dipping and are metamophosed in the middle greenschist facies. In the sediments the metamorphic grade increases to the east where the cordierite isograd occurs 2.7 km from the volcanic sedimentary contact.

Hearne Lake Area

A section across an extensive mylonite zone in the Hearne Lake map-area (851) previously seen only at isolated helicopter landings (Henderson *et al.*, 1973) was examined in detail near a lake located at 62°44'N, 112°02'W. The mylonite zone extends for 30 km across the northeast corner of the map-area and has a width of about 2½ km at the locality examined. It varies from a finely laminated granitic mylonite at its western contact with a major intermediate to mafic volcanic belt through to cataclastic granitic rocks on the eastern margin of the zone where it is gradational into the massive granitic rocks to the east. The mylonite zone is intruded by massive to weakly foliated quartz monzonite and pegmatite and contains highly deformed volcanic inclusions near the contact with the volcanics.

A lens of presumed Proterozoic conglomerate and arkose previously reported by Henderson (1939) occurs on the small islands and on the adjacent shores of the lake. The fault-bounded lens is 1500 m by 100 m, parallels the mylonite zone (north-northeast) and is only weakly deformed. The well rounded quartz, quartzite and arkose cobbles of the conglomerates have retained their original shape which contrasts strongly with the adjacent cataclastic to mylonitic rocks.

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VOLCANISM AND PLUTONISM, SLOAN RIVER MAP-AREA (86K), GREAT BEAR LAKE, DISTRICT OF MACKENZIE

Project 730039

P.F. Hoffman and I. Bell[1]
Regional and Economic Geology Division

Three months were spent mapping the south half of Sloan River map-area (Fig. 1). Mapping in the north half was begun in 1973 (*see* Hoffman and Cecile, 1974) and the project is scheduled for completion in 1975.

The most important results of this year's field work concern the relation of mineral deposits at Port Radium to regional volcanic facies changes.

General Geology

The map area straddles the north end of the "Great Bear Batholith" (Fraser *et al.*, 1972), a belt of latest Aphebian volcanic and plutonic rocks in the west half of the Bear Province. The area contains one of the world's great accumulations of intermediate and acidic welded ash-flow tuff. The tuffs are broadly folded about gently-plunging northwest axes, but northeast-dipping limbs predominate such that high stratigraphic levels occur only in the northeast and low ones in the southwest. For this reason, it is uncertain whether the important changes in volcanic facies from east to west across the map-area are related mainly to paleogeography or stratigraphic level.

Throughout most of the area, no basement to the volcanic pile is known. However, at their most easterly extent, the volcanics are intercalated with sedimentary rocks that abut against older granitoid rocks of the "Hepburn Metamorphic-Plutonic Belt" (Fraser *et al.*, 1972). This contact, in part depositional and in part tectonic, results from west-side-down movement during volcanism along a fundamental crustal break, the Wopmay Fault.

The volcanic rocks are intruded by discordant epizonal plutons having narrow contact metamorphic aureoles. The plutons are massive and have sharp contacts. The older ones range from granodiorite to quartz monzonite; the younger ones are granite and quartz diorite, the latter being relatively small. The large post-volcanic plutons do not extend east of the Wopmay Fault, although a single small granite stock of identical type intrudes gneisses of the Hepburn Belt near the southeast corner of the map-area (*see* Fig. 1).

Both the volcanic and plutonic rocks are offset by steeply-dipping, northeast-trending, right-lateral, strike-slip faults. These faults splay and die out approaching the older Wopmay Fault, and have a complementary set of northwest-trending, left-lateral faults in the Hepburn Belt. Strike-slip faulting probably preceded deposition of the Helikian sediments that cover the Great Bear Batholith to the north and west, but dip-slip rejuvenation of the faults persisted through Helikian time. The volcanic and plutonic rocks are deeply weathered beneath the Helikian cover, a fact which may be important in the evolution of their mineral deposits.

Western Volcanic Sequence

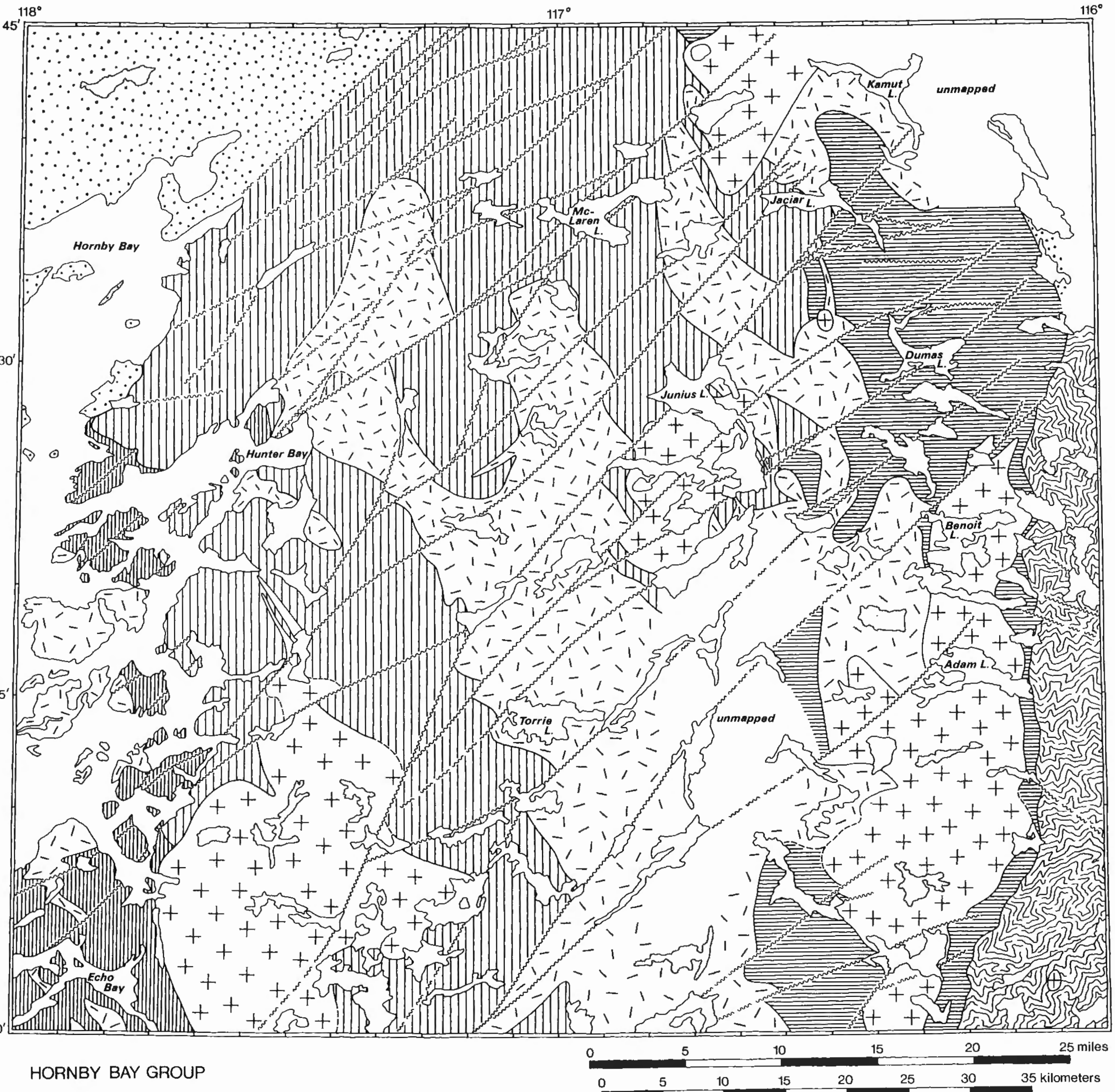
The volcanic rocks in Figure 1 are divided into western, central and eastern sequences. The western sequence, stratigraphically the lowest, is exposed along the rugged coast of Great Bear Lake from Echo Bay to Doghead Point (*see* Fig. 2). Earlier maps of this region include Feniak (1952) in the north and Mursky (1973) in the south.

Of fundamental importance is the facies change from south to north (Fig. 3). To the south, a great shield volcano is exposed in cross-section. At its base is a transition upward from subaqueous to subaerial tuff and tuffaceous sediment, intruded by andesitic plagioclase-hornblende porphyry. In detail, the succession is (1) distal deep water facies — fine-grained, laminated, silicified tuff ("banded chert"); (2) proximal deep water facies — tuffaceous mudstone with turbidites and slump breccias of redeposited tuff; (3) shallow water facies — crossbedded tuffaceous sandstone and tuff-pebble conglomerate; and (4) subaerial facies — graded and reverse-graded, crystal and lithic, air-fall tuff. The lowest flows are thin, finely-porphyritic, basaltic (?) andesite, but the bulk of the shield volcano is built of coarsely porphyritic andesite flows and flow breccia, interstratified with thinner units of bedded air-fall tuff. Trachytic alignment of plagioclase phenocrysts is common except in the upper flows, which are expecially altered and contain abundant gossans.

To the north, the andesite thins markedly and is in part overlain by and in part interfingered with dacite-rhyodacite ash-flow tuff and sediment. The lower ash-flows are mostly massive, densely welded, and crystal-rich; the upper ones are strongly eutaxitic, moderately to weakly welded, highly altered, and rich in lithic fragments. The sedimentary units locally contain acid porphyry domes, some probably extrusive, and consist of conglomerate, sandstone and mudstone, derived in part from the andesite shield volcano and in part from the acidic ash-flows and porphyry domes. Crossbedding indicates northward transport, that is, away from the shield volcano.

One conglomerate high in the sequence at Doghead Point contains granodiorite and quartz monzonite pebbles resembling the large pluton on Hogarth and Workman Islands a few kilometres to the south. This pluton intrudes only the lower part of the western sequence and is itself intruded by a feeder to the distinctive plagioclase-quartz porphyry sill that discontinuously

[1]McGill University



HORNBY BAY GROUP

sandstone, conglomerate

GREAT BEAR BATHOLITH

granite, quartz monzonite

granodiorite, quartz monzonite, quartz diorite

SLOAN RIVER VOLCANICS

eastern sequence

central sequence

western sequence

HEPBURN METAMORPHIC-PLUTONIC BELT

granodiorite, migmatite, psammitic gneiss, amphibolite

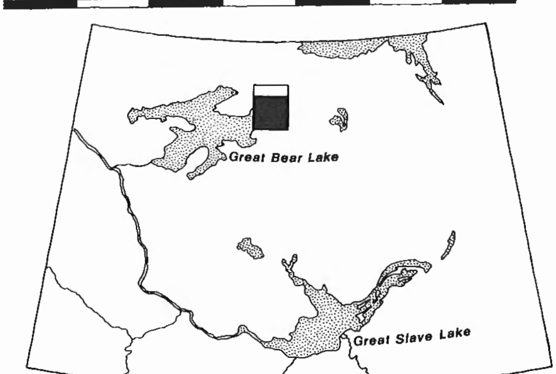


Figure 1. Geology of three-quarters of the Sloan River map-area showing the distributions of the western, central and eastern sequences of volcanic rocks.

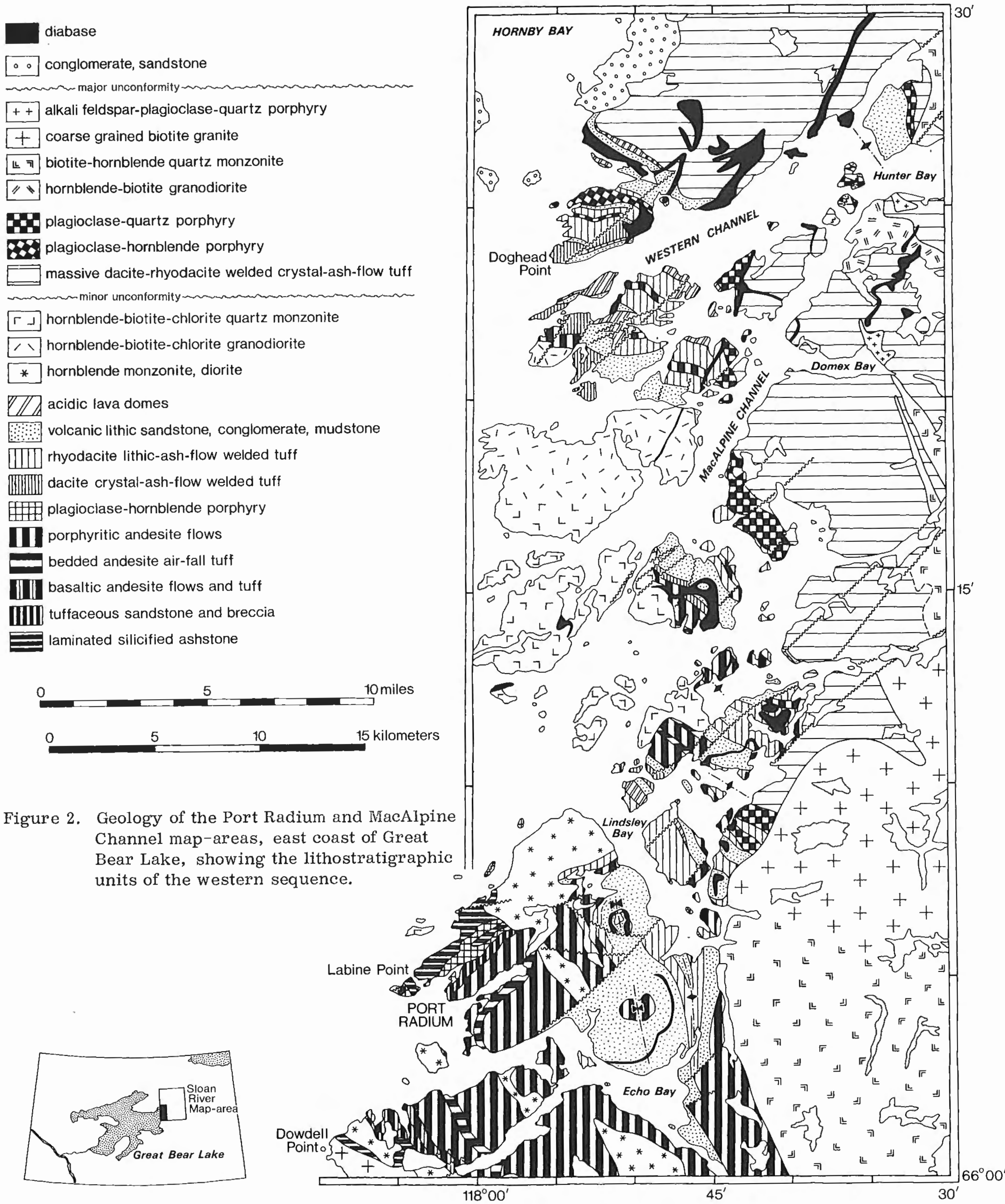


Figure 2. Geology of the Port Radium and MacAlpine Channel map-areas, east coast of Great Bear Lake, showing the lithostratigraphic units of the western sequence.

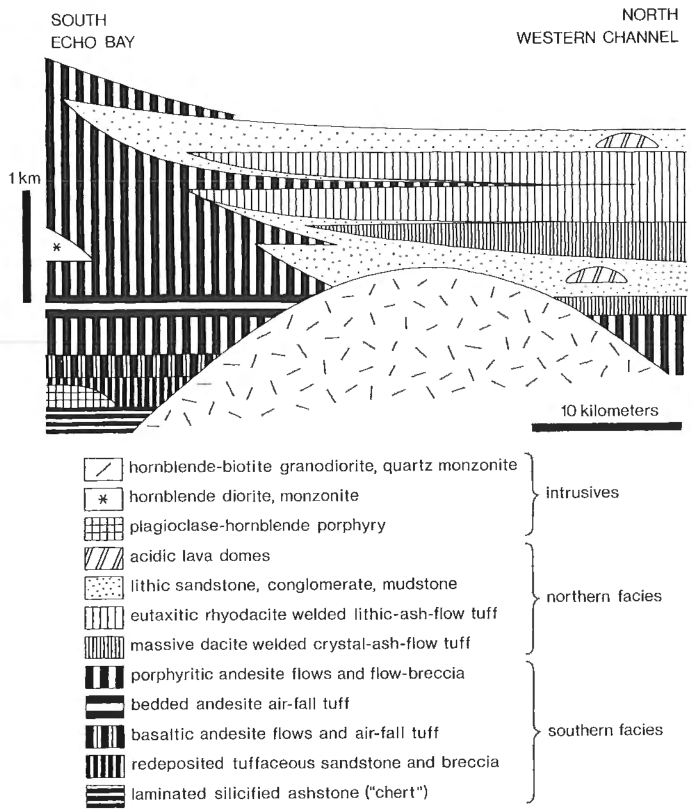


Figure 3. Facies relations in the western sequence from Echo Bay to Doghead Point.

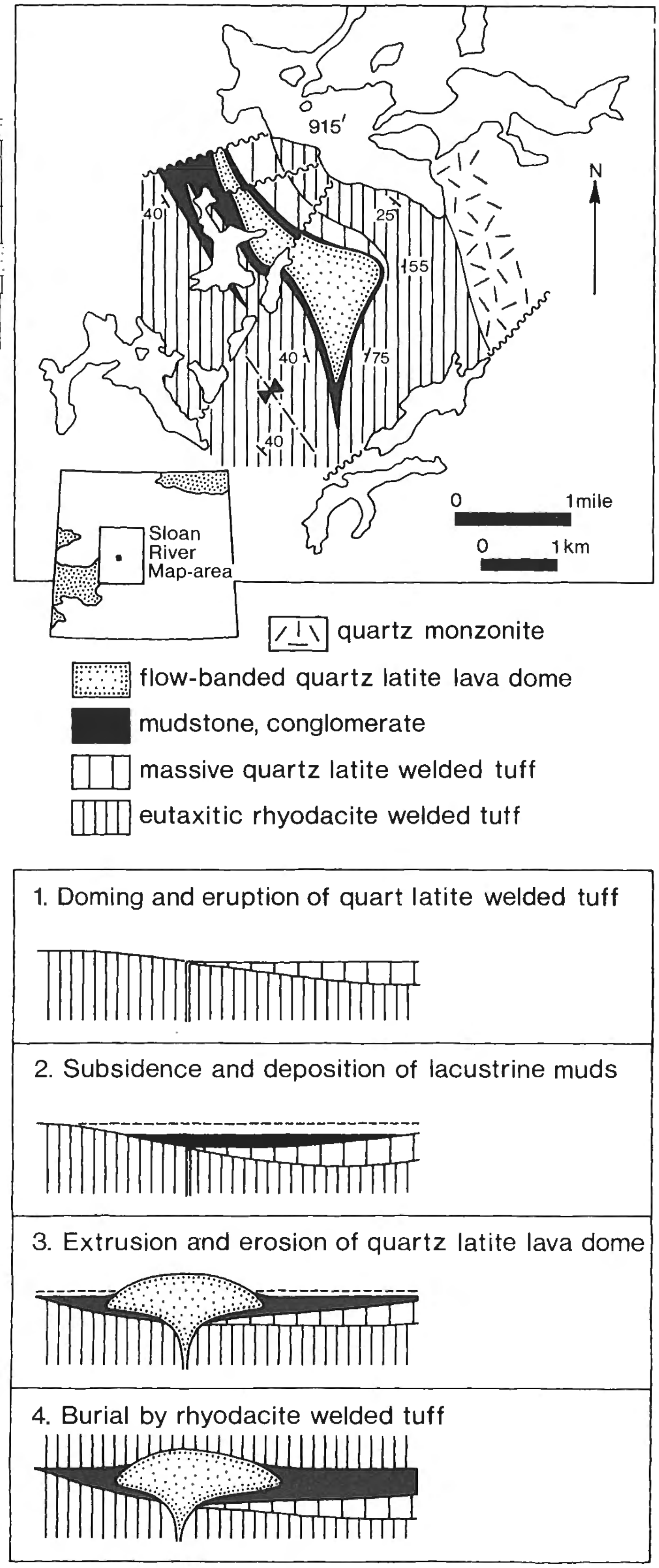


Figure 4. Map and genetic reconstruction of a quartz latite lava dome in the central sequence at 66°28'30"N, 117°07'W.

separates the western and central sequences. Therefore, this pluton must by syn-volcanic and, by extension, so must the family of older, uniquely quartz-poor, monzonite-diorite intrusions around Echo Bay (*see* Fig. 2).

The western sequence was tilted gently to the west, lightly block-faulted, and weathered before deposition of the overlying central sequence.

Central Volcanic Sequence

The central sequence consists of enormously thick piles of densely welded ash-flow tuff rich in broken crystals. Paucity of interstratified sediment distinguishes it from the western and eastern sequences.

The belt extending southeast from Western Channel almost to the south edge of the map-area (*see* Fig. 1) is stratigraphically the lowest part of the sequence. The tuff in this belt is very well exposed, very monotonous, reddish dacite-rhyodacite with prominent columnar jointing. Eutaxitic structure is weakly developed. In its upper part, the tuff is intruded by sills of dacite-rhyodacite porphyry, compositionally identical to the tuff but with unbroken phenocrysts.

More heterogeneous tuff occurs northwest of McLaren Lake and in the pendant-shaped belt between Junius Lake and Hunter Bay (*see* Fig. 1). Massive, coarsely phenoclastic quartz latite is interstratified with strongly eutaxitic rhyodacite. A major flow-banded,

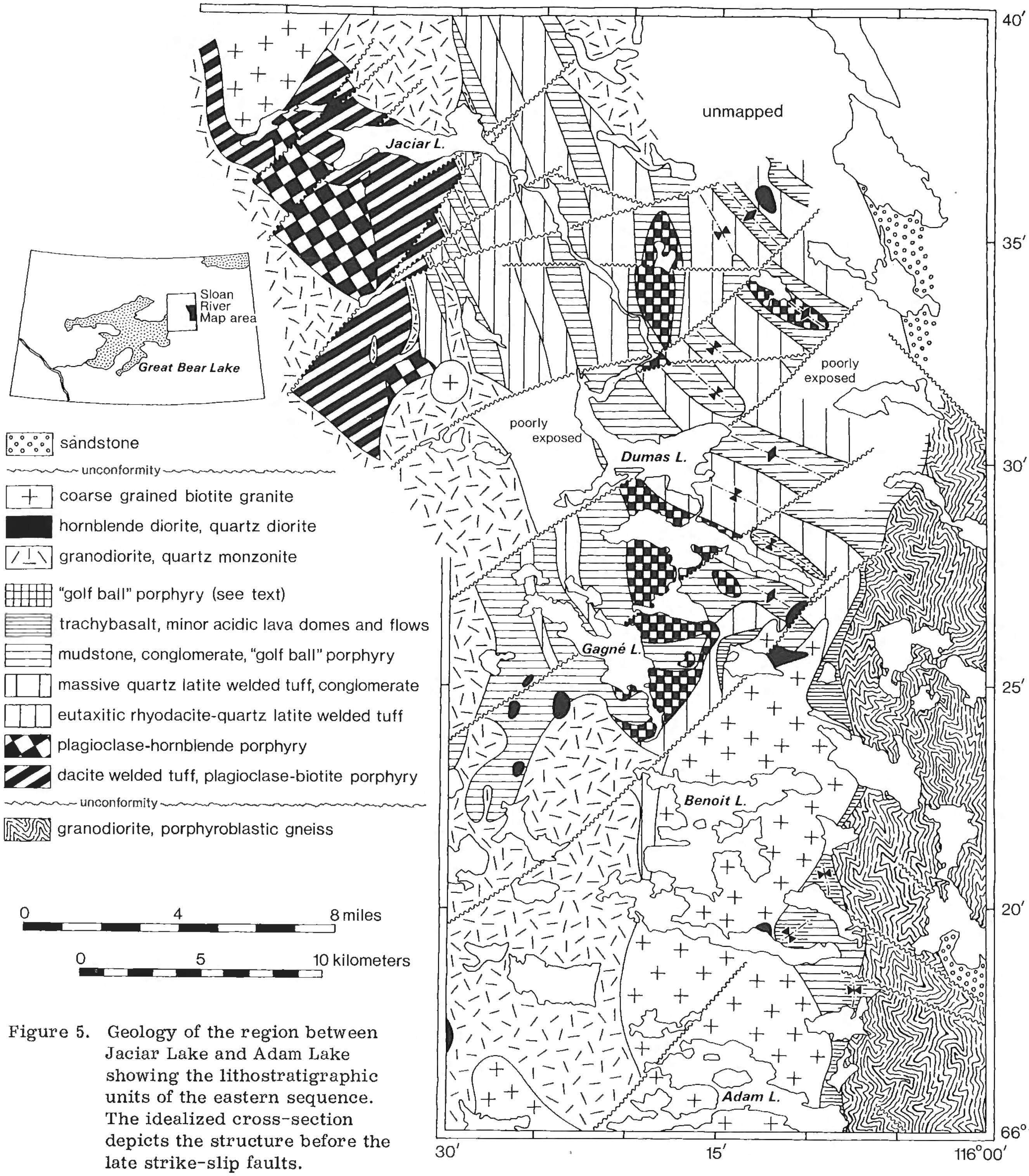
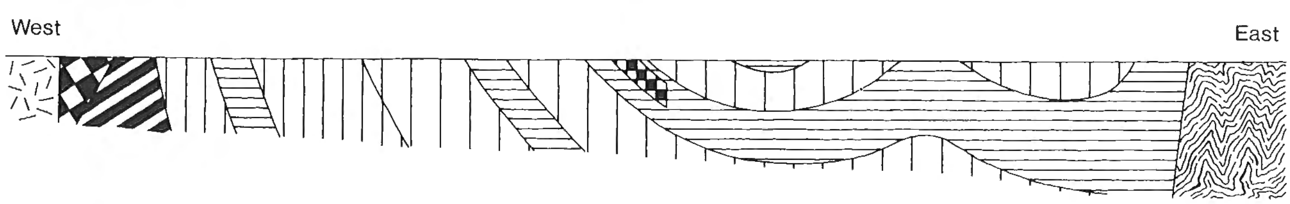


Figure 5. Geology of the region between Jaciar Lake and Adam Lake showing the lithostratigraphic units of the eastern sequence. The idealized cross-section depicts the structure before the late strike-slip faults.



quartz latite, lava dome is located within a lens of lake sediment and probably marks one of the elusive eruptive centres of the ash-flow tuff. A map and interpretation of its origin is shown in Figure 4.

The upper part of the central sequence is exposed in a triangular area between Junius, McLaren and Jaciar lakes (*see* Fig. 1). Extensive lenticular units of dark green, moderately eutaxitic, dacite-rhyodacite, ash-flow tuff are interspersed with thinner brick-red, strongly eutaxitic, ash-flow tuff relatively poor in crystal fragments. The tuff is discordantly intruded by a fine plagioclase-biotite porphyry and a slightly younger rhyodacite porphyry with coarse phenocrysts of plagioclase and hornblende, plus minor alkali feldspar and quartz. The latter also intrudes lower parts of the central sequence to the west.

No plutons are known to have intruded the central sequence before deposition of the conformably overlying eastern sequence.

Eastern Volcanic Sequence

The eastern sequence is best exposed around Dumas Lake (*see* Fig. 5) but a narrow strip against the Hepburn Belt extends to the south edge of the map-area. The "buttress unconformity" between the eastern sequence and Hepburn basement is exposed at latitudes 66°02', 66°05', 66°18'30" and 66°25'30"N.

The sequence is made up of several cycles containing, from the base upward, (1) a thick, densely welded, crystal-rich, rhyodacite-quartz latite, ash-flow tuff; (2) a sedimentary unit ranging laterally and vertically from mudstone with varve-like lamination, to mudstone with turbidites, to crossbedded sandstone, to volcanic-pebble conglomerate; and (3) a relatively thin capping of potash-rich, rarely pillowed, porphyritic, basalt flows, locally with acidic lava domes. The mudstone units contain intrusions of "golf-ball porphyry", a distinctive quartz latite with large rounded phenocrysts of alkali feldspar. At least one such intrusion, east of Gagne Lake, is multilobate in plan view. The quartz latite ash-flow tuffs contain broken "golf-balls", indicating that the tuff and porphyry are extrusive and intrusive equivalents of the same magma.

The sedimentary units and, even more so, the basalts thicken toward the Wopmay Fault. The Hepburn basement near the fault is intruded by swarms of basalt and acidic dykes that can be traced into flows and sills in the eastern sequence. Conglomerates against the fault consist of boulders of Hepburn basement rocks, plus intraformational sediment and basalt clasts. Sedimentation is clearly related to slippage on the Wopmay Fault, perhaps triggered by ash-flow eruptions, in a manner similar to resurgent cauldera (Smith and Bailey, 1968), to produce the observed cyclicity.

Stratigraphic Nomenclature

The only formal stratigraphic nomenclature applied to the volcanic rocks is based on mapping of the western sequence around Echo Bay (*see* Kidd, 1933, an altogether outstanding report). The andesite and underlying tuffaceous sediments were assigned to the "Echo Bay Group", and the overlying conglomerate and sandstone (*see* Fig. 3) to the "Cameron Bay Group". The groups were thought to be separated by an unconformity because the conglomerate contains clasts of andesite. This year's mapping indicates, rather, that there is no angular discordance, that the andesite and sediment interfinger, and that the clasts result from syn-volcanic erosion of the andesite shield volcano. There is therefore, no unconformity.

The facies changes in the western sequence has frustrated attempts (e.g. Mursky, 1973) to extend the two-fold stratigraphic subdivision north of Echo Bay. The ash-flow tuffs, in particular, have been assigned in some places to one group and elsewhere to the other. Furthermore, the two group names have increasingly been applied throughout the Great Bear Batholith to rocks in the central and eastern sequences. By now, their stratigraphic significance, once clearly defined, is lost.

A new stratigraphic nomenclature is in preparation. The three sequences will constitute formations of a single group. The western formation (i.e. western sequence of this report), especially, will contain several members. Discussion of this proposal will be welcomed by the senior author.

Volcanic Facies and Mineral Deposits

The mineral deposits at Port Radium and Terra Mine, 50 km to the south, have a similar and highly specific geologic setting. Both are located in the western sequence, at the base of the andesite volcanic pile, and where the pile is relatively thick. This suggests a spatial, if not genetic, relation to the centre of the andesite shield volcano. In all probability, both are in the same volcano, offset by a major strike-slip fault in the valley of Tilchuse River. In addition, it may be significant that both deposits are close to where a large pluton, mostly underwater at Port Radium, truncates the base of the andesite pile. Perhaps, contact metamorphism concentrates minerals originally of volcanic origin. Regardless of origin, the base of the andesite pile, exposed at the south tip of Stevens Island, near the north tip of Vance Peninsula, east of Dowdell Point, and along the Camsell River south of the map-area, is an attractive exploration target. Exploration should not ignore the possibility of exhalative massive sulphide mineralization in the tuffaceous sediments directly beneath the andesite pile.

The potential of the area for "porphyry copper" mineralization associated with plutonism was viewed pessimistically by Hoffman and Cecile (1974). This view might best be tempered in the case of the intrusives around Echo Bay and on the islands to the north. This is because they are apparently older and more probably syn-volcanic than the large plutons to the east.

Regional Tectonic Setting

Hoffman and Cecile (1974) on the basis of work mainly on the eastern and central sequences, suggested that volcanism occurred in an environment of crustal attenuation analogous to the Basin and Range Province of the western United States and Mexico. However, there is little direct evidence of basin and range faulting and, while an extensional environment is still favoured, slip apparently occurred exclusively on the Wopmay Fault.

Badham (1973), on the basis of the calc-alkaline petrochemistry of the western sequence, favoured a volcano-plutonic arc analogous to the Cenezoic central Andes, generated above an east-dipping subduction zone. However, the rocks are consistently more potassic (Badham, 1973) than is typical of the Andean arc-crest.

Perhaps both models are in part correct, and by combining them the observed change in volcanic facies from west to east may be rationalized. It is suggested that the map-area covers only the back part of the arc, the front parts being covered to the west. Thus, the western sequence — andesite shield volcanos standing high above dacite-rhyodacite ash-flow plateaus — represents the back part of the arc-crest, its high potash content relating to the progressive increase in potash/silica ratio from front to back in arcs generally. The central and, especially, the eastern sequences — containing a bimodal association of acidic ash-flows and lavas, and potassic basalts — represent the fill of an exteme back-arc rift basin, essentially an incipient "marginal basin" (Karig, 1971). Assuming a scale of arc development comparable to the Andes, the front of the arc may be as far west as the Mackenzie Mountains. Thus, the entire arc edifice is the basement on which the Helikian continental terrace wedge was deposited.

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GEOLOGY OF THE CALDER RIVER MAP-AREA (86F), DISTRICT OF MACKENZIE

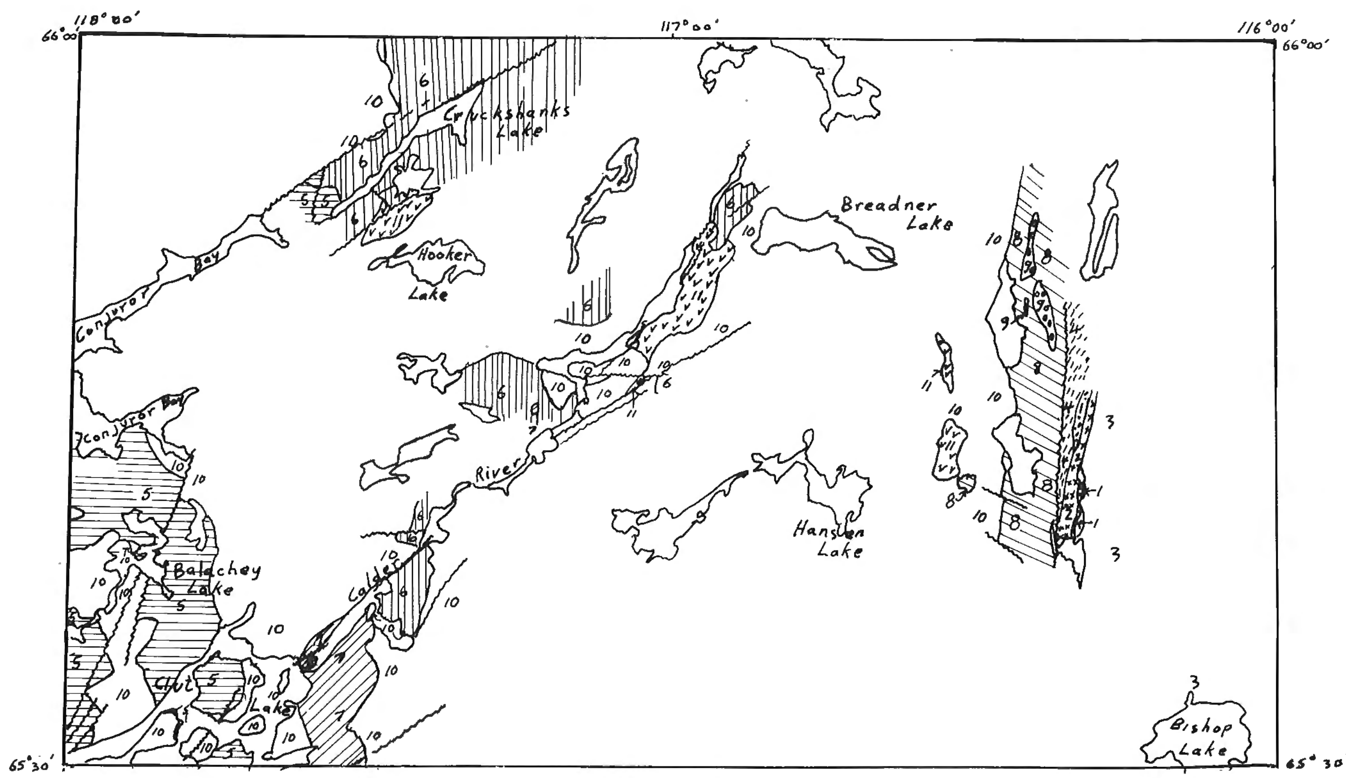
Project 730041

J.C. McGlynn
Regional and Economic Geology Division

Work was concentrated during the past summer in the north half of Calder River map-area. Mapping of most of the south half of the area was completed in 1973 (McGlynn, 1974) and the remainder of the area will be completed in 1975.

The map-area spans two major tectonic divisions of Stockwell's Wopmay Belt (Stockwell, 1970) which has been called the Wopmay Orogen by Fraser *et al.* (1972). These tectonic divisions are the Great Bear Batholith and the Hepburn Metamorphic-Plutonic Belt and their mutual boundary is defined by the Wopmay Fault (Fraser *et al.*, 1972). During this past summer most of the volcanic and sedimentary rocks of the Great Bear Batholith in the north part of the area were mapped, as well as some of the older supracrustal rocks east of the Wopmay Fault.

The oldest rocks in the area (Fig. 1, units 1 and 2) occur just east of the Wopmay Fault and comprise a conformable sequence of siltstone and slates overlain by basic volcanic rocks. These rocks were assigned to the Snare Group by Lord and Parsons (1952) and this correlation remains a reasonable one. The thickness of the lowest sedimentary unit cannot be known as it is everywhere cut by granitic rocks, but within the area some hundreds of feet are exposed. The top of the volcanic unit is not exposed, but some two



1. Snare siltstone-shales
2. Snare basic volcanic rocks
3. Migmatites, mixed gneisses of the Hepburn Metamorphic-Plutonic Belt
4. Sheared granodiorite
5. Interbedded porphyritic andesite flows, tuffaceous sandstones, turbidites, mudstones, ash flow tuffs
6. Massive dacite to rhyodacite ash flow tuffs
7. Quartz latite to rhyodacite ash flow tuffs
8. Mudstones, turbidites, sandstones and ash flow tuffs
9. Porphyry intrusions
10. Granodiorite, quartz monzonite, granite
11. Rhyolite porphyry intrusions

Figure 1. Geological sketch map of the north half of the Calder River map-area.

thousand feet are present in the sequence. The bulk of the volcanic sequence comprises massive thick flows of probable basaltic composition. Many individual flows have thin scoriaceous tops preserved. A few pillow lava flows occur near the base of the sequence. The Snare rocks are metamorphosed to greenschist facies except near granitic intrusions where the grade is amphibolite facies. The rocks are folded about northeasterly-trending axes. To the east, the Snare sedimentary rocks grade to migmatites, veined gneisses and granitic gneisses of the Hepburn Metamorphic Plutonic Belt (unit 3). The Snare rocks are cut by high level granodiorite and quartz monzonite (unit 4). In the area mapped these rocks occur along the Wopmay Fault and are intensely sheared, crushed and in many places converted to mylonites.

West of the Wopmay Fault are rocks of the Great Bear Batholith. In the area mapped this summer these rocks were in fault contact with Snare rocks and sheared granodiorites that cut Snare rocks but to the south (McGlynn, 1974) and north (Hoffman and Cecile, 1974) supracrustal rocks of the Great Bear Batholith were found resting unconformably on rocks of the Hepburn Metamorphic-Plutonic Belt. Supracrustal rocks just west of the Wopmay Fault are intensely deformed and so are older than at least some of the movement along that fault.

The oldest supracrustal rocks (unit 5) of the Great Bear Batholith in the north half of the Calder River area occur in the western part of the area around Clut and Balachey lakes and just east of Conjuror Bay of Great Bear Lake. This sequence is composed of interbedded andesite flows, turbidites comprising mudstones, tuffaceous sandstones and mudstone conglomerates, shallow water crossbedded tuffaceous sandstones, conglomerates and water worked tuffs and subaerial dacite to rhyodacite tuffs, some of which are eutaxitic and some of which are massive and probably welded. All tuffs are rich in crystal fragments and some have lithic fragments. The andesite flows are porphyritic and commonly display trachytic texture, having rudely aligned plagioclase phenocrysts. Within this lower sequence the various facies not only change upward but laterally. The andesite flows, for example, are most abundant in the lower part of the sequence and in the western portion. Conglomerate beds wedge out very rapidly along their strike.

These rocks are overlain conformably by a thick sequence comprising thick piles of massive ash flow crystal tuffs (unit 6). These rocks are grey to maroon or purple, and in composition are dacites to rhyodacites and quartz latites. They are intruded by sills, dykes and possible stocks of similar composition. Some units are eutaxitic and some contain scattered to abundant lithic fragments. Little or no sedimentary units, water worked tuffs, or flows, occur within this sequence, in marked contrast to the older formation.

East of Clut Lake and south of the Calder River is a third sequence of light grey to pink and maroon to purplish grey quartz latites and rhyodacite ash flow crystal tuffs (unit 7). These rocks are often eutaxitic and contain no sediments, and are thought to overlie tuffs of unit 6 conformably. Eutaxitic textures are locally well developed and some units contain lithic fragments.

Separated from these units by large bodies of granitic rocks is a sequence of sedimentary and tuffaceous rocks (unit 8) that occur just west of the Wopmay Fault. These rocks are correlated with similar rocks that form the youngest formation of the supracrustal rocks of the Great Bear Batholith in Sloan River area to the north (Hoffman and Cecile, 1974) and with similar rocks along Wopmay Fault in the south part of Calder River area (McGlynn, 1974). The sequence, where mapped this past summer, consists of a sedimentary unit with several bands of welded, locally eutaxitic rhyodacite to quartz latite ash flow tuffs that are rich in feldspar fragments. The tuffs appear to be low in the sequence and thin out laterally in all directions. The sediments comprise laminated mudstones, thinly bedded mudstone units, siltstone units, turbidite units and rather thick (up to 6 feet) fine-grained massive laminated sandstones. The sandstone units occur in the upper part of the sequence. A distinctive porphyritic rock (unit 9) characterized by large fractured round phenocrysts (up to 2 inches in diameter) of potash feldspar intrudes the sediments as dykes and possibly sills. They are locally associated with an ash flow tuff of similar composition, suggesting that the tuffs and intrusions are co-magmatic.

The supracrustal rocks in the western part of the area strike westerly to northwesterly and dip moderately (10-30^{o}) to the northeast or north. Local dip reversals to the south are caused by gentle folding about northwesterly axes. The strata along the Wopmay Fault are more intensely folded about axes that strike northward. These rocks have a strong cleavage that, in the mudstones particularly, all but destroys evidence of bedding.

All of these rocks are cut by granitic intrusions (unit 10) of the Great Bear Batholith. No basement to the supracrustal rocks was found. Narrow metamorphic zones surround these granitic rocks, but the regional grade of metamorphism in the volcanic and sedimentary rocks is probably low greenschist. Along the margins of some granitic intrusions the supracrustal rocks are tilted at steeper angles. In places, however, the older rocks retain their gentle dips, suggesting that some of the granitic rocks may intrude as sheet-like masses. The granitic rocks are massive, even grained or porphyritic and range in composition from granodiorite to quartz monzonite to granite.

Both granitic and volcanic and sedimentary rocks are cut by dykes, sills and stocks of acidic porphyry (unit 10). The rock is salmon pink in colour and contains rectangular phenocrysts of alkali feldspar that vary in length from 1/8 to 2 inches. Locally dyke swarms of these rocks occur and mappable masses are found southwest of Breadner Lake.

All rocks in the Great Bear Batholith are cut by northeast striking, steeply dipping, right lateral faults which die out before they reach the Wopmay Fault. Quartz stockworks or "giant quartz veins" occur locally along these fault zones.

Most mineral deposits that have been found in the area are copper or silver showings, and they are most abundant in the western part of the area around Clut and Balachey lakes and the Camsell River. These occur, therefore, in the lowest unit that contains sediments and andesite flows as well as ash flow tuffs. This suggests that the mineralization may relate in part to the extrusion of the flows and possibly to the mixing of volcanic gases and sea water to give exhalite deposits. In the same area, these are large irregularly shaped zones of peculiarly altered supracrustals and granitic rocks. The alteration seems to be a very low temperature type giving an almost saprolitic aspect to the rocks. This alteration may result from action of groundwater circulating under younger and since-eroded cover rocks. Such activity may be effective in concentrating ore minerals in the rocks.

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GEOLOGY OF THE FOXE FOLD BELT, BAFFIN ISLAND, DISTRICT OF FRANKLIN

Project 740020

W.C. Morgan, J. Bourne, R.K. Herd, J.W. Pickett[1] and C.R. Tippett[2]
Regional and Economic Geology Division

The 1974 field season was the first of a four year project to study and map the Foxe Fold Belt, Baffin Island (37 A, D; 27 B, C; parts of 37 C and 27 A), for publication on a scale of 1: 250,000 with local areas at 1: 50,000. The area, part of that mapped during the 1968 and 1970 phases of the helicopter reconnaissance of Baffin Island (Jackson, 1969, 1971), consists of Precambrian rocks that lie within Churchill Structural Province. The fold belt is composed of the Aphebian Piling Group (Jackson and Taylor, 1972), that is underlain to the north by a basement of Archean granitoid gneisses and migmatites, and intruded, chiefly in the south, by granitic plutons. Three months fieldwork using helicopter and foot traversing was carried out in 1974 on the west coast of central Baffin Island, between latitudes 68°N and 70°N, to map a cross-section of the east-trending fold belt. Parts of Foley Island (37 A) and Lake Gillian (37 D) map-areas were mapped at 1: 250,000 scale, and the east part of the Koch Island sheet (37 C) was mapped to study rocks of the Mary River Group within the Committee Fold Belt (Jackson and Taylor, 1972), for comparative structural and stratigraphic purposes. Mapping at 1: 50,000 scale was also undertaken, chiefly in the Flint Lake region (37 D/3 north half; 37 D/6 south half; parts of 37 D/2, D/7) where the succession of miogeosynclinal rocks near the north margin of the Piling Group is not affected by complex structures. Paleozoic bedrock on the Baird Peninsula and on islands in Foxe Basin was not examined.

Basement Rocks

The basement rock are well exposed north of the Piling Group (37 D) and underlie that group and the Mary River Group (37 C, D). They are not present south of the Piling Group (37 A) in the study area. Leucocratic grey to pink granitoid rocks that contain a very weakly defined mineral foliation and range in composition from quartz monzonite to granodiorite are characteristic, and particularly homogeneous rocks are common in a 10- to 15-mile-wide zone north of the Piling Group. Well-banded granitoid gneisses, amphibolite, migmatite, agmatite, megacrystic granodioritic gneisses with potash feldspar megacrysts, and strongly lineated augen-gneiss are also present. North-northeast-trending amphibolite dykes up to 200 feet thick cut across the regional foliation in places. Metamorphosed ultramafic intrusions are rare. Basement rocks are chiefly metamorphosed to amphibolite facies but granulite facies rocks characterized by presence of hypersthene occur north of Grant-Suttie Bay.

Mary River Group

Mary River Group rocks outcrop as two northeast-trending zones in the northern part of the map-area (37 C, D) and also underlie islands in Grant-Suttie Bay. The main zone, which outcrops between Grant-Suttie Bay and Eqe Bay, is 9 miles wide and can be traced northeast for over 40 miles. This zone is divisible into two lithological sequences:

1. Metagreywackes and slates.
2. Metavolcanics with iron-formation.

The lower sequence of metagreywackes and slates forms a thinly bedded, several thousand foot thick sequence of turbidites that are rich in volcanoclastics. They contain at least one agglomerate horizon with blocks of dacite, locally welded together, and several tuffaceous horizons. Graded beds and ripple drift cross-laminations are present in the metagreywackes, while the slates are commonly laminated. One small diatreme breccia was observed. Thin amphibolite sills and dykes occur throughout the sequence. A few thin horizons of silicate-oxide facies iron-formation are located towards the southern contact near Eqe Bay.

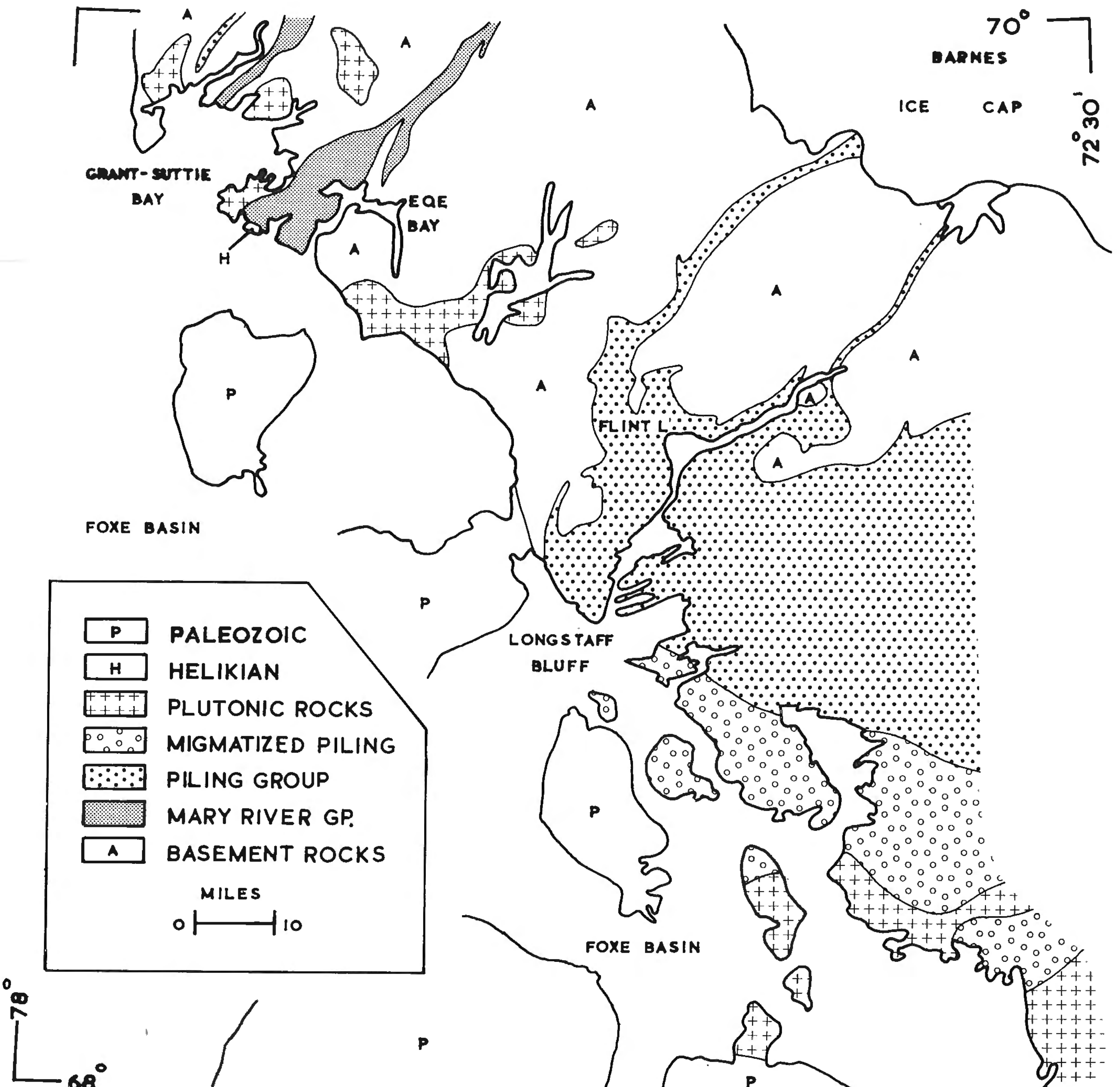
The metavolcanic sequence outcrops to the northwest of the metagreywackes and appears to be dominantly basaltic, although dacitic and rhyolitic flows and pyroclastics are also present. Horizons containing pillows, amygdules, tuff, agglomerate, phenocrysts and flow structures are well preserved. Bands of oxide, silicate-oxide and silicate facies iron-formation and sheets of metamorphosed ultramafic rocks are present at different positions in the sequence. A single thin conglomerate horizon containing highly deformed pebble and cobble sized clasts occurs within the metavolcanic sequence. The northern margin of the belt is locally bounded by a thick sill of metamorphosed gabbroic anorthosite that is foliated, layered, contains relict igneous textures, and is cut by numerous thin, folded metabasic dykes and sills.

Metamorphic grade in this zone is chiefly of greenschist facies between Grant-Suttie Bay and Eqe Bay, but increases to the southeast where garnet, staurolite and kyanite are found. Local quartz segregation veins with tourmaline, beryl, muscovite, andalusite and pyrrhotite cut garnet-staurolite schists at Eqe Bay. The grade also increases as this zone is traced northeast from the Grant-Suttie Bay area. Metavolcanics to the northeast are represented by amphibolites and metasediments by paragneisses.

The second zone of Mary River Group rocks, located south of Isortoq Fiord, is thinner, is of higher

[1] Department of Geology, Memorial University, St. John's Newfoundland.

[2] Department of Geology, Carleton University, Ottawa Ontario.



metamorphic grade, and contains a conspicuous body of quartzite.

Piling Group

This group has been subdivided into two lithological sequences:

1. Quartzite-marble-schist sequence.
2. Metagreywackes and slates.

The lower quartzite-marble-schist sequence occurs along the northern margin of the east-trending Piling Group (37 D) and wraps around a series of basement culminations that resemble gneiss domes. In addition the sequence forms several highly deformed northeast-trending attenuated linear zones within basement rocks to the north. Although stratigraphic correlation throughout the area is difficult the general succession that overlies the granitoid gniesses consists of five main units: basal quartzite, muscovite schist, calc-silicate gneisses, marble, and rusty schists at the top. The quartzite may be white massive orthoquartzite or may be impure and grey or black. Bedded or laminated quartzite associated with mica schist and paragneiss can also occur at different horizons throughout the succession. The muscovite schist is commonly migmatitic, or contains pegmatitic segregation veins, and locally has paragneiss and quartzite interbands. The calc-silicate gneisses range from massive to varieties interbanded with marble or pelite. Included in the marble unit are light buff dolomitic rocks with minor amounts or layers of calc-silicate minerals, and grey, white or orange calcite marbles with interbands of different rock types. The uppermost unit in the succession, the rusty weathering graphitic schist and paragneiss, contains variable amounts of pyrite and pyrrhotite and in places forms distinctive beds of sulphide facies iron-formation. Thin beds of magnetite-rich silicate-oxide facies iron-formation are present within the sequence, particularly in the lower two units and have also been observed within marble.

A monotonous, thick, well-bedded succession of metagreywackes and slates overlies the quartzite-marble-schist sequence to the south (37 A, D). Although individual greywacke beds are commonly graded, other primary structures such as crossbeds, ripple-drift cross-laminations and scours are rare. A few beds of quartzite, meta-arkose, carbonate rocks, calc silicate rocks, tuffs and sulphide facies iron-formation occur throughout the sequence. Altered basic metavolcanic rocks and amphibolite with carbonate-filled vesicles and pillow structures are present near the southern limit of the non-migmatized metagreywacke-slate sequence (37 A). Sheet-like bodies of layered metamorphosed ultramafic rocks underlie an extensive area near the mouth of Straits Bay and on South Tweedsmuir Island (37 A).

Conformable and cross-cutting sheets of white or pinkish pegmatite and granite are found in most lithological units within the Piling Group. These granitic rocks may contain tourmaline, garnet and beryl. Although they are most common in the north and south of the group they are also present in a northwest-trending zone along the coast. The granite pegmatite is locally foliated, boudinaged or folded, tends to be concentrated in fold cores, and represents a late syntectonic phase of intrusion.

Deformation is variable within the Piling Group. The central part of the metagreywacke-slate sequence is structurally simple and is dominated by tight to isoclinal upright and overturned doubly plunging east-trending folds. Strongly overturned folds are present to the south of this zone. Macroscopic interference fold patterns occur in the migmatized metagreywacke-slate sequence on the south side of the Foxe Fold Belt as well as in the quartzite-marble-schist sequence that is interfolded with basement granitoid gneisses on the northern margin of the belt. An early phase of recumbent isoclinal folding in the north is considered to be related to thrusting that caused interleaving of lithologic units and local transportation of basement gneisses over supracrustal rocks. The majority of the mesoscopic intrafolial folds that occur in this area probably developed at this stage. Later polyphase deformation resulted in the present interference fold patterns and development of gneiss dome-like structures.

Metamorphic grade is low in the central part of the metagreywacke-slate sequence and appears to be largely of greenschist or low amphibolite facies. The grade of metamorphism increases both north and south and pelitic bands in the metagreywacke sequence locally have poeciloblasts of andalusite, staurolite and cordierite. Some quartz segregation veins contain large crystals of pink andalusite. Garnet is rare in these rocks but has been noted in the south. Pelitic rocks in the quartzite-marble-schist sequence commonly contain garnet and sillimanite and are highly pegmatized and migmatized adjacent to the basement contact. The calc-silicate and marble units have a varied mineralogy that includes tremolite-actinolite, diopside, forsterite, serpentine, grossular, idocrase, wollastonite, humite, scapolite, sphene, spinel, graphite, phlogopite, quartz, dolomite and calcite.

A thin zone of possible Piling Group miogeosynclinal rocks is located north of Isortoq Fiord (37 C). Bands of marble, calc-silicate gneisses, rusty blastomylonitic graphite-sillimanite-garnet paragneiss, pegmatite and irregular pods of metamorphosed anorthosite occur in this zone.

Plutonic Rocks

Plutons and batholiths of intrusive granitic rocks are common in the basement particularly in the west of the area. Granitic rocks also intrude the Mary River and Piling groups and are very extensive south of the latter. Intrusions in the basement are chiefly medium- to coarse-grained grey to pink, massive to indistinctly foliated, leucocratic quartz monzonite. Granitic intrusions into Mary River Group rocks are well exposed at Grant-Suttie Bay (37 C) where xenoliths of iron-formation and massive specular hematite are enclosed in quartz monzonite. Garnetiferous biotite quartz monzonite and granodiorite with conspicuous megacrysts of potash feldspar are common in an extensive zone of migmatized metagreywackes and slates along the southern margin of the Piling Group (37 D). Garnet, cordierite and sillimanite are abundant in paragneisses in this zone. These foliated plutonic rocks grade into massive bodies with sparse xenoliths and screens south of the migmatite zone. Some of these rocks appear to be charnockitic.

Helikian Metasediments

A small outlier of low-grade metasediments, which are considered by the authors to be of Helikian age, is exposed on the coast of Foxe Basin between Grant-Suttie Bay and Eqe Bay (37 C). This 2 mile by $\frac{1}{2}$ mile outlier, located west of Harbour Bay, was first mapped by Blackadar (1958, 1963) who considered it to be part of the adjacent zone of Mary River Group rocks. These Helikian metasediments overlie metavolcanics of the Mary River Group, and the contact, which is well exposed on the coast, is an angular unconformity. The basal Helikian rocks are considerably altered and could possibly be a sheared regolith. The main rock type in the outlier is a very conspicuous well-bedded, bright pink quartzite that displays graded bedding, trough crossbedding, large scale tabular crossbedding and small erosion channels. Some beds are characterized by small vuggy hematite-rich spots. Pebbly conglomeratic quartzite beds up to 5 feet thick are common and contain clasts of white quartz, opalescent blue-quartz and red jasper. One- to two-foot-thick interbeds of highly cleaved brick red slate and phyllite occur throughout the succession. These rocks resemble some of the Helikian strata that occur north of Pond Inlet (Jackson and Davidson, in press).

Diabase Dykes

Northwest-trending fresh massive diabase dykes that form a part of the Franklin diabase dyke swarm (Fahrig *et al.*, 1971) and which are of Hadrynian age occur throughout the map-area.

Economic Geology

Occurrences of high-grade oxide facies iron-formation containing pure magnetite-hematite bands of variable thickness have been described from Mary River Group rocks in the Grant-Suttie Bay-Eqe Bay area by Blackadar (1958) and Jackson (1969). A 60-foot to 100-foot-thick band of massive pure specular hematite with some magnetite that outcrops on an island in Grant-Suttie Bay (69°45'30"N, 77°22'06"W) was also examined during the present study. This massive zone in iron-formation is associated with basic metavolcanics but is irregularly cut and intensely veined by pink massive medium-grained leucocratic quartz monzonite.

Spectacular gossans are ubiquitous within rusty graphitic schists at the top of the quartzite-marble-schist sequence and in the lower part of the metagreywacke-slate sequence in the northern part of the Piling Group. The gossans develop from sulphide facies iron-formation, form horizons that range in thickness to a maximum of 100 feet, contain pyrite and pyrrhotite either disseminated or forming massive beds, and give fairly strong magnetic anomalies. Minor amounts of chalcopyrite occur locally.

Marble and calc silicate gneisses in the attenuated zones of Piling Group rocks north of Flint Lake locally contain traces of galena (69°20'00"N, 75°10'27"W) and fluorspar (69°17'45"N, 75°01'48"W). The quartzite-marble-schist sequence also contains traces of galena with minor malachite-azurite stain south of Flint Lake (69°09'45"N, 74°05'27"W). Traces of chalcopyrite and minor malachite-azurite stain were observed in pegmatite and metasediments immediately south of the ultramafic rocks on the east coast of Tweedsmuir Island (68°26'48"N, 74°13'24"W). Metavolcanic rocks of the Mary River Group, ½ mile north of the west end of Foxtrot Lake, Grant-Suttie Bay (69°53'20"N, 77°01'25"W), also contain traces of chalcopyrite.

Quartz veins up to 2 feet thick and 20 feet long that contain conspicuous inch-sized massive galena and pyrrhotite cut across the Piling Group metagreywacke-slate sequence east of the airstrip at Longstaff Bluff (68°56'00"N, 76°16'24"W). The veins also contain biotite and muscovite and some have traces of pyrite, sphalerite and chalcopyrite.

A 6-inch-thick mineralized zone of disseminated galena with traces of chalcopyrite and sphalerite is present in Mary River Group rocks on the north shore of Eqe Bay (69°41'30"N, 76°27'30"W). The mineralized zone which occurs in garnet amphibolite has a central 1½-inch core of massive galena and was traced along strike for over 3 feet. Garnet amphibolite horizons at this locality are commonly 2 to 3 feet thick and form boudins 10 feet long. They occur in biotite-garnet-staurolite-kyanite schists and gneisses.

Mary River Group metavolcanics on the coast north of the mouth of Harbour Bay (69°36'06"N, 76°57'54"W) contain noticeable traces of chalcopyrite. A 40-foot-thick zone in these metavolcanics below the Helikian metasediments shows very conspicuous and extensive malachite stained surfaces. Conspicuous malachite stain also occurs on bedding planes and joints in Helikian quartzite on the coast of Foxe Basin about 300 feet north of the unconformity. The stain is present throughout some specimens of the quartzite and was observed on the coast for a distance of approximately 50 feet.

Radioacitivity in a breccia that occurs in an east-southeast-trending fault zone, cutting Piling Group quartzite in close proximity to the contact with the underlying granitoid gneiss basement, was examined with scintillometers. The exposed brecciated zone, which occurs approximately 1 mile north of the north shore of Flint Lake (69°15'30"N, 74°26'15"W), is approximately 5 to 6 feet thick and was traced for a distance of about 60 feet. Fragments of white and grey quartzite and mica schist are enclosed in a vuggy sheared siliceous matrix that is locally feldspathic. In addition to radioactive minerals the breccia contains disseminated pyrite, chalcopyrite and galena. The highest radioactivity measured in the breccia was in a 2-foot-wide zone that locally gave readings of 400 μR/hr. Background radioactivity in the region was in the order of 15 μR/hr. Southeast-trending reddened shear zones and pink pegmatites, common in the granitoid gneiss that underlies the quartzite in this area, have a higher radioactivity than background and locally gave readings up to 110 μR/hr. Although parts of the radioactive breccia contain sub-rounded clasts and resemble a conglomerate, it should be noted that no conglomerate was mapped during the field season at the contact between the basement and Piling Group.

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GEOLOGY OF THE PENRHYN GROUP METAMORPHIC COMPLEX, MELVILLE PENINSULA, DISTRICT OF FRANKLIN

Project 710053

J.E. Reesor, A.N. LeCheminant, J.R. Henderson[1]
Regional and Economic Geology Division

The project was designed to study the Aphebian Penrhyn metamorphic rocks and their geological setting in the southwest end of the belt of Penrhyn Group rocks mapped on the Melville Peninsula by Heywood (1967). The field component of the study has been completed with the area shown in Figure 1 covered for publication on a scale of 1: 250,000. Contributions of the geology have been made by J.R. Henderson, I. Hutcheon and J.E. Reesor in 1973 and by these and A.N. LeCheminant and A. Miller in 1974.

Prince Albert Group (?)

Metavolcanic and metasedimentary rocks tentatively correlated with the Prince Albert Group (Heywood, 1967) occur in close proximity with Penrhyn Group rocks in map-sheets 46 N/3 and N/4. Discontinuous outcrops penetrated by granite and pegmatite are closely associated with granodiorite gneiss, migmatite, and leucocratic biotite-feldspar-quartz gneiss. Some of the gneisses and migmatites contain lenses and layers of fine-grained biotite-quartz-feldspar paragneiss and amphibolite and appear to have been derived, at least in part, from the Prince Albert Group (?) rocks.

Dominant rock types of the Prince Albert Group (?) in this area consist of fine- to medium-biotite-quartz-feldspar paragneiss (medium to dark grey, thin-bedded); amphibolite and hornblende plagioclase gneiss; oxide iron-formation; and minor garnet-biotite and sillimanite-biotite schist. The iron-formation averages 3-4 m wide, is complexly folded, and can rarely be traced more than a few hundred metres along strike. The rock is thinly laminated with alternating layers of quartz and magnetite 1-5 mm thick. In addition to quartz and magnetite the iron-formation commonly contains a coexisting pair of amphiboles (probably cummingtonite-grunerite coexisting with hornblende-actinolite). Minor pyrrhotite, pyrite and rarely chalcopyrite may be present. Typical associated rocks consist of fine-grained amphibolite, hornblende-rich paragneiss and brown-weathering sillimanite-biotite and garnet-biotite schist.

In general the Prince Albert Group (?) rocks are characterized by the presence of amphibolite, hornblende-rich paragneiss, and iron-formation and by the absence of carbonates, calcium silicate gneiss, and graphite-bearing schist and paragneiss, all of which are ubiquitous in the Penrhyn Group. Prince Albert Group (?) rocks are additionally characterized by their intimate association and structural involvement with gneisses considered to be 'basement' to the Penrhyn Group.

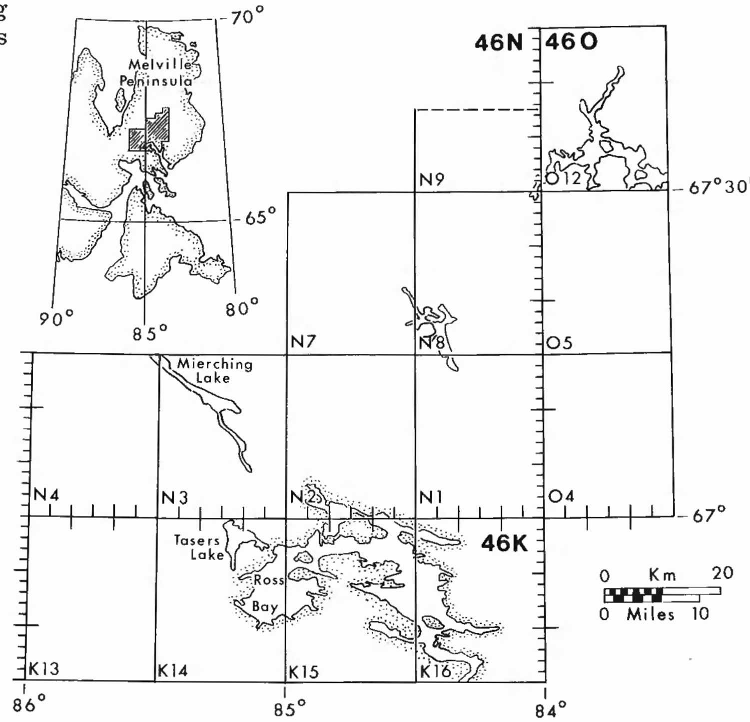

Figure 1. Location of work in 1973 and 1974.

Structures in Prince Albert rocks are obscured by complex invasions of granitoid rocks of several ages. In outcrop, earlier structures and related foliation are re-deformed by upright folds that trend east-northeast with a strongly developed axial plane foliation. There is a strong interference with earlier folds trending at a high angle to this direction. The earlier folding may have had a northerly trend which has been disrupted by the intense east-northeast second folding. A sporadically developed open warping in a northwesterly direction is the latest folding episode recognized.

Granitoid Gneiss (Table 1)

Gneisses of varying composition, texture and structural aspect occur extensively throughout the region mapped. Within the zone of Penrhyn rocks they form lenticular sheet-like bodies as well as elongate domal complexes ranging up to a few kilometres wide and several tens of kilometres in length. In the southwest of the area gneisses form the dominant unit with

[1]Department of Geology,
Grand Valley State College,
Allendale, Michigan 49401.

Table 1

A tentative structural-lithological succession

Era	Succession
Aphebian	Diabase dykes
	Granite, Quartz monzonite, Granite pegmatite
	———— intrusive ————
	Penrhyn Group - orthoquartzite, marble, calcium-silicate gneiss, sillimanite-cordierite-garnet schist, biotite-quartz-feldspar paragneiss (amphibolite facies metamorphism circa 1800 m.y.)
	------------- unconformable? -----------
	Amphibolite dykes (mid-Aphebian?)
	———— intrusive ————
	Gneissic granite, quartz monzonite, pegmatite (2200 m.y. ± ?)
	———— intrusive ————
Archean	Granitoid gneiss - granodiorite gneiss, granite, gneiss, migmatite, augen granite gneiss (2500 m.y. +)
	———— intrusive? ————
	Prince Albert Group (?) - biotite-feldspar-quartz paragneiss, fine-grained, grey to dark grey; garnet-biotite and sillimanite-biotite schist; amphibolite; oxide iron-formation; leucocratic biotite-feldspar-quartz gneiss
	(basement to Prince Albert Group(?) not recognized)

only a few thin infolds of Penrhyn metasediments. In the northwest part of the area gneisses are intimately intermixed with rocks of the Prince Albert Group(?). In map-areas 46 O/12 and O/5 the gneisses occur as lenses or sheets interlayered with Penrhyn metasediments. Preliminary geochronological studies by Rb/Sr and U/Pb methods indicate ages for some of the gneisses in excess of 2500 m.y. Closely associated pink foliated granite and pegmatite, which are almost identical in aspect to granitic rocks intrusive into Penrhyn Group rocks, may be of mid-Aphebian age. Preliminary ages are approximately 2200 m.y.

The gneisses vary in composition from granodiorite to granite and are typically medium- to coarse-grained with irregular foliation and layering. In the northern parts of map-areas 46 N/3, N/4, and N/7 the gneisses are characterized by a cataclastic texture. A distinctive, readily mappable unit of homogeneous augen granite gneiss forms an extensive mass along the north boundary of the map-area. Augen of potash feldspar range up to 5 cm in size and hornblende and/or biotite give the rock a typical colour index of 10-15.

Complex folding of migmatitic zones is well exposed along the shores of Ross Bay and the adjoining parts of Lyon Inlet. Structures trend east-northeast and plunge gently to moderately northeast and southwest. In areas of poor outcrop to the south and west of Ross Bay, gneissic foliation dips in varying directions from outcrop to outcrop implying a continuation of the strong folding noted in areas of continuous outcrop. In northern parts of the map-area steep foliation in the gneisses gives way to moderately to gently northerly dipping foliation and layering. Local zones of intense deformation, each a few kilometres apart, are characterized by steep dips in gneisses that otherwise dip 10-15 degrees northerly. This is particularly evident in map-area 46 N/9.

Amphibolite Dykes

Granitoid gneiss and rocks of the Prince Albert Group(?) in map-areas 46 N/4 and N/7 have been intruded by west-northwest-trending amphibolite dykes. These dykes have not been recognized cutting Penrhyn

Group metasediments. Dykes consist of black, medium grained, weakly foliated amphibolites ranging from 5-50 m wide which have been sheared and boudined into short segments (typically 100-300 m long). One dyke in map-area 46 N/4 has been traced for more than 3 km.

Penrhyn Group

Penrhyn metasediments consist of a contrasted succession of marble, calcium-silicate gneiss, biotite-quartz-feldspar paragneiss, schist, and biotite quartzite (*see* Reesor, 1974, p. 153). In some localities a distinctive orthoquartzite up to 20 m thick forms the basal unit of the succession and in map-area 46 O/5 an amphibolite, presumably derived from a thin basic volcanic flow, forms an important unit just above the basal orthoquartzite.

Primary variations in sedimentary facies are difficult to recognize due to upper amphibolite facies metamorphism combined with intense deformation. There appears to be an increase in the proportion of quartzite associated with marble units in the north-central part of the area (particularly in map-areas 46 N/8 and 46 O/5). Marble units thin to the south with concomitant increase in pelitic units as well as an increase in the pelite content of all units (particularly noticeable in map-areas 46 K/15).

Extensive gossan zones occur in the Penrhyn Group particularly in map-areas 46 N/1, N/2 and N/8. Gossans are developed on highly sheared graphitic schist, fine-grained graphitic quartzite and pegmatite. Pyrite and pyrrhotite are common accessory sulphides which may be associated with minor chalcopyrite and rare sphalerite. Gossan zones vary from one or two metres to 20 metres in width. They are stratigraphically controlled and are best developed near the base of the succession though they may be found at higher stratigraphic horizons.

Granite, Quartz Monzonite, Pegmatite

All units previously described are intruded by varying amounts of late granitoid rocks. Pegmatite and granite of this unit are commonly concentrated in zones of structural complexity and are particularly common cutting both Penrhyn rocks and 'basement' gneisses along the northern contact of the Penrhyn Group in map-areas 46 N/7, N/8 and 46 O/12. Granitoid rocks may make up 70-80 per cent of the outcrop yet within such zones a unit such as a marble horizon can commonly be traced.

Granitoid rocks are characteristically pink weathering with a low colour index (typically 2-5), and highly variable texture ranging from aplitic to coarsely pegmatitic. Intrusive contacts clearly establish that these rocks are younger than the Penrhyn metasediments. Nevertheless there are similar granitoid rocks association with the 'basement' gneisses some of which may be significantly older. Determinations by Rb/Sr and U/pb methods at two localities yield preliminary ages of about 2200 m.y. Discrimination between these two groups of granitoid rocks is extremely difficult. The extent of the older granitoid group is not known and in many instances these rocks have been mapped with the younger granites.

Diabase Dykes

The youngest igneous rocks in the region are brownish weathering west-northwest-trending diabase dykes. They cut all units and are plentiful at some localities and absent in others.

Metamorphism

Metamorphic mineral assemblages throughout the area indicate upper amphibolite facies metamorphism. Pelitic assemblages containing sillimanite-garnet-biotite and cordierite (± potash feldspar) increase in frequency of occurrence and grain size southerly in the map-area. Calcium silicate gneisses commonly contain the following assemblages: calcite-humite group-spinel-graphite; diopside-quartz-scapolite-calcite; diopside-forsterite-calcite; calcite-quartz-diopside. The iron-formation assemblage is typically magnetite-quartz, plus a coexisting pair of amphiboles. Fayalite has been recognized in two occurrences.

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R.H. Ridler
Regional and Economic Geology Division

With contributions by
L.A. Tihor and J.H. Crocket, and J.H. Foster

Introduction

Field work was concentrated in the Matachewan area of northeastern Ontario, between Mistinikon Lake and Highway no. 11 (Fig. 1) from June 10 to September 10. The purpose of the field studies was to extend the known stratigraphy of the Kirkland Lake area to the west and southwest by correlation of major exhalite (Ridler, 1973) zones. In addition, supportative topical studies and reconnaissance examinations were pursued throughout the area of Figure 1. In particular, preliminary paleomagnetic studies, by J.H. Foster of the Geological Survey, to assess the usefulness of the technique as an aid to stratigraphic correlation in a relatively unmetamorphosed Archean volcanic assemblage were pursued in the Kirkland Lake area (*see* following section of this report). R. Wanless of the Geological Survey sampled a variety of Archean plutonic and volcanic rocks for zircons in an attempt to construct a radiometric analogue of the known stratigraphy. L. Tihor, supervised by J. Crocket of McMaster University and the author, began a Geological Survey supported Ph.D study of the distribution of gold in exhalites of the Kirkland - Larder lakes area (*see* following section of this report). The author was more than capably assisted by J. Knowles as the senior assistant and by W. Houston. The author also acknowledges the courtesy and co-operation of the Ontario Division of Mines and Quebec Department of Natural Resources personnel, particularly H. Lovell and E. Dimroth respectively. Specifically, field work this summer was guided and greatly aided by the recent mapping of Lovell (1967, 1972 and Moore, 1966). The author also benefitted from the comments of the many geologists from industry, academe and government who visited our field camp at various times throughout the summer. In this regard Takeo Sato, on sabbatical from the Geological Survey of Japan, was particularly appreciated. Field work comprised location, examination and sampling of exhalite occurrences and reconnaissance examination of areas of critical structural or stratigraphic importance.

Results

Boston Iron-Formation

The Boston Iron-Formation extends with minor interruptions from the type area (Ridler, 1970) to Mistinikon Lake where it disappears beneath extensive Aphebian Cobalt Group cover (Fig. 1). It changes facies from oxide to carbonate at approximately $80^{\circ}30'$ west. In the Matachewan area the typical sub-facies is limestone (with important chloritite) but in the vicinity of the Matachewan Consolidated mine (Fig. 1, loc. A) changes to pyritic green "ferromagnesian dolomite"* similar to the "Larder Lake" type exhalite (Fig. 1).

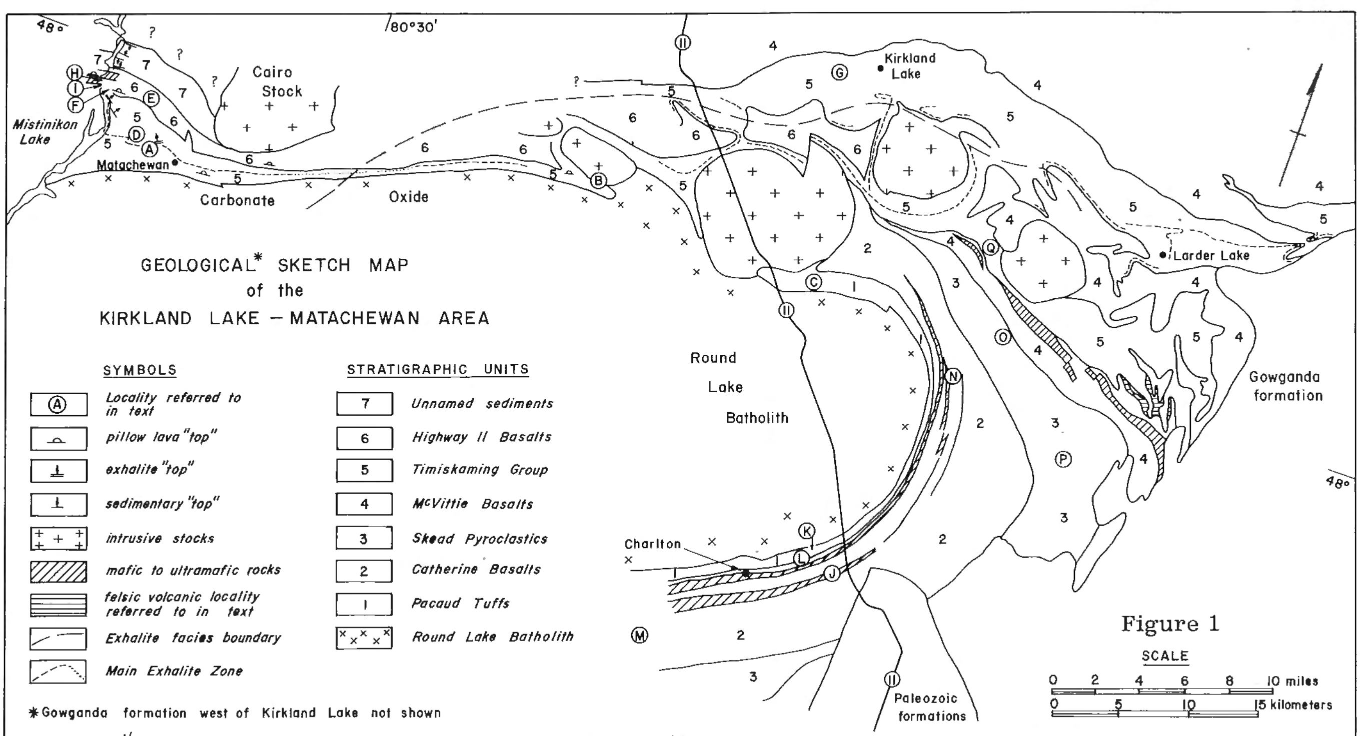

Figure 1

It is clear from Derry's (1948) description of the alteration accompanying the orebody that it is proximal and faces north, away from its feeder zone. Although characteristically unbedded, several localities did display poorly-to-well-developed bedding composed of alternating layers of carbonate and chloritic silicate.

Timiskaming Group

The associated Timiskaming Group is likewise extended into the Matachewan area from Kirkland Lake (Fig. 1). Between the two camps the group is composed predominantly of a relatively thin (5,000-7,000 feet) assemblage of laminated mafic to intermediate fine-grained tuffs, banded oxide exhalite (the Boston Iron-Formation), and minor pillowed and massive lava flows; an apparently distal assemblage. The group overlies the Round Lake Batholith disconformably but both the margin of the batholith and locally the lower portions of the Timiskaming Group are mildly to moderately mylonitized. The recognition of a boulder of, apparently, the Round Lake Batholith in Timiskaming conglomerate at Kirkland Lake is consistent with the interpretation of the batholith as basement (Ridler, 1972). In addition, massive "post-tectonic" medium-grained granite (sensu-stricto) was observed cutting the Round Lake Batholith and the adjacent greenstone at localities B and C (Fig. 1). The tendency to lump such disparate rocks in standard maps has obscured the true relations. The intensity of deformation and metamorphism increases in the sliver of greenstone between the Watabeag Lake Batholith (not shown on Fig. 1), Cairo Stock and Round Lake Batholith but otherwise is moderate.

In the Matachewan area the Timiskaming Group comprises a thick sequence (minimum 10,000 feet) of north-facing mafic to felsic tuffs and carbonate exhalite overlain by felsic to alkaline tuffs and breccia and derived very immature arkosic grits and conglomerate. This sequence is intruded by apparently consanguinous high level quartz and feldspar porphyries. The porphyries may be auriferous, e.g. the Young-Davidson Mines (Fig. 1, loc. D) or bear copper and molybdenum, e.g. the Ryan Lake Mine (Fig. 1, loc. E). Although no exhalite is known or was found in this upper Timiskaming sequence, stratiform zones of pyritic volcanics were noted and a pyritic gossan associated with very felsic tuffs (rhyolitic) at the summit of the group and immediately overlain by mafic lavas of the Highway no. 11 group, was noted at Mistinikon Lake (Fig. 1). The Timiskaming assemblage in the Matachewan area is proximal, constituting a significant intermediate to the felsic volcanic centre.

Examination of the new road-cut on Ontario Highway no. 66 at Chaput Hughes (Fig. 1, loc. G) revealed very thin pyrrhotite-rich laminae (which weather black) within several sandstone lenses in a conglomerate. Such laminae were parallel to normal bedding and locally parallel to delicate crossbedding. As with the normal sedimentary laminations the pyrrhotite-rich laminae were occasionally truncated by small-scale scours. These relations suggest a detrital origin for the pyrrhotite in a low Eh environment. Neither the pyrrhotite-rich sands nor the conglomerate are anomalously radioactive.

Highway no. 11 Group

The Highway no. 11 Basalts which conformably overlie the Timiskaming Group are also extended into the Matachewan area as can best be seen by removing the apparent offsets along the Montreal River Fault set at Matachewan. They are characterized by about 5,000 feet of north-facing massive and pillowed mafic to ultramafic lavas (spinifex texture, locality Fig. 1, loc. H) and sills with typical rugged magnetic relief and constitute an excellent gross marker horizon. A distinctive ultramafic zone about 1,500 feet thick outcrops on either side of Mistinikon Lake and is probably extensive along strike (Fig. 1). An interflow graphitic slate with pyrite concretions occurs at locality Fig. 1). A relatively thin zone of apparently more intermediate, crudely pillowed lava occurs at the top.

Post Highway no. 11 group sediments

The Highway no 11 basalts are abruptly but conformably overlain by an as yet unnamed distal group of well-bedded, relatively undeformed turbidites which may attain 2,000 to 3,000 feet in thickness. Primary sedimentary structures such as grain gradation and scouring are abundant and leave little doubt that the group occupies a structural trough with a central anticline. Pillow "tops" in the mafic lava sequence to the north consistently face northeast suggesting a pronounced angular unconformity at the base of the group on the north limb of the structure. The lithology and structural relations of this sedimentary group are identical to those of analogous groups classified as "Timiskaming" elsewhere but it appears likely that the group is younger than the Timiskaming Group of the Kirkland Lake area, if it is not diachronous and (barring major) faulting and therefore, is among the stratigraphically youngest groups in the Abitibi Belt.

Structure of the Matachewan area

The structure of the Matachewan area, principally as it affects the Timiskaming Group and its contained exhalites, has been known for some time, to be very complex, even polyphase (Derry *et al.*, 1948). Early, principally east-west folding has created a pronounced, dominantly chloritic foliation, generally parallel to bedding. The early folds have been refolded and plunge south to southwest. The younger deformation post-dates the high level porphyries and has produced an axial planar fracture cleavage which locally is very

*Usually various fine-grained mixtures of phyllosilicates, chert and the carbonate species dolomite and/or ankerite ± magnesite ± siderite.

intense in the supracrustal rocks. The geometric sense of the folding is Z (Fig. 1). The geometry of the pyritic, auriferous carbonate exhalite at the Matachewan Consolidated Mine has been profoundly, and from a mining point of view, probably adversely affected by this intense deformation. This zone of polyphase deformation is a probable extension of the Timiskaming mobile belt of the Kirkland Lake, Larder Lake, Cadillac areas (Ridler, 1970).

Skead Group

The Skead Group, comprising the Pacaud Tuffs, Catharine Basalts and Skead Pyroclastics, is clearly extensive into the Charlton area (Fig. 1). Of particular note is a basal zone several thousand feet thick within the Catharine Basalts which possesses gabbroic and ultramafic rocks. These are documented elsewhere, (Lawton, 1957; Grant, 1963; Moorehouse, 1944) but in addition a very fresh exposure of serpentinized peridotite within this unit, has been unearthed in a new rock-cut on Highway no. 560 (Fig. 1, loc. J). Textures similar to but probably not spinifex are exposed in very mafic rocks immediately adjacent to this outcrop on the south side of the road. This unnamed gabbro-ultramafic zone within the Catharine Basalts may contain some ultramafic flow members. At Charlton the exposed part of the zone consists of two phase layered sequences (peridotite overlain by pyroxenitic gabbro), overlain by gabbro "topping" to the southeast consistently with the enclosing pillow lava.

A variety of exhalite and exhalative-related phenomena have been observed at diverse stratigraphic levels within the Skead Group. The most persistent zone occurs a few tens of feet above the basement (Round Lake Batholith) in the Pacaud Tuffs. It is a relatively thin (always less than 2 feet), predominantly-banded sulphide facies (pyrite, pyrrhotite, tr. chalcopyrite) with chert and cherty tuffs and local oxide facies (magnetite/chert). An additional occurrence of apparently the same zone occurs at locality K in Figure 1 (Moorehouse, 1944), significantly extending the zone to the southwest and confirming the essential conformity of the east end of the Round Lake Batholithic basement with the overlying Pacaud Tuffs.

A stratiform zone of "Larder Lake type" pyritic carbonate facies with minor gold occurs at locality L (Fig. 1) (Moorehouse, 1944). It lacks regional extent and is associated with basal tholeiites of the Catharine Basalts. The underlying massive flows are noticeably carbonatized while the overlying ones are less so. Moorehouse (1944) also described a thin "banded iron-formation" (essentially an interflow oxide exhalite) in the Catharine Basalts at locality M (Fig. 1), but at other localities (e.g. Fig. 1, loc. N) laminated pyritic chert and/or carbonate, with a little chalcopyrite are common.

Elsewhere in the group, particularly in the Skead Pyroclastics, are stratiform pyritic zones with associated specularite, magnetite, carbonate, chalcopyrite, gold and chlorite (e.g. Cathroy Larder Mine (Fig. 1, loc. O), New Telluride mine (Fig. 1, loc. P)). These may be in part exhalite or their associated "feeder" systems, or may be endogenous. As yet no single, regionally developed "main" exhalite zone has been recognized within the Skead Pyroclastics, although the available evidence from this formation suggests that the exhalite facies was sulphide.

McVittie Basalts

The McVittie Basalts Formation (Ridler, 1972, 1970) possesses, in addition to the predominant basaltic flows, a complex and extensive mafic to ultramafic zone and an associated small mass of felsic volcanic breccia. These occur subjacent to the basal unconformity of the Timiskaming Group (Fig. 1). The breccia can be fairly coarse and locally contains fragments of sulphide and a bright green micaceous rock in addition to the characteristic quartz-feldspar porphyry fragments. The overlying basal conglomerate of the Timiskaming Group contains cobbles and boulders clearly derived from both the felsic breccia and ultramafic rocks. At one locality (Fig. 1, loc. Q), (pers. comm., R. Hyde) zones of ultramafic cobbles have individuals possessing excellent spinifex texture. The above association of ultramafic and felsic volcanic rocks is reminiscent of the geology of the Munro Township area (Pyke *et al.*, 1973).

GOLD DISTRIBUTION AND GAMMA-RAY SPECTROMETRY IN THE KIRKLAND LAKE — LARDER LAKE GOLD CAMP

by

L.A. Tihor and J.H. Crocket[1]

During the summer of 1974 rock samples and gamma-ray spectrometric readings were taken from the major rock units of the Kirkland Lake — Larder Lake area. This work was carried out as part of the Ph.D thesis research of one of the writers (Tihor), with the financial support and supervision (Ridler) of the Geological Survey of Canada.

The project has two main goals:

1. to study the distribution of gold and other trace elements in rocks both adjacent to and away from major gold deposits. This will provide background values as well as delineate possible enrichment or depletion haloes around known gold occurrences;

2. to determine if the ground gamma-ray spectrometer is useful as a geophysical exploration tool in the search for exposed and/or blind gold deposits.

Chemical analyses for gold will be carried out during the winter by means of neutron activation analysis and for other elements by X-ray fluorescence. U, Th, K and Th/U determined for these rocks from the summer of 1974 field season are shown in Table 1.

[1] McMaster University.

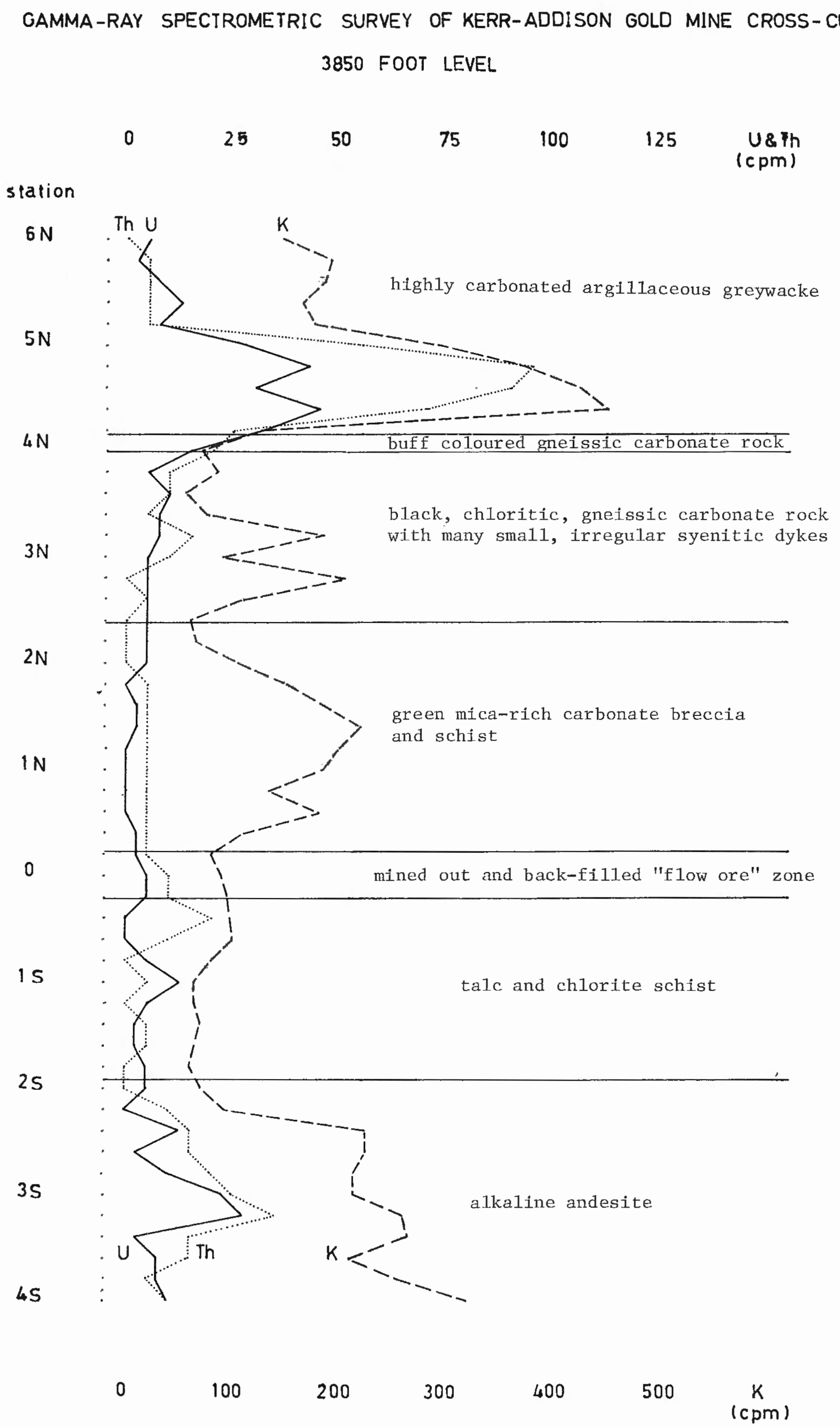

Figure 2

Stations numbered are 30.5 metres (100 feet) apart.
Readings were taken at 6.1 metre (20 foot) intervals.

Table 1

U, Th, K, and Th/U for rocks of the study area

	n	Th/U	U (ppm)	Th (ppm)	K (%)	
Otto Stock	4	7.48	2.60	19.44	4.65	$\bar{x}$
			0.97	5.31	0.70	σ
felsic syenitic rocks (excluding Otto stock)	6	2.00	2.56	5.12	2.49	
			1.20	1.42	0.44	
mafic syenitic rocks	5	3.55	2.14	7.59	3.75	
			0.68	1.60	1.17	
Timiskaming tuff-argillite	4	3.42	9.58	32.72	3.58	
			2.99	12.53	0.50	
Timiskaming conglomerate B	3	4.13	1.72	7.10	1.79	
			0.49	1.36	0.25	
carbonate rocks	32	2.26	0.19	0.43	0.68	
			0.26	0.56	0.71	
Timiskaming alkaline andesites	38	2.70	0.23	0.62	0.37	
			0.29	0.80	0.30	
Timiskaming greywacke	24	3.97	1.01	4.01	1.67	
			0.62	2.16	0.60	
Timiskaming conglomerate A	4	----	0.00	0.31	0.50	
			0.00	0.00	0.27	
Timiskaming trachyte B	6	4.31	6.33	27.28	5.04	
			4.06	8.15	2.53	
Timiskaming trachyte A	12	3.84	1.82	6.98	2.13	
			0.45	1.91	0.47	
------unconformity------						
gabbroic sill	1	----	0.00	0.31	1.11	
peridotite	1	----	0.00	0.00	0.15	
McVittie basalt	1	2.91	0.32	0.93	1.85	
Blake River Group volcanics	9	6.17	0.06	0.37	0.24	
			0.10	0.31	0.21	
Skead pyroclastics	2	2.47	0.75	1.85	1.23	
			0.26	0.31	0.68	
Catharine basalts	9	3.06	0.16	0.49	0.38	
			0.26	0.31	0.22	
Round Lake Batholith	2	3.32	0.65	2.16	1.35	
			0.49	0.62	0.22	

Underground traverses were made on the 3,850 and 1,900-foot levels at the Kerr-Addison gold mine at Virginiatown. The gamma-ray spectrometer profiles for the 3,850-foot level are very interesting in that each rock unit appears to have a unique radiometric "fingerprint" (Fig. 2).

Detailed surface surveys were run across ore grade pillars at Kerr-Addison and at the Cheminis mine, as well as across barren rocks down strike from the ore zones. Readings were also taken adjacent to exposed ore faces underground at Kerr-Addison.

Preliminary mine data strongly suggest a positive correlation between gold and both potassium and uranium but, a negative correlation between gold and thorium. Laboratory determinations of gold and further field radiometric surveying will be undertaken to substantiate these tentative conclusions and to further evaluate the use of the gamma-ray spectrometer as a prospecting tool for economically-interesting gold deposits.

PALEOMAGNETISM OF THE SKEAD GROUP, KIRKLAND LAKE AREA, ONTARIO

by

J.H. Foster[1]

As a feasibility study, 100 of Ridler's unoriented hand specimens of relatively unmetamorphosed volcanic rocks from the Skead Group (Ridler, 1972) were cored and sawn into cylindrical specimens prior to the field season. Each specimen was assigned an arbitrary top and azimuthal reference. Each specimen was then subjected to a 12-step partial alternating field demagnetization to a maximum of 1000 oersteds. On the basis of 5 plots (stability index vs. demagnetization field, normalized intensity vs. demagnetization field, normalized north vs. east, normalized north vs. vertical, and equal area projection of the remanent vector) each specimen was rated for paleomagnetic suitability. Several were rated excellent.

On the basis of these favourable data, cores at 22 sites (6 cores per site) were drilled early in the 1974 field season as a pilot study. Each core was oriented with an astro compass. Each site was identical to the location from which the original stable unoriented block specimen had been collected. This meant that chemical analyses, thin sections and structural data were available for each of the sampling sites (Ridler, unpubl. data).

Each core was cut into two specimens. One specimen per core was taken through 12 steps of partical demagnetization to a maximum of 2,800 oersteds. A second specimen from each core was taken through 3 steps of partial thermal demagnetization. Again, based on five plots per specimen, each site was assigned a range of optimum demagnetization treatment. Cluster statistics were done for each demagnetization step within that range for each specimen. At the site mean level, with N = 6, 12 of the 22 sites showed a radius of the 95% cone of confidence (α 95) of less than 15°, with 7 of these 12 having an α 95 of less than 5°. Remanent magnetization in an apparent polarity normal-reverse-normal stratigraphic sequence was discovered.

The section of the Skead Group that appears most promising for follow-up paleomagnetic work is the Skead Pyroclastics. Additional sampling along strike and on other folds is in progress and planned for next field season to establish whether the stable components of magnetization are primary, or the products of later,

[1]Regional and Economic Geology Division.

post-folding thermal events. A second goal of a further sampling program will be to delineate more closely the boundaries between the apparent reversals in the stratigraphic sequence.

If the evidence for such a sequence is strengthened by additional data from the test area, we would have a powerful tool for regional correlation within the Skead Group. In addition, further search for useful paleomagnetic data in younger Archean formations would be justified.

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94. VOLCANOGENIC ROCKS OF THE PRINCE ALBERT GROUP, MELVILLE PENINSULA (47 A-D), DISTRICT OF FRANKLIN

Project 720062

Mikkel Schau
Regional and Economic Geology Division

Mapping volcanogenic rocks of the Prince Albert Group continued this year (Schau, 1973, 1974) along the east coast of Melville Peninsula (47A and D) in an effort to determine the nature and location of volcanic centres and their place within the stratigraphic section and the nature of subsequent deformation affecting the Prince Albert Group in belts recently outlined by Heywood (1967, 1974). J. Maley, L. deBie, A. Béland, K. Arthur and Y. Michie ably assisted the operation, aided on a half time basis by a G47A Bell helicopter piloted by E. Beaumont and serviced by E. Godleski. Base camp, on the Kingora River, approximately 40 miles west of the small community of Hall Beach, in the District of Franklin, was occupied between June 27 and August 21, 1974.

The results of most interest include the finding of more magnetite-bearing iron-formations similar to those previously reported (Heywood, 1967; Wilson and Underhill, 1971). The establishment of a partial section in the Prince Albert Group, the finding of thin ultramafic dykes and sills of the same type as found last year (Schau, 1974), the presence of very coarse grained metre-thick anorthosite layers in a widespread gabbro, the locating of several acid volcanic centres, and the recognition of thick mafic flows above felsic volcanics, constitute the important geological results.

The rocks of the Prince Albert Group are thought to rest upon a basement of diverse character, but nowhere was the unconformity seen. A variety of lithologies are present, ranging from calc-silicate layers to poorly-foliated granite gneisses, but most common is a grey well-layered gneiss. The presence of different structures within th gneiss include large, gently dipping recumbent structures not seen in the nearby steeply-dipping Prince Albert Group. In some instances, undeformed ultramafic dykes cut the gneiss. These dykes are seen in gneisses known to be old in the Hayes River region, and as well, are taken to indicate the extreme age of the enclosing gneisses.

Prince Albert Group

Sinuous belts of the "Archean" Prince Albert Group strike in a northeast direction towards Roche Bay where they swing northward to go along the west shore of Hall Lake. The belts are steeply dipping. In the south, beds and structures are considerably flattened so that primary structures are absent. To the north, however, a few structures, especially pillows, are discernible. Iron-formations are more important to the south, and although all relations are not fully understood in these areas it appears that quartzitic rocks and acid volcanogenic rocks underlie the mafic volcanic rocks.

At the extreme north of Melville Peninsula, on the south shore of Fury-Hecla Strait, a partial section about 6 km thick of the Prince Albert Group is preserved. These rocks have been described by Blackadar (1963) who noted that pillow structures are common here. Acid recrystallized volcanogenic rocks constitute the bottom third of the section. These are overlain by oxide facies iron-formation, quartzites, and quartzose breccias which are in turn overlain by "andesitic" flows, breccias and tuffs, and "topped" by oxide facies iron-formation. Basaltic pillowed and massive flows capped by a quartz-rich breccia-conglomerate overlie the "andesites". At the top of the section is a 1 km thick set of trough-crossbedded immature grits and sandstones in which are thick local flows (?) of basalt. These flows (?) within the grit unit are peculiar in that they consist of a sheared tuffaceous and fragmental base, above which is a layer of very magnesian material, usually a talc and chlorite schist, overlain by medium-grained gabbro, which may be fractured into metre size blocks. These coarse-grained rocks are overlain by true pillowed basalts and a sheared tuffaceous top. The flows (?) vary in thickness from several hundred metres where the complete series is developed, to thin layers of chlorite schist only a few metres thick. Flattened intercalations of medium-grained and fine-grained greenschist and amphibolites are seen north of Hall Lake. Here the sequence is also interpreted to be in the core of a south-plunging syncline.

Felsic volcanic centres were found in the Bouverie Islands (UTME 445000, UTMN 7725000)[1] and near the south end of Hall Lake (UTME 435000, UTMN 760500) with associated iron-formations of oxide facies. Fragmental rocks of the Prince Albert Group in the latter area include breccias with fiamme structures now represented by biotite-rich shapes. These indicate that some of the felsic volcanic units were subaerial, whereas the presence of pillows suggest some of the mafic volcanism was subaqueous. Within the Prince Albert Group, under the mafic rocks near the north end of Hall Lake, is a breccia-conglomerate with dark volcanic clasts and clasts of medium-grained granodiorite. In thin section the plutonic rock appears to have been severely crushed and mineralogically retrograded in comparison to the non-crushed appearance of the dacite. This is indirect evidence for the plutonic basement.

In summary, a mixture of quartzite and other clastic sediments, iron-formation, felsic volcanic rocks and basic to ultrabasic volcanic rocks make up the Prince Albert Group.

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[1] All localities within text are all in UTM zone 17W.

Ultramafic layers are locally abundant as chocolate brown to green, thinly layered, ultramafic sheets, described previously (Schau, 1973, 1974; Schau and Campbell, 1974; Schau, this publication, report 95; Eckstrand, this publication, report 76; Frisch, and Goulet, this publication, report 87). In most localities they are sheared and contain local breccia zones. Along the south shore of Fury and Hecla Strait ultramafic units are clearly intrusive as shown by a folded iron-formation of oxide facies complexly intruded and in part assimilated by an ultramafic sill and dyke complex. East of this locality, along the shore thin ultramafic sheets cut more gently dipping quartzite-rich breccia-conglomerates. Elsewhere, ultramafic sheets seem to be part of the basic flows of the Prince Albert Group previously described. In the south, ultramafic units emplaced in "old" gneiss are more massive than their sheared counterparts in the Prince Albert Group. Ultrabasic magmas are interpreted as being emplaced both as flows and as dykes and sills in the Prince Albert Group rocks; they must represent a late igneous phase in the depositional history of the Prince Albert Group.

Gabbro is widespread. On the east coast of Melville Peninsula the gabbro is characterized by large euhedral to rounded plagioclase phenocrysts which may on occasion form layers up to a few metres thick that extend for many hundreds of metres. The phenocrysts decrease in abundance towards the south. They are an easily distinguishable lithology, even in migmatite terrane or in sheared metagabbro units. Because of subsequent deformation the original shape of the gabbro body is not known although it would appear from the parallel orientation of anorthosite layers and bedding that the gabbro was introduced as sills in the still relatively flat-lying Prince Albert Group. One thin lava flow in the Bouverie Islands contains abundant plagioclase phenocrysts of the same aspects as those in the intrusive gabbros suggesting the coeval emplacement of gabbro and the mafic volcanic units.

Although the gabbro and some ultramafic sheets are clearly intrusive, it is thought that they were emplaced during the latter part of the deposition of the Prince Albert Group.

Granitic rocks are very abundant in the region. The western border of the Prince Albert Group near Hall Lake is intruded by a massive medium-grained characteristically porphyritic granite to granodiorite which nearly everywhere separates the gneisses from the Prince Albert Group. It cuts across structures in the Prince Albert Group, especially north of Hall Lake and includes parallel, closely-spaced roof pendants, as well as stoped blocks of recognizable Prince Albert Group or mafic intrusives. Locally, migmatite and gneiss grades into the granitic rock. To the southwest of Roche Bay, this unit is foliated and locally crushed along northeast-trending, steeply-dipping surfaces. In this region gneisses and gneissic granitic rocks are difficult to distinguish.

Metamorphosed diabase dykes which traverse both Prince Albert Group and granitic rocks, are faulted and folded in events thought to be associated with the deformation of the Penrhyn to the south.

Feldspathized zones to small local pods of medium-grained miarolytic granite, cement faults and intrude all units except fresh diabase dykes throughout the mapped region.

Structure

The Prince Albert Group is folded into large, tight-to-upright isoclinal folds which are responsible for the linear outcrop pattern. Because primary structures are rare in most tightly folded regions in the south, it is not known whether complete synclines are still preserved in the southern portion of map-area 47 A. Preliminary work suggests that only portions of the synclines were protected from the encroachment of the granitic intrusions. To the north, gneisses, thought to be old, outcrop both east and west of the belt. North of Hall Lake the Prince Albert Group outcrop area is wider, and in this region local, interior, complicated folds occur. On the Bouverie Islands folding of the Prince Albert Group is relatively simple, with steep western limbs and gently dipping eastern limbs to form asymmetrical folds with a gentle southeast plunge which contrasts sharply with the near horizontal northeast-southwest trend of the folds in the region near Roche Bay.

The difference in structural intensity through the region is due in part to the superposition of the Penrhyn deformational event. The domal styles displayed by Aphebian Penrhyn sediments and their basement are not continuous throughout the region, instead they are best displayed in the southeast corner of 47 A, and extend southward into map-sheet 46 (Heywood, 1967; Reesor, 1974; Reesor *et al.*, this publication, report 92) to form the Foxe Fold Belt (Davidson, 1972). As the region of Penrhyn outcrop is approached, the northerly trend of the Prince Albert Group changes to the northeast. The plutons are foliated along the same trend. In "older" gneisses the style of latest folds change from conical, open folds in the north (UTME 413000, UTMN 7655000) through concentric styles (UTME 420000, UTMN 7640000) to similar styles not distinguishable from later or earlier folds near the Penrhyn outcrops. The first appearance of Penrhyn rocks is in a tight northeast-trending syncline with a horizontal plunge and a near vertical axial plane, and not as expected, a thrust fault or recumbent fold with a southwest-dipping axial plane. No outliers of these Aphebian sediments have been found north of the border syncline.

The latest deformational events have been along faults which have bent and displaced Ordovician sediments.

On regional compilation maps the belts of Prince Albert Group are shown as being both Aphebian and Archean (Douglas, 1968). The belts are now known to be structurally, stratigraphically and lithologically continuous (Schau, 1974; Campbell, 1974). The fact that they are cut by granitic plutons that are in turn cut by folded and faulted metadiabase dykes that are seen to underlie the Aphebian Penrhyn Group (Lecheminant, pers. comm.) shows that the Prince

Albert Group is not a lateral equivalent of the Penrhyn. Aphebian (?) quartzites rest upon 1) Prince Albert Group, 2) the granites that cut it, and 3) the metadiabase dykes that cut both at Folster Lake and environs map-area 47 B (Frisch, 1974). Zircons from gneisses, basement to the Penrhyn group, are considered Archean (Reesor, 1974; Wanless, pers. comm.). Further geochronological studies are in progress.

Minerals of economic interest

Iron-formations have been the object of considerable interest (Wilson and Underhill, 1971) in the southern portion of map-area 47 A. These beds sweep northward to form locally thickened sections at least as interesting as those to the south. The beds form local inclusions in ubiquitous gabbro intrusions, but the region near (UTME 424500, UTMN 7649500) is an example of a potentially interesting region. Other elements of interest have also been found, albeit in small concentrations, and are included as a matter of record. Eckstrand (this publiction, report 76) reports on the sulphide concentration in a "young" feldspathic pyroxenite stock, minor copper stains are associated with the older meta-ultramafic units, and as veins in greenstones. Base metals are found in a zone within the quartzose sediments on Cox Island and, finally, molybdenum is found in a vein in granite (Table 1).

TABLE 1

SOME SELECTED OCCURRENCES OF MINERALS ON MELVILLE PENINSULA

UTME (in zone 17W)	UTMN	DESCRIPTION
426800	7656396	Molybdenite in a small local vein in granite.
444600	7714082	Yellow stained radioactive quartz-rich rock associated with granite.
433652	7603417	Small amounts of chalcopyrite associated with fiamme structures in acid volcanic rock.
447500	7725555	Very scarce chalcopyrite and malachite staining in sheared ultramafic layer (several occurrences in this region).
442035	7714180	Malachite stained, chalcopyrite, galena, and sphalerite-bearing quartzose metasedimentary rock forms local small zone in quartzose metasedimentary rocks.

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KOMATIITIC AND OTHER ULTRAMAFIC ROCKS IN THE PRINCE ALBERT GROUP, HAYES RIVER REGION, N.W.T.

Project 720062

Mikkel Schau
Regional and Economic Geology Division

Spinifex textures were reported from the Laughland Lake sheet (56 K) in the District of Keewatin within the very widespread ultramafic sheets in this area (Fig. 1) (Schau, 1974). Chemical analyses of rocks from the region are now available which detail the presence of komatiites and other peculiar chemistries in the ultramafic rocks emplaced within the Prince Albert Group.

Komatiites according to Brooks and Hart (1974) are volcanic rocks with high magnesia, high Ca/Al ratios and are deficient in potash and titania. There are two groups: peridotitic komatiite and basaltic komatiite. Because peridotites fall within the above chemical limits it is also necessary to have evidence of the presence of magma of this composition to demonstrate the presence of peridotitic komatiite. In the Hayes River region the ultramafic rocks have been severely deformed three times so fine relict textures are rare. Spinifex textures, a commonly found quench texture of Archean ultrabasic rocks, have been found in a number of places (Eckstrand, this publication, report 76) and Eckstrand (1973) suggests that green and chocolate brown units with layering 1 m thick would, if not severely deformed, contain spinifex texture. These layered rocks are extremely common and the layers are often conformable with surrounding beds (Fig. 4). Therefore, although spinifex is not associated with each occurrence reported here, the presence of some spinifex in the region, as well as the layering noted above (Fig. 4), is taken to be suggestive of the presence of some liquids of this composition. In many cases cross-cutting relations are also seen (Schau, 1973, 1974) which further supports the existence of ultramafic liquids. The location of analyzed komatiitic rocks is shown in Figure 2 and Table 7, and their average chemical composition in Table 1.

Basaltic komatiite is a rare rock type (Brooks and Hart, 1974). One good example is reported below (Table 2); other more hydrous or carbonated rocks also qualify chemically, if recalculated on a water-free basis, but because of probable addition of calcium as well as CO_2 and H_2O, these examples are not included. In thin section the basaltic komatiite is a chloritized and partially crushed medium-grained amphibolite composed mainly of labradorite and a green hornblende.

Spinifex texture also occurs in a peculiar biotite-rich rock (Fig. 3) (Schau, 1973), as well as in the more familiar tremolite-chlorite rock. "Tremolite" sheaves or plates rimmed by actinolite are set in a matrix of randomly oriented biotite grains and rare chlorite flakes. The mineralogy persists along strike though the spinifex textures may give way to spheroidal aggregates. The presence of biotite has been confirmed by X-ray diffraction and representative analysis of the minerals (courtesy G. Plante) are given in Table 3.

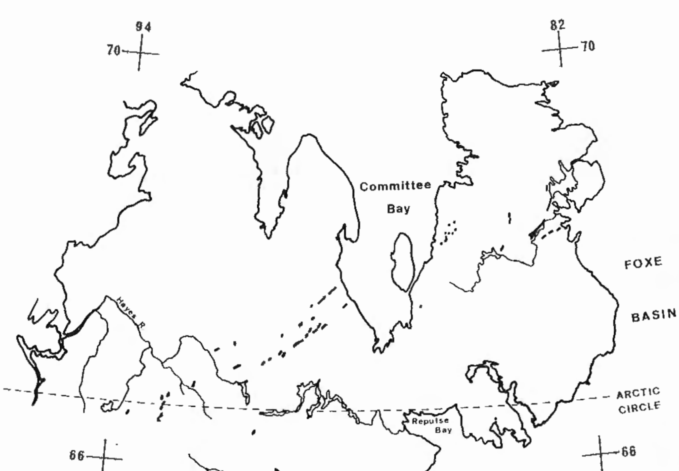

Figure 1. Map showing approximate location of ultramafic sheets and pods in Districts of Franklin and Keewatin. (From data by Heywood 1961, 1967, 1974; Field work by Campbell 1972, 1973; Frisch 1972, 1973, 1974; Schau 1972, 1973, 1974.)

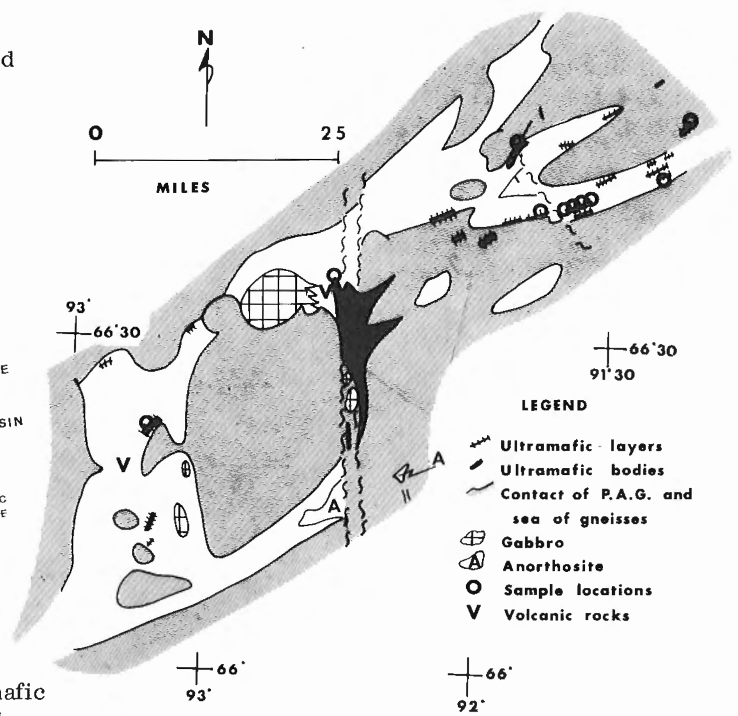

Figure 2. Map showing location of analyzed rocks in the Hayes River region mentioned in text. (From field work Schau 1972, 1973.)

Table 1.

Average composition of 20 komatiites from the Prince Albert Group in Hayes River Region ("Rapid-rock" analysis)*

	"KOMATIITES" $\bar{X}$	S
SiO_2	43.7	3.5
Al_2O_3	6.6	2.6
Fe_2O_3	2.8	1.6
FeO	8.6	3.6
CaO	9.0	3.4
MgO	20.96	7.8
Na_2O	.54	.72
K_2O	.15	.19
TiO_2	.43	.34
P_2O_5	.05	.02
MnO	.25	.08
S	.21	.33
NiO	.00	.00
Cr_2O_3	.29	.15
CO_2	1.46	3.24
H_2O	4.66	2.35

Table 2.

Amphibolite with basaltic kamotiitic composition* from rince Albert Group in Hayes River Region (No. 21)

SiO_2	46.6
Al_2O_3	8.8
Fe_2O_3	2.1
FeO	10.1
MgO	16.3
CaO	10.4
Na_2O	1.4
K_2O	.61
TiO_2	.75
P_2O_3	.08
MnO	.22
S	.00
Cr_2O_5	.24
CO_2	.00
H_2O	2.10

*Analysis by "rapid rock methods", courtesy J. Bouvier and Staff, G.S.C.

Table 3.

Electron Microprobe Analysis* of silicate minerals in spinifex bearing biotite ultramafites in Hayes River Region (No. 22)

	Amphibole centre	Amphibole rim	Biotite
SiO_2	52.39	46.56	36.92
TiO_2	.12	.31	.97
Al_2O_3	3.43	6.58	13.84
Cr_2O_3	.19	.19	.15
Fe as FeO	8.69	10.37	12.75
MnO	.19	.20	.10
MgO	18.42	16.92	17.52
CaO	12.19	12.08	.07
Na_2O	1.59	2.37	.53
K_2O	.04	.13	9.16
Total	97.25	98.71	92.01
N	10	6	3
Modal Abundance	35%	7%	55%

*Electron microprobe analysis courtesy G. Plante, G.S.C.

Table 4.

Biotite-bearing ultramafic rocks in Prince Albert Group

	Calculated bulk composition from Table 3 No. 22	Rapid rock analysis* No. 23	Rapid rock analysis* No. 24
SiO_2	42.4	44.3	46.6
Al_2O_3	9.4	9.5	12.2
Fe_2O_3	See below	2.6	2.5
FeO	10.8	9.4	11.1
MgO	17.4	17.2	10.5
CaO	5.2	7.2	7.6
Na_2O	1.0	.9	1.5
K_2O	5.3	4.2	3.6
TiO_2	.6	.6	1.03
P_2O_5	-	.08	.09
MnO	.14	.20	.35
Cr_2O_3	.16	.26	.04
CO_2	-	0.0	0.0
H_2O	-	3.30	2.20

*Analysis by "rapid rock methods", courtesy J. Bouvier and Staff, G.S.C.

Figure 3. Thin section showing spinifex texture in biotite ultramafic. GSC Photo 202660.

Table 5.

Rapid rock analysis* of some biotite-bearing ultramafic rocks of the Prince Albert Group

	25	26	27	28
SiO_2	42.20	41.63	40.88	43.35
Al_2O_3	1.97	1.06	.69	.41
TiO_2	.07	.06	.06	.05
Fe_2O_3	1.68	1.15	1.59	1.23
FeO	4.50	5.10	5.10	4.40
MnO	.24	.24	.27	.17
MgO	41.46	41.94	42.40	39.84
CaO	.02	.03	.07	.06
Na_2O	.00	.03	.00	.01
K_2O	1.56	.76	.38	.16
P_2O_5	.03	.04	.03	.02
CO_2	.00	.00	.00	.00
H_2O	7.40	8.00	8.50	9.60
S	.11	.11	.13	.19
Cr_2O_3	.20	.20	.22	.35
Total	100.46	100.36	100.32	99.85
F	.06	.07	.06	.08
Cl	.03	.02	.03	.01

*Analysis by "rapid rock methods", courtesy J. Bouvier and Staff, G. S. C.

Figure 4. Layered ultramafic with komatiitic composition. GSC Photo 202122-H.

Table 6.

Percentages of some minor elements of biotite-bearing ultramafic rocks (optical spectroscopic methods)*

	25	26	27	28
Sr	NF	.0017	.0015	.0014
Ba	.0036	.0023	.0015	.0013
Zr	<.0030	<.0030	<.0030	<.0030
Y	<.0020	<.0020	<.0020	<.0020
La	NF	NF	NF	NF
Cr	.14	.13	.13	.25
Ni	.22	.23	.21	.26
Co	.0085	.0083	.0091	.0100

*Analysis by optical spectroscopic methods, courtesy K. Church and Staff, G.S.C.

An estimate of the bulk chemical composition has been obtained from the modal abundance of the minerals (Table 4). Although not accurate, it is a reasonable estimate of the gross chemical characteristics of the rock. It does not qualify chemically as a komatiite. Two other analyzed rocks from the region have a similar composition and mineralogy (Table 4) but do not contain spinifex textures. They come from within conformable ultramafic units and near the contacts with the country rocks. According to Irvine and Baragar (1971) these rocks would be classified as alkalic picrite basalts. There is a continuous variation from normal ultramafic rocks to biotite-rich ultramafic rocks. At one site, samples taken less than a metre apart from an apparently homogeneous ultramafic layer, contain what appears to be a variation of biotite from none to a minor constituent in thin section. The resulting variation in chemistry is detailed in Table 5. Eckstrand (this publication, report 76) also details the rapid variation of visible biotite within layered spinifex-bearing rocks. Thus the presence of biotite-bearing ultramafic rocks is clearly established. Whether the rocks are locally and variably "biotitized" (cf. Waters, 1955) or are pecular ultramafic lavas, is not clear. Highly alkalic ultramafic lavas are characterized by low silica content, high potash, phosphate, titania, Sr, Ba and Zr (Higazy, 1954). The rocks in question are poorer by over an order of magnitude in TiO_2, P_2O_3, Sr, Ba and Zr (Table 6) so that the biotite ultramafics do not have the appropriate minor element composition for an alkalic ultramafic lava. They do carry the normal complement of Cr, Ni and Co expected in normal (non-potassic) ultramafic rocks (Table 6).

In summary, spinifex textured peridotitic komatiites are still known only in Archean rocks (Brooks and Hart, 1974). Therefore the presence of peridotitic komatiites in the Hayes River region strongly suggests that the enclosing rocks of Prince Albert Group are Archean as well. Rocks with basaltic komatiitic chemistry are not restricted to the Archean, but are rare throughout time; the presence of rocks with this chemistry in the Prince Albert Group is of interest, especially as they occur near peridotitic komatiites. The origin of the biotite-bearing spinifex textured ultramafic rock is not clear. Certain minor element concentrations in it are at least ten times less abundant than in recent potassic ultramafic lavas; hence an origin appealing to local, non-texture-destroying potash metasomatism of peridotitic komatiites might be an explanation. This interpretation is favoured by the minor element concentrations. If metasomatic additions have taken place, the komatiitic compositions may also be the result of similar processes. If the rocks are examples of Archean komatiites they may be of particular economic interest. Although no metalliferous sulphides have been found associated with these rocks in this area, such an association has been documented elsewhere (Eckstrand, 1973).

Table 7.

Localities of ultramafic rock mentioned in text (UTM's in zone 15W)

A. Localities of specimens used to generate average komatiite in Table 1

	UTME	UTMN		UTME	UTMN
1	540330	7412490	11	488100	7357880
2	565040	7404700	12	548000	7397200
3	565040	7404700	13	578000	7413260
4	565040	7404700	14	488080	7358390
5	552150	7398900	15	553680	7400290
6	577250	7412960	16	593680	7400290
7	553050	7398980	17	576520	7412230
8	563350	7405790	18	488120	7358150
9	551190	7398280	19	577620	7413440
10	551190	7398280	20	578390	7414370

B. Locality of amphibolite with basaltic komatiite composition in Table 2.

	UTME	UTMN
21	578390	7414370

C. Localities of biotite-bearing ultramafic rocks from Tables 3, 4, 5 and 6.

	UTME	UTMN
22	522500	7383200
23	553050	7398980
24	553680	7400290
25	549200	7406000
26	549200	7406000
27	549200	7406000
28	549200	7406000

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96. ENVIRONMENTAL GEOLOGY PROTOTYPE STUDY; OTTAWA-HULL AREA

Project 700049

J.R. Bélanger
Terrain Sciences Division

Final maps at scales of 1:50,000 and 1:125,000 showing the trend of the drift thickness have been produced and will be included in the Atlas of Urban Geology of the Ottawa-Hull Region. Additional maps are being prepared for the same area to indicate other geological properties of the surficial deposits.

The activities also have been directed towards the development of a new method of compiling geotechnical information to serve as input to the Urban Geology Automated Information System (UGAIS). The purpose of the new method is to offer a user-oriented system rather than a machine-oriented one, thus eliminating fixed input format and coding of the information. The compilation sheet or "UGAIS Data Record" is similar to an engineering report, using the same terminology, and is stored as such on magnetic computer tapes. A report-writer program has been written in COBOL language and the entire system has been tested and has proved to be a great improvement on the previous one. A sample of the UGAIS Data Record is included to illustrate the format and type of information that can be stored on the compilation sheet.

UGAIS DATA RECORD

FILE NO. 9551-s

DATE 26-07-74

RECORD NUMBER 03 (Col 1) CARD 0 0 (6)

N.T.S. MAP 31 h 12 (8)

UTM ZONE 18 (16)

EASTING 581920 (18)

NORTHING 5051100 (24)

LOCATION PRECISION 20 ft (31)

REFERENCE gd-9551-S-3 (35)

DATE (M/Y) 06 (49) 74 (51)

SURFACE ELEV. 142.7 ft ASL (53)

METHOD 28 (59) PURPOSE 11 (61)

PENETRATION: HAMMER 140 lb (63)

DROP 30 in. (66)

SPOON DIAM. 2 in (69)

RELIABILITY 1 (72)

BOTTOM OF HOLE (depth) 40.0 ft (74)

Maximum Char./Line

RECORD NUMBER (5)	CARD	DEPTH (6)	SOIL TYPE (16)	DESCRIPTION Colour, %, Grain Size, Physical & Chemical Prop., Structure, Genetic. (27)	ATTERBERG DEPTH (4)	P L (3)	M C. (3)	L L (3)	PENETRATION DEPTH (4)	BL/FT (3)	WATER depth (4)
03	01	0.0	Organic clay	Organic brown clay,							
	02			weathered							
	03	0.7	Silty clay	Brown weathered silty clay,					3.5	11	
	04			very stiff.							
	05	4.5	Clay	Grey to blue grey	7.0	24	54	48	7.0	2	
	06			marine sensitive clay,very	10.	19	59	52	10.0	2	
	07			soft,highly plastic.	14.	20	56	54	14.0	2	
	08			Shear strength: 500-700							
	09			lb/sq.ft.							
	10	15.4	Silty sand	Grey silty sand with gravel	15.		9		16.0	27	
	11			medium dense							16.
	12	19.0	Till	Boulder till with sand and							
	13			gravel, some silty clay,	20.		14		20.0	75	
	14			very dense.					26.0	78	
	15								30.0	100	
	16	31.0	Limestone	Weathered grey limestone,							
	17			interbedded with shale							
	18										
	19										
	20										
Column 1	6	8	14	30	57	61	64	67	70	74	77

Project 730029

F. Morin
Terrain Sciences Division

The 1974 phase of this project involved terrain verifications of data stored in the Hamilton geoscientific data bank, and, to a certain degree completion of the fragmental information it contains.

Figure 1. Small auger drill used to bore and sample 48 of the 64 boreholes drilled in the Hamilton area.

Figure 2. Active shoreline erosion scarp along Lake Ontario (10 to 12 feet high). Erosion is in the Halton silty clay till facies.

Accordingly, the following were undertaken and completed:

1. A two-man hammer seismic survey was conducted to provide complete depth to bedrock information on map-sheets: 30 M/4e, f, g; 30 M/5c, d; and 40 P/1h. This was done by the Geophysics Division of the Geological Survey of Canada. Seismic lines were located along all existing roads in the above map-areas with readings taken at quarter-mile intervals.

2. A drilling program was carried out, funded jointly by the Geological Survey of Canada and the Hamilton-Wentworth regional municipality. The purpose of this drilling was threefold:

   a) to verify geoscientific information stored in the data bank,

   b) to calibrate the seismic information so as to provide better estimates of the depth of bedrock, and

   c) to add a substantial amount of much needed quantitative information to the data bank.

The drilling generated 186 samples, most of which were in shelby tubes. The deepest holes (up to 70 feet) were drilled with hollow stem augers, 7½ inches in diameter (16 holes); the shallower holes (maximum 45 feet) were drilled with 4-inch diameter augers (17 holes) (*see* Fig. 1). These 33 boreholes, along with 31 boreholes drilled in mid-autumn of 1973 give sufficient coverage for the project objectives of providing basic soil information for the area.

In addition, the shoreline of Lake Ontario, within the project boundaries, was mapped so as to identify areas of active erosion and potential flooding by high waters (*see* Fig. 2).

Finally, an attempt was made to map areas with unstable slopes. This was done by aerial photograph identification of landslide scars, and field checking of these observations to as great an extent as possible (*see* Fig. 3).

Close co-operation with a field party led by Dr. B. Feenstra of the Ontario

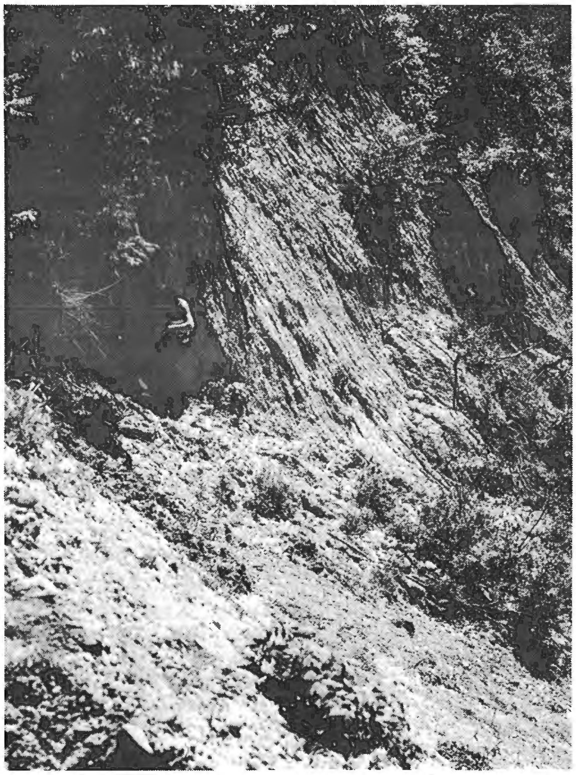

Figure 3. Slump face along Sulfur Creek in the Dundas Valley. Movement has taken place in silty facies of the Halton till.

Ministry of Natural Resources was maintained throughout the field season. Dr. Feenstra was mapping the surficial geology of three of the 1:25,000 map-sheets within the project area (30 M/4e, f, and g). This co-operation proved highly useful for this project since it provided a better understanding of the stratigraphy of the region and a surficial geology map for the only part of the project area for which none had existed.

Project 730019

J. Veillette
Terrain Sciences Division

Mackay (1973) showed that temperature measurements in plugged, air-filled seismic shotholes are representative of surrounding ground temperature if taken after a day or so following completion and capping of the hole. A similar experiment conducted on a shallow borehole on central Banks Island during summer 1974 supports Mackay's conclusions, and suggests that a period of only two hours following the capping of a shallow hole may be sufficient to provide reliable ground temperature estimates.

Local conditions

The borehole was located in the centre of a high-centre polygon, about 80 feet in diameter. Patches of moss, less than 2 inches thick, covered about 50 per cent of the immediate area, with the remainder of the area consisting of mineral soil. Permafrost was encountered at 20 inches below ground level. Subsurface material consisted of ice-saturated gravelly sand to 6 feet, then mostly clear ice to 21 feet, and gravelly sand to 22 feet.

Continuous coring was done with a modified CRREL barrel 3½" O.D. powered by a J.K.S. 300 diamond drill. Barrel rotational speed was maintained in the 25 to 40 rpm range. Approximately 6 hours of actual coring time was spent at the site, with some drilling difficulty experienced in the upper 6 feet.

Thermistor cable installation

Following drilling completion, a PVC pipe 3½" O.D. was lowered to a depth below maximum seasonal thaw penetration (about 3 feet below the top of the permafrost table) and allowed to freeze in place. The hole was left uncapped for about 2 hours.

A 20-foot thermistor cable with thermistors at the 0, 2, 4, 6, 10, 15, and 20-foot marks was then inserted in the hole. The top of the pipe was then capped.

Temperature measurements

Figure 1 illustrates temperature measurements for the period July 5 to July 12. Readings were taken at shorter intervals for July 5 and 6. The first reading was taken immediately after the hole was capped at 2100 hours, July 5. The 2-foot thermistor, only 4 inches below the top of the permafrost table, reflects surface temperature variations. All thermistors below the 2-foot level were within 1^{o}F of equilibrium after one hour,

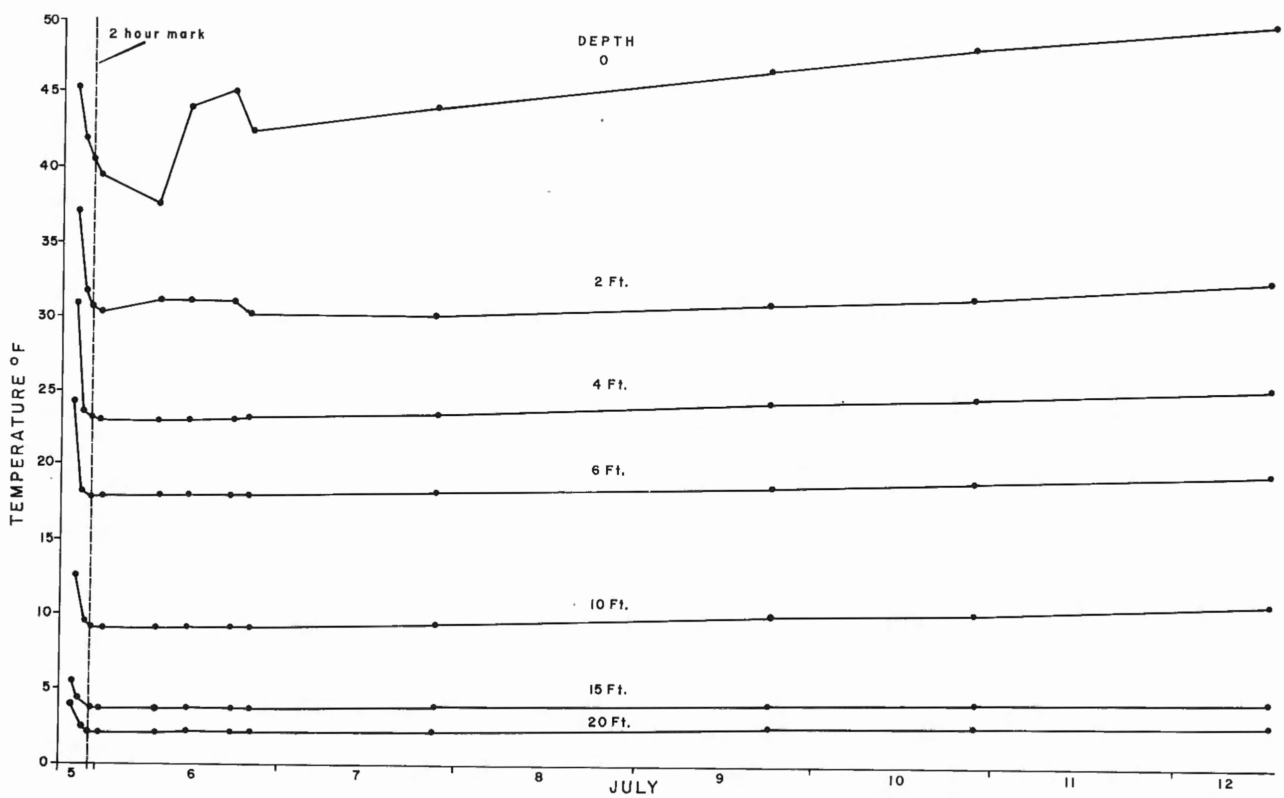

Figure 1. Stabilization of ground temperatures in borehole after drilling, Banks Island, N.W.T.

and reached their lowest temperatures after 2 hours. Readings were recorded on a daily basis until the latter part of August.

Discussion

The scarcity of temperature profiles for the area precludes a definite conclusion as to the validity of these results. It was assumed that the lowest temperature recorded following disturbance would represent the closest estimate of temperature equilibrium, since the seasonal trend at this time of year is toward higher temperatures within the zone of seasonal fluctuations. Extrapolation of temperature curves for the rest of the recording season suggests that an accurate temperature estimate has been obtained.

The recording of stabilized borehole temperatures after only 2 or 3 hours could greatly facilitate field procedure. The complete operation of coring and temperature recording possibly could be done in one day, without necessitating a second trip to the site.

The drilling technique employed is probably of great importance in borehole temperature disturbance. The short temperature stabilization period observed in this experiment could well be due to the utilization of a dry coring technique where low rotational speeds are used to cut around the core. The use of Tricone roller bits or wing bits with compressed air circulated in the hole may induce a greater disturbance.

Further testing is needed to assess the validity of the method and the prerequisites for its application.

The assistance of Roger Thomas in taking temperature measurements is appreciated.

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99.

ACOUSTIC PROFILING AND SEDIMENT CORING IN LAKE ONTARIO, LAKE ERIE, AND GEORGIAN BAY

Project 68005

T.W. Anderson[1] and C.F.M. Lewis[2]

The Geological Survey carried out two cruises on the Great Lakes during the summer. A one-week cruise in May involved seismic refraction and reflection profiling and gravity coring of bottom sediments in Georgian Bay aboard the *M. V. Limnos*. The second cruise was a two-week, piston and gravity coring-echo sounding survey of Lake Erie and Lake Ontario in July aboard the *M. V. Martin Karlsen*. Some of the more interesting findings of the Lake Ontario portion of the July cruise will be elaborated on since much time and effort was directed towards this part of the field program.

The Georgian Bay cruise was primarily exploratory in nature. Dr. J.A. Hunter, S.M. Blasco and R.L. Good experimented with various refraction systems in obtaining sediment velocity and thickness data. This information is essential to interpret properly echograms and seismic reflection data obtained on previous years' cruises. Water, sediment, and bedrock velocities, and depth to the sediment-bedrock interface were accurately defined at 195 stations from three refraction lines. Cursory examination of the profiles proved the effectiveness of the 366-m hydrophone cable and S.I.E. RS-44 receiver utilizing either dynamite or air gun signal source.

The main purpose of the Lake Ontario cruise was to resolve some specific problems of stratigraphy, sediment distribution, and bottom configuration as revealed in previous regional survey cruises. Four main objectives were involved: 1) to study the Quaternary stratigraphy of the bottom sediments, 2) to identify subbottom reflections in echogram and seismic profiles, 3) to study the bottom configuration and sediment distribution on elevated planes, ridges and sills, especially to define shorelines and nearshore areas of extreme low-water levels, and 4) to map the areal extent of Holocene mud distribution in the offshore areas. An immediate and significant use of this information is to provide support data for an International Field Year for the Great Lakes (IFYGL) map of the geology of Lake Ontario which is presently in preparation by the Geological Survey, Ottawa. Additional sounding and coring work was carried out in support of studies by J.R. Bowlby, Queen's University, Kingston on periglacial features and environments recorded in sediments of the Kingston basin.

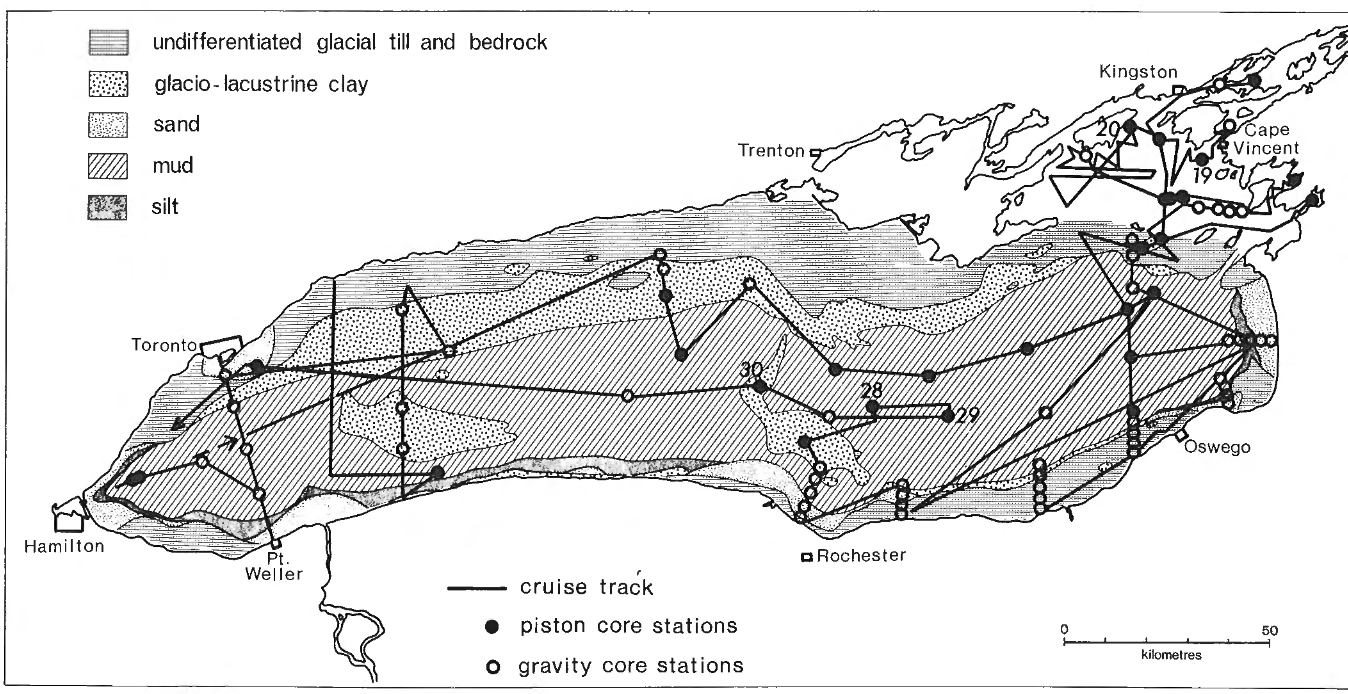

Figure 1. The surficial sediments of Lake Ontario (after Thomas *et al.*, 1972) showing cruise track and piston and gravity core locations.

Terrain Sciences Division, [1]Burlington, [2] Ottawa.

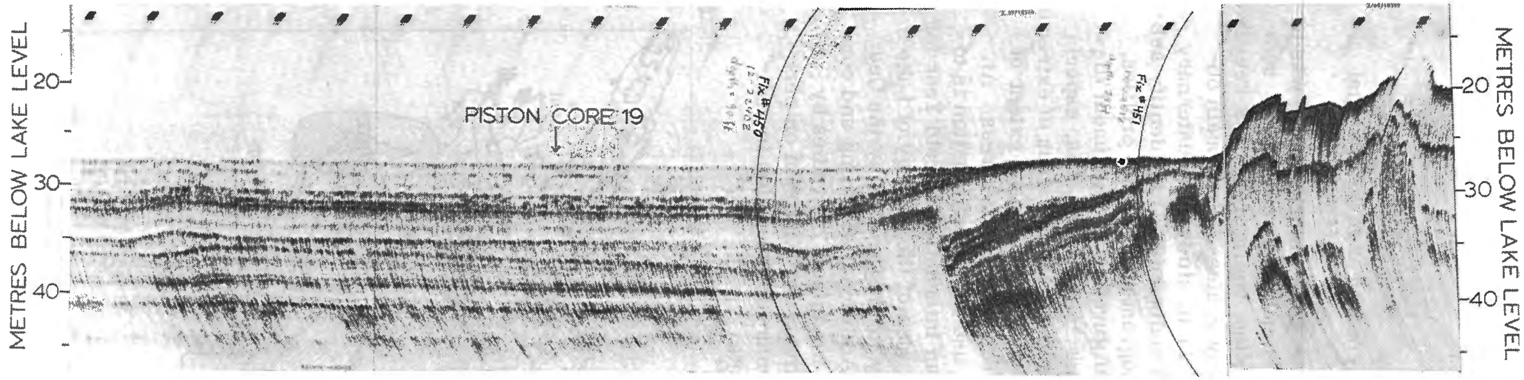

Figure 2. Echogram stratigraphy at Piston Core Station 19 showing glaciolacustrine clays adjacent to bedrock at right and postglaical muds overlying glaciolacustrine clays at core site. (Kelvin-Hughes echosounder, 14.25 KHz frequency.)

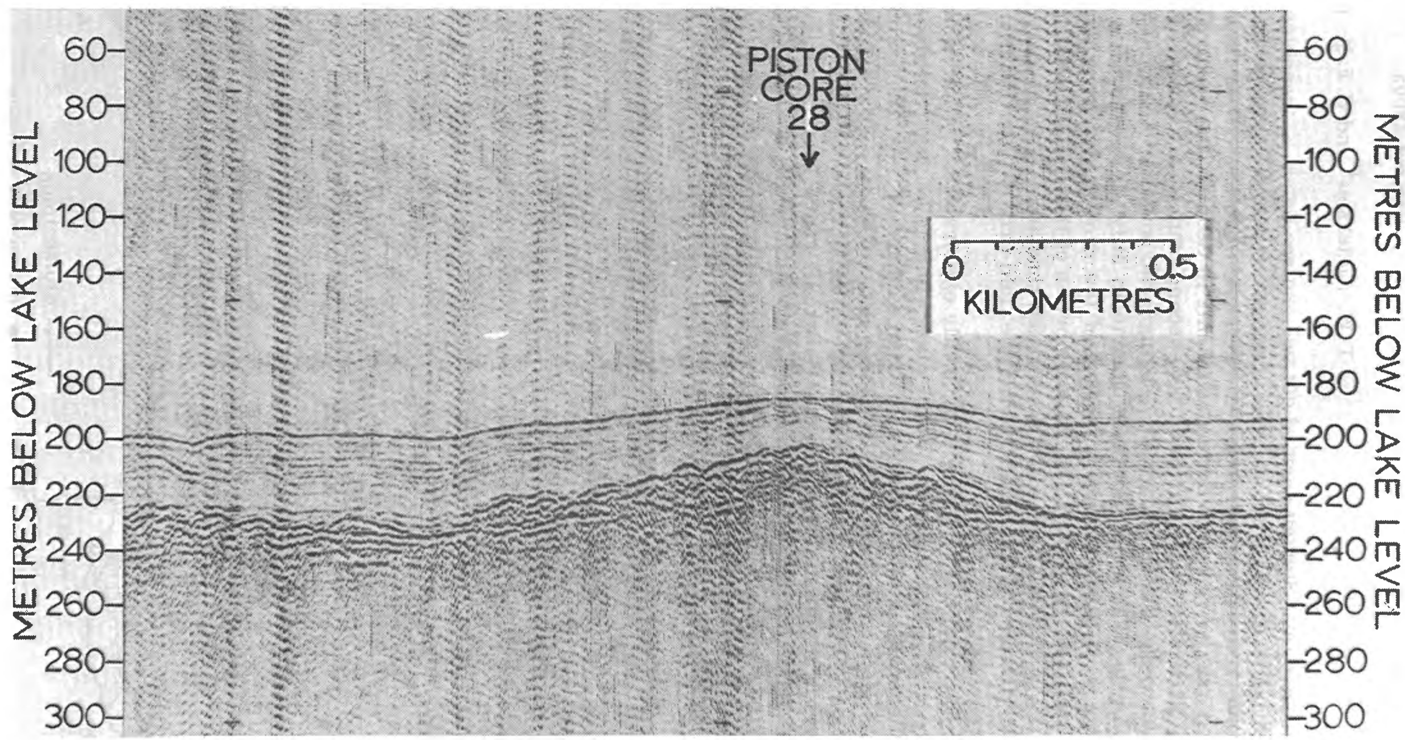

Figure 3. Seismic profile at Piston Core Station 28 showing the hummocky till surface overlain by glaciolacustrine and postglacial clays. (High resolution airgun seismic reflection record.)

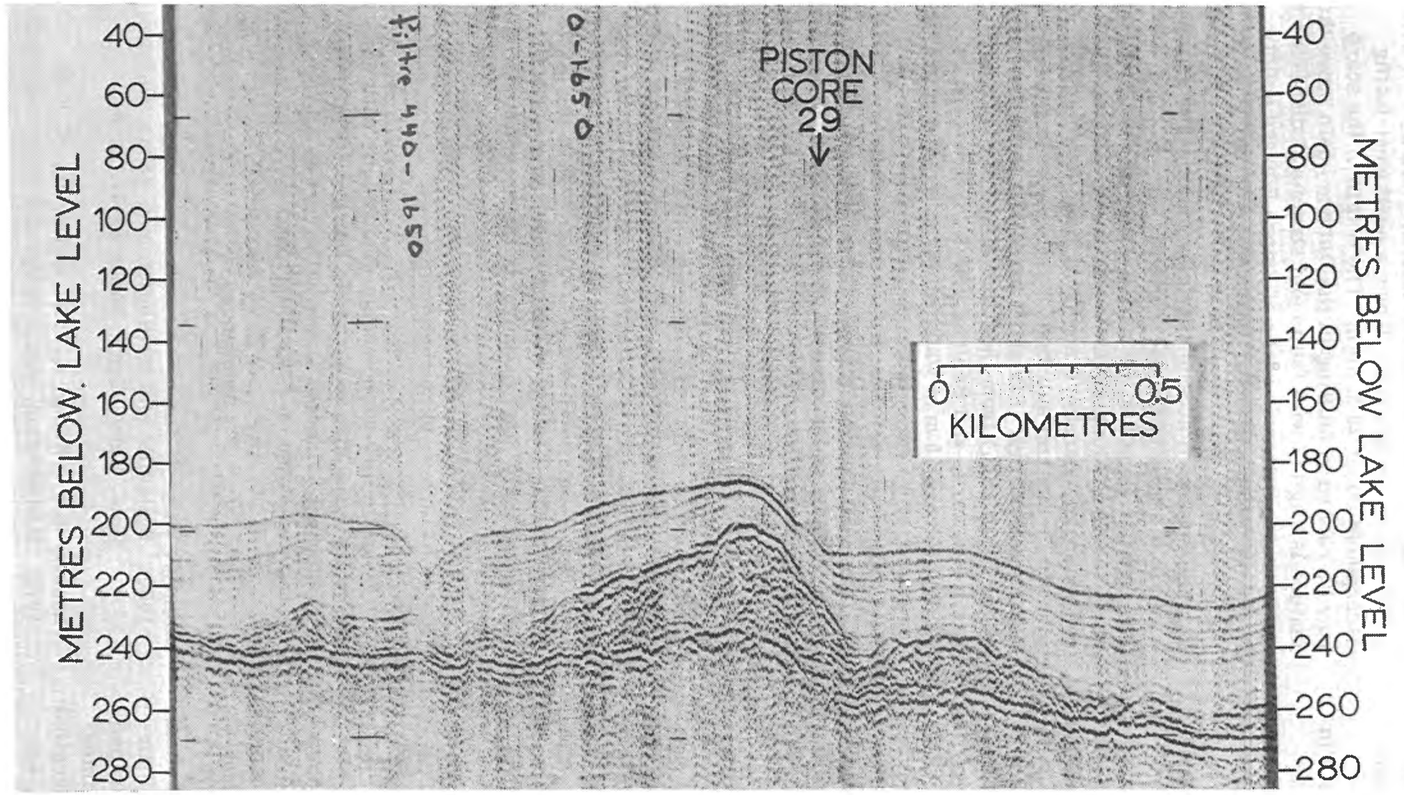

Figure 4. Seismic profile at Piston Core Station 29 showing the bedrock surface (lowermost reflector), hummocky ice marginal deposits, and uppermost glaciolacustrine and postglacial clays. (Record as in Figure 3.)

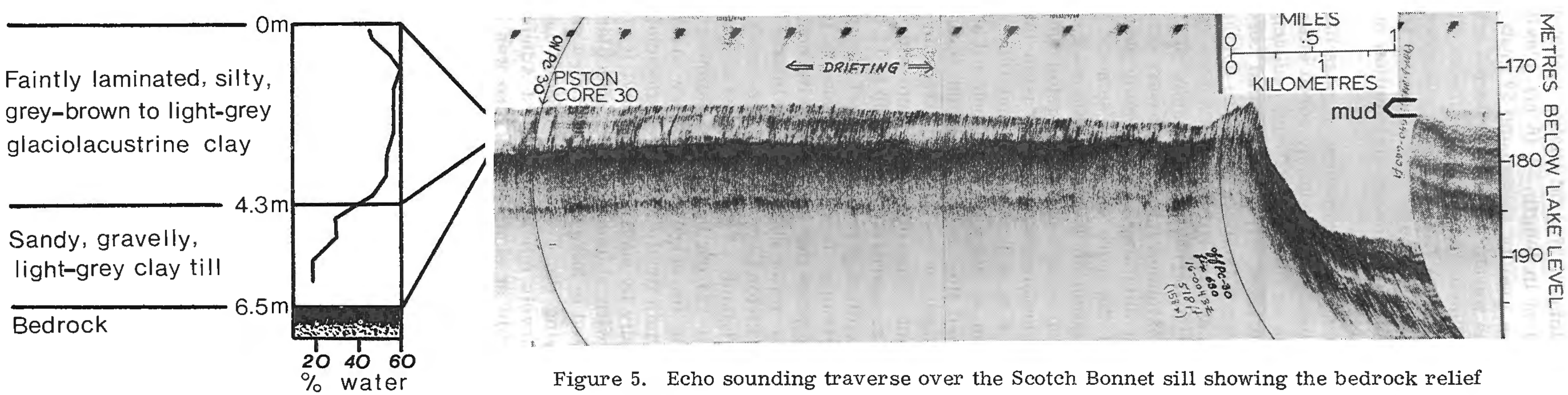

Figure 5. Echo sounding traverse over the Scotch Bonnet sill showing the bedrock relief and overlying stratigraphy. (Kelvin-Hughes 14.25 KHz echogram; left side is southeast and right side is northwest.)

A total of 27 good quality piston cores ranging from 6 to 21 m in length, 7 (6 m) gravity cores, 61 (1 m) Benthos gravity cores, and 57 grab (Shipek bucket) samples were obtained at selected areas throughout the lake. The cruise track and the locations of the 1,200-lb. (540-kg) Alpine piston and gravity cores are shown in Figure 1. The underlay in Figure 1 is the lake bottom sediment distribution map from Thomas *et al.* (1972).

As many piston cores as possible were obtained in areas between previously cored sites in an effort to compile an inventory of long sediment records throughout the lake. These additional cores along with approximately 60 logged cores obtained on previous years' cruises will provide a more complete synthesis of the Quaternary stratigraphy of the basin. Some cores extended into till and were oriented for the purpose of obtaining paleomagnetic profiles at a later date. One of the more carefully selected piston core sites was Station 19 located 18 km southeast of Kingston in the deep trough of the Kingston basin. The site is a 15-m glaciolacustrine depression infilled with an estimated 6 m of postglacial mud (Fig. 2). Because of its location in front of a bedrock sill at Cape Vincent, it is hoped the early postglacial sediments will shed some light on the possible extension of a marine environment (Champlain Sea) into the eastern Ontario basin at approximately 11,000 to 12,000 years ago.

Benthos gravity and short piston cores were taken at particular areas in the lake to test for and sample buried plant detritus beds believed deposited during a lower-water stage of Lake Ontario about 11,000 years B.P. Piston Core 20, located on the east side of Amherst Island, 14 km southwest of Kingston, intersected peat at 123 cm below the sediment surface, thus confirming its original discovery in 1968. The peat is underlain firstly by varved glaciolacustrine clay, and secondly by massive grey clay; it is overlain by banded marl with abundant shells and plant detritus. It is believed to have accumulated on a subaerial surface following the draining of glacial Lake Iroquois when lake levels fell to the lowest Admiralty stage. Peat, probably of similar age, also was cored in the St. Lawrence River east of Kingston.

Fifteen-metre piston cores were obtained at Stations 28 and 29 to investigate buried, dome-shaped features indicated in the seismic records (Figs. 3 and 4) of a previous cruise on Lake Ontario. These mounds are believed to be related to deposition at an ice margin during the advance or retreat of Wisconsin(?) glacier ice through the Ontario basin. The sub-bottom ridge at Station 28 is probably a hummocky till surface with glaciolacustrine and postglacial clays draped over it. The lowermost reflector at Station 29 is interpreted to be a bedrock surface overlain by ice-marginal deposits up to 35 m in thickness, which, in turn, are overlain by approximately 15 m of glaciolacustrine and postglacial clay.

The glaciolacustrine clay outcrop located north of Rochester and west of Station 28 was piston cored (Station 30, Fig. 1) in an effort to determine the nature of the underlying till and bedrock surface. This elevated feature is known as the Scotch Bonnet sill (Thomas *et al.*, 1972) and has been interpreted as a morainic accumulation deposited during a temporary halt of the ice front as it receded from the eastern Ontario basin (Thomas *et al.*, 1972; Sly and Lewis, 1972). Data from Piston Core 30 and the associated echo sounding traverse (Fig. 5) indicate the sill is controlled by bedrock relief which, in this area, forms a northwest-facing escarpment about 20 m high. The origin of the scarp may be related to faulting in the Ontario basin since the feature is aligned with faults and structural displacements in the Paleozoic rocks of Prince Edward county to the northeast (Liberty, 1960). The crestal area of the escarpment is overlain by 3 to 6 m of till and glaciolacustrine clay; Holocene silty clay muds occur in the basin at the base of the escarpment.

Another aspect of the cruise involved sounding and close sampling along seven traverses to examine the offshore mud/nearshore sediment boundary and to identify bottom and sub-bottom reflections in the echogram stratigraphy. Six short traverses were run (at water depth 15 m) from the south shore of the eastern basin lakeward, and Benthos gravity cores were collected at every 15 m of water change. Four 6 m gravity cores also were collected at strategic points on a cross-lake profile between Port Weller and Toronto.

The contact zone between the offshore muds and the nearshore sediments varies considerably from one traverse to another presumably as a result of variable sediment supply/erosional processes. In some traverses (e.g. Port Weller-Toronto and at the eastern end of Lake Ontario), the nearshore sediments pass from sand into silty sand, to sandy silt and eventually to silty mud, lakeward. The transitional character of the sediments thus makes it difficult to pin-point the areal distribution of Holocene muds in such areas. In other traverses, e.g. northeast of Oswego and on the north flank of the lake basin, the mud/nearshore contact is defined sharply due to removal of the recent muds and erosion of the exposed glaciolacustrine clays.

Acknowledgments

We gratefully acknowledge discussions with and on-board assistance of Mr. J.R. Bowlby, Department of Geological Sciences, Queen's University, Kingston, during the cruise on Lake Ontario.

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QUATERNARY GEOLOGY, STRATIGRAPHIC STUDIES AND REVALUATION OF TERRAIN INVENTORY MAPS, FRASER LOWLAND, BRITISH COLUMBIA (92 G/1, 2, AND PARTS OF 92 G/3, 6, 7, AND H/4)

Project 730155

John E. Armstrong
Terrain Sciences Division, Vancouver

Introduction

The Fraser Lowland, which is traversed by the Fraser River, is a triangular-shaped low-lying area of depositional origin with its apex 105 km east of the Strait of Georgia. It is bounded on the north by the Coast Mountains, on the southeast by the Cascade and Chuckanut Mountains, on the west by the Strait of Georgia and has an area of approximately 3,510 km^2.

Investigations of the Quaternary geology of the Fraser Lowland were undertaken between 1948 and 1956 by Armstrong and four preliminary maps and three reports were published by the Geological Survey. In addition twelve outside papers were published by various journals. Three of the preliminary map-sheets, namely Vancouver (Armstrong, 1956a), New Westminster (Armstrong, 1957), and Sumas (Armstrong, 1960a) have been reprinted, however, all are now out of print. The fourth map-area, Chilliwack, is still available (Armstrong, 1960b). The aim of the present project is to revaluate and update the previous work culminating in publication of final maps and reports.

Resulting from the work done during 1974, much additional information has been obtained that will result in considerable revision of the published geological maps and much better elucidation of the complex stratigraphy.

Summary of Geology

As a result of the work done between 1949 and 1956, Armstrong demonstrated that during Pleistocene time this area was subjected to repeated glaciations separated by interglacial or nonglacial intervals. These climatic changes were accompanied by eustatic, isostatic, and possibly tectonic adjustments resulting in continually changing sea levels. As a consequence of this complex geological history, very thick Pleistocene deposits (300 m plus) of widely diversified origin were laid down.

Strata of five major Pleistocene formational units, each probably representing a major geologic-climatic unit are exposed in the Fraser Lowland. These are as shown in Table 1.

Table 1

Formation	Approximate geochronological age (includes data from elsewhere in B.C. and based on radiocarbon dates prior to 1974)	Maximum thickness (approximate composite thicknesses)
Fraser Drift	10,500 - 22,000 B.P.	305 m
Quadra Sediments	22,000 - 44,000 B.P.	185 m
Semiahmoo Drift	>44,000 - >52,000 B.P.	125 m
Highbury Sediments	>52,000 B.P.	90 m
Westlynn Drift	>75,000 B.P. ?	215 m

Radiocarbon dates on some of the material collected in 1974 from more than 40 localities in the Fraser Lowland may result in modification of the geochronological ages shown above.

The Fraser Drift originally was subdivided as below (Armstrong *et al.*, 1965; Armstrong, 1956b).

Sumas Stade - Sumas Drift	(10,000 to 11,000 B.P.) <u>11,400 to 11,800 B.P.</u>
Everson Interstade - Capilano Sediments	(11,000 to 13,000 B.P.) <u>11,800 to 13,000 B.P.</u>
Vashon Stade - Surrey Drift Evans Creek Stade	(13,000 to 24,000 B.P.) <u>13,000 to 20,000 B.P.</u>

Radiocarbon dates obtained since 1965 by other workers suggest the chronological ages should be adjusted as shown in the second set of figures underlined above. These undoubtedly will be subject to further change. During the past season Armstrong has identified three drift sheets that originally were correlated with Sumas Drift but which represent three post-Vashon local advances of ice across the eastern part of the Fraser Lowland. Each is separated by glaciomarine deposits, originally mapped as Capilano Sediments. The final stratigraphic sequence is dependent on new radiocarbon dates.

The Fraser Drift may be correlated with Classical Wisconsin. The Highbury and Quadra sediments are nonglacial deposits and probably represent interglacial climates, possibly somewhat cooler than at present. Pollen studies on new material should be helpful in interpreting the climates.

The three main drift formations each include one or more till sheets and one or more glaciomarine diamictons. The tills are mainly lodgement tills but include some flow tills. In many places the Fraser tills show evidence of redeposition by solifluction processes. In all the tills the stones are embedded in a matrix ranging from clayey silt to silty sand. The tills are normally compact and present only minor engineering problems.

The glaciomarine deposits are till-like in appearance but contain less stones and more clay and silt than the tills. In many places the Fraser glaciomarine diamictons have not been preloaded. They are commonly called "sensitive clays" and are subject to settling, sliding, and poor drainage, problems that challenge the soils engineer.

Pre-Fraser Deposits - Composite Section

Recent investigations in the above listed map-areas have resulted in a more detailed evaluation of the pre-Fraser stratigraphy as shown in the section.

Unit	Name	Maximum Thickness
	Fraser Drift	
	Erosional Unconformity	
	Quadra Sediments	
Q6	Sandy gravel, gravelly sand, and sand; deltaic and fluvial deposits; in places in channels cut into unit Q5 and older deposits. Some of these deposits were informally named "Colebrook Gravel" in previous papers. They may be in part glaciofluvial ice-contact deposits related to Fraser Drift.	35 m
Q5	Fine sand, silt, and clayey silt, horizontally stratified and bedded fluvial deposits. Some of these deposits were informally named "Nicomekl Silt" in previous papers.	30 m
Q4	Fine to coarse sand and gravelly sand, horizontally stratified, extensively crossbedded, fluvial deposits. Contain lenses of sandy gravel and may include beds up to 4 m or more thick of silty clay and clayey silt. These deposits grade laterally and vertically into those of unit Q5. May be in part glaciofluvial in origin.	75 m
Q3	"Point Grey Beds": clayey silt, silt, silty sand, fine sand, and peat, horizontally stratified and bedded fluvial deposits and swamp or bog deposits.	25 m
Q2	Sand, gravelly sand, and sandy gravel, horizontally stratified, crossbedded fluvial deposits; in places in channels, cut into unit Q1. Boulder gravel up to 30 m thick exposed in Coquitlam Valley may belong here.	30 m
Q1	Silty sand and sandy silt, horizontally stratified and thinly bedded fluvial deposits which may be in part equivalent to Q3.	30 m

Unit	Name	Maximum Thickness
	Erosional Unconformity	
	Semiahmoo Drift	
Se9	Lodgement till with a sandy silt matrix; contains lenses of substratified sand and gravel. In the typical section in Highbury tunnel (Point Grey area, Vancouver) the till overlies unconformably units Se 4, 3, 2, and 1.	15 m
Se8	Substratified gravel and sand, lenses of till. Contorted bedding and slump features, probably ice contact in origin.	25 m
Se7	Rhythmically bedded clayey silt and silt grading laterally into fine sand and silty sand. Contains scattered pebbles. Probably glaciolacustrine deposits.	45 m
Se6	Substratified glaciofluvial sand, gravelly sand, and sandy gravel.	8 m
Se5	Massive diamicton, mainly pebble-sized stones in a clayey silt matrix; probably glaciomarine in origin.	10 m
Se4	Clayey silt, silt, and silty clay; contains scattered stones and marine shells; massively bedded. Marine and/or glaciomarine deposits.	25 m
Se3	Lodgement till with a clayey silt matrix; similar to Sel in places lies directly on Sel.	8 m
Se2	Substratified glaciofluvial sandy gravel and gravelly sand.	11 m
Sel	Lodgement till with a clayey silt matrix.	11 m
	Erosional Unconformity	
	Highbury Sediments	
H5	Silty sand, sandy silt, fine sand, silt, coarse sand, and gravel horizontally stratified and bedded fluvial deposits, probably of floodplain origin.	26 m
H4	Clayey silt, silt, organic clayey silt, and peat, horizontally bedded fluvial floodplain deposits. Peat and organic sediments have maximum thickness of 13 m; at Maryhill (Coquitlam) H4 grades laterally into H5 and lies unconformably on H3.	18 m
H3	Sand, gravelly sand, sandy gravel, and minor silt and silty sand, horizontally stratified, crossbedded fluvial deposits; in places occupy channels in H1 and H2.	21 m
H2	Sandy silt, organic silt, and peat, horizontally bedded lagoonal deposits; in places contains marine shells.	5 m
H1	Fine sand, sandy silt, silty sand, and clayey silt. Horizontally stratified and bedded marine deposits, probably a shallow marine and brackish lagoonal environment. H1 grades upward into H2; also H1 may be a proglacial offshore marine equivalent of W3.	35 m

Unit	Name	Maximum Thickness
	Erosional Unconformity	
	Westlynn Drift	
W4	Substratified glaciofluvial sandy gravel and gravelly sand.	30 m
W3	Rhythmically bedded clayey silt and silty clay; lenses of till, sand and gravel. Found in mountain valleys above elevations of 75 m.	150 m
W2	Massive diamicton, pebbles and cobbles in sandy and clayey silt matrix. Contains marine shells. Glaciomarine deposit.	10 m
W1	Lodgement till with clayey silt matrix. Stones range from pebbles to boulders in size.	12 m
	Pre-Westlynn Drift and Sediments	
PW1	Silt, clayey silt, sandy silt, silty sand, sand, and gravelly sand.	60 m
PW2	Till, gravel, and sand.	35 m

Items of Special Interest

(1) Everson Interstade (Fraser Glaciation) glaciomarine deposits were found at elevations of 100 m on the west side of Stave Lake, 150 m northeast of Websters' Corner and at an elevation of 135 m 16 km north of Hatzic. These three localities are 5 to 16 km up valleys incised in the Coast Mountains. Glaciomarine deposits at 45 m were found in the Ryder Lake area about 100 km east of Vancouver. All localities help establish the extensive retreat of Surrey ice before the advance of Sumas ice.

(2) A mammoth tusk was found at 45 m elevation at the top of the glaciomarine deposits in the Ryder Lake area. Overlying these are 7 m of sands and gravels with organic material, which grades upward into glaciofluvial deposits, and at elevations of 90 m Sumas till overlies the section.

(3) A section of organic sediments, 13 m thick containing 9 m of peat was observed below two glacial sequences at Maryhill, Coquitlam. One, 1.2-metre section of peat contains boulders up to 1 m in diameter. The peats also contain logs and insects.

(4) A bed of faulted peat, 3 m movement, was observed below two glacial sequences at Port Moody.

(5) Sumas-type till was found at Furry Creek on Howe Sound overlying glaciomarine deposits. This would indicate a late ice advance southward down Howe Sound in addition to the previously established late advance westward in the Fraser Lowland.

(6) Fluvial fan deposits of post or late glacial age were observed near Yale. At 30 m above the Fraser River they contain an organic layer. The deposits are higher in elevation than the middens (9,000+ years old) near Yale.

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101. INTEGRATED LANDSCAPE MAPPING OF EASTERN MELVILLE ISLAND, DISTRICT OF FRANKLIN

Projects 710041 and 710042

D.M. Barnett, S.A. Edlund and L.A. Dredge
Terrain Sciences Division

The integrated pilot mapping project of Eastern Melville Island, initiated in 1973 (Barnett and Dredge, 1974), was designed to gather and correlate basic data dealing with a range of environmental factors of possible concern for future environmental management, including potential pipeline routing.

The approach was designed to produce a coherent environmental statement based on both field and air-photo interpretation for more than 6,000 square miles mapped at 1: 125,000. Such a system is believed to be readily applicable throughout the Sverdrup Basin and possibly farther afield. This note deals with data presentation ancillary to the basic photomosaics.

A three-level hierarchy was formulated for presentation of the Melville Island data. Although rank is implicit in a hierarchy, in practice the ranks indicate degree of generalization of the data. The names assigned to the levels are "Landscape Type", Geobotanical Facies" and "Terrain Units", each being a natural subdivision of the rank above. In this way the user has a selection of various aspects of the landscape which he may wish to examine with a choice of three levels of detail.

Regional Unit: LANDSCAPE TYPE (LT).

This basic unit is based on published geological formation boundaries, but it includes additional units such as Quaternary Alluvium and Quaternary (?) brown gravels. A geomorphological component is inherent in this unit as well as a vegetational aspect. The expanded legend covers a range of information pertinent to the scale of the unit.

Intermediate Unit: GEOBOTANICAL FACIES (GbF).

This unit is a subdivision of the Landscape Type having composite distinctive character, including vegetation, while retaining visible affinity with the larger unit, *or* bedrock unit masked by veneer of variable thickness showing some characteristics of the underlying unit.

Detailed Unit: TERRAIN UNIT (TU).

This unit is a subdivision of the Geobotanical Facies unit having distinctive character detectable on air photographs. These units recur on a variety of different landscape types. It is at this most detailed level that greatest judgment is required in order to limit the units to a manageable number. The system allows for the addition of further terrain units from other environments within the numerical format.

Eleven 1: 125,000 airphoto mosaics have been prepared using this hierarchical system for presentation on three map-sheets. Twenty Landscape Type units were described and each assigned a letter code conforming to geologic convention. These units then were subdivided into Geobotanical Facies, represented by a single number which follows a convention from the number "1" for Alluvium and then moves from sea level upward.

Fifty-one distinctive Terrain Units were recognized within the sum of the Geobotanical Facies. The units recur throughout eastern Melville Island; none are exclusive. Terrain Units are assigned a three-digit number which follows a decimal point that separates it from the Geobotanical Facies. In the Terrain Unit portion the lead digit indicates the primary basis for pattern recognition with 0 indicating landform, 1 indicating veneer, and 2 indicating geobotanical pattern. In addition the landform group is further subdivided so that the second digit of the group of three is set up so that 0 indicates a fluvial environment, 2 a coastal environment, 4 a periglacial environment, 6 a glacial environment, 8 a bedrock controlled environment, and 9 a localized deposit. The final digit identifies the specific landform. Therefore each Terrain Unit within a Landscape Type has a specific address:

(LT) Bjorne Sandstone → veneered unit
Trb 4.109 ← Rubble veneer (TU)
Unvegetated Bjorne Sandstone (GbF)
(above marine limit)

Accompanying the maps are expanded legends (Fig. 1) in which the units are divided into environmental variables which are treated at three levels corresponding to the three mapping levels, to enable information storage and retrieval at each level (in anticipation of a range of questions requiring differing degrees of detail). The section designated 'Summary Evaluation' involves value judgments based on both hard data and field experience as the reconnaissance nature of the project did not permit more rigorous sampling. The maps and legend are available through Geological Survey Open File (released late 1974). An encyclopedic text, corresponding to the legend format, also is being prepared to enable the user to obtain rapidly specific answers to more detailed questions. Available information on any Terrain Unit type can be located in the text in 30 seconds.

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DIAGRAM OF EXPANDED LEGEND

- LANDSCAPE TYPE (heavy stippling)
- TERRAIN UNIT (no stippling)
- GEOBOTANICAL FACIES (light stippling)
- || INFORMATION BOUNDARY Gbf

	LANDSCAPE TYPE % AREA	L T	BJORNE SANDSTONE (Trb) 692.2 sq.km. 11% of area mapped		
	GEOBOTANICAL FACIES % AREA	GbF	1. Bjorne Alluvium (4% Trb)	2. Bjorne Sandstone BML (44% Trb)	3. Vegetated Bjorne Sandstone AML(11%Trb)
	TERRAIN UNIT % AREA	TU	1.003 Alluvial Terrace well vegetated (41% GbF 1.)	2.007 Clay veneer (2% GbF 2)	3.209 Well veg. moderately dissected bedrock (90% GbF 3)
SUMMARY EVALUATION / ENVIRONMENTAL VARIABLES	MORPHOLOGY & RELIEF	L T			
		GbF			
		T U			
	DRAINAGE	L T			
		GbF			
		T U			
	SURFACE MATERIALS (includes SSC)	L T			
		GbF			
		T U			
	VEGETATION	L T			
		GbF			
		T U			
SUMMARY EVALUATION / ZOOLOGICAL COMPONENT	MAMMALS (rated by current utilization)	L T			
		GbF			
		T U			
	BIRDS (rated by current utilization)	L T			
		GbF			
		T U			
SUMMARY EVALUATION	GROUND ICE & ENGINEERING PROPERTIES	L T			
		GbF			
		T U			
	TRAFFICABILITY (rated 0-1-2)	L T			
		GbF			
		T U			
	SENSITIVITY TO TRAVEL/TO TRENCHING (rated 1-5)	L T			
		GbF			
		T U			

Figure 1. Each environmental component is treated at the three levels of detail (heavy stippling for Landscape Typ lighter stippling for Geobotanical Facies, no stippling for Terrain Units). This allows the user to select the required level of detail for each question posed.

Projects 670031 and 730031

W. Blake Jr. and C.F.M. Lewis
Terrain Sciences Division

Introduction

During the period from August 3 to 31 the writers participated in Phase II of Cruise 74-026, *C.S.S. Hudson*. The chief aim of the surficial geology program on this multidisciplinary cruise was to obtain data on bottom sediments and bathymetry over a wide area in northern Baffin Bay, Nares Strait (to latitude $79^{\circ}13'$ in Kane Basin), Parry Channel, and adjacent inlets and bays. In Lancaster Sound and Barrow Strait the work supplemented the survey carried out by Lewis *et al.* (1974) aboard *C.S.S. Baffin* in 1973. The track of *C.S.S. Hudson* in 1974 is shown in the paper by Ross and Falconer (*see* this publication, report 51), and Figure 1 indicates the location of cores and grab samples referred to in the present report.

Bottom Sampling

Grab samples were obtained at 37 stations using a Shipek sampler, and in addition, samples of the near-surface bottom sediments were obtained from most of the 13 stations where rock drilling was attempted; these were in part retrieved from sediment wedged into the angle-iron legs of the drill stand, in part by means of a short plastic core tube fastened to the drill stand. Short cores, obtained with an Alpine gravity corer equipped with a 100-lb. head were taken at three stations; otherwise all coring (29 stations) was carried out with the Benthos corer, equipped with a 2,000-lb. head. Because of unexpected difficulties in rigging this corer for piston coring, it was used simply as a gravity corer at most sites (25 stations). With two exceptions, described below, all cores recovered were less than one barrel-length (i.e., <3 m) long, although the corer frequently penetrated much deeper, as indicated by sediment adhering to the outside of the barrels or the head. Finally, samples of the bottom sediment were obtained at each of the three sites where dredging was carried out.

In addition to the various types of sediment sampling, photographs of the bottom were taken by N.E. Fenerty, Atlantic Oceanographic Laboratory, at 23 stations between August 17 and 30. Figures 2 to 4 illustrate the three main types of bottom encountered, although the examples shown here are all from Barrow Strait and Peel Sound, areas which are of particular interest because of possible pipeline routes. Figure 2, from Station 119 ($74^{\circ}24.1'$N, $97^{\circ}45.0'$W) in Kettle Passage south of Lowther Island, is an example of the most common type of bottom encountered, a lag gravel surface in which many of the angular rock fragments are more than 10 cm in diameter. The subsurface material, as collected in a water depth of 122 to 125 m by the

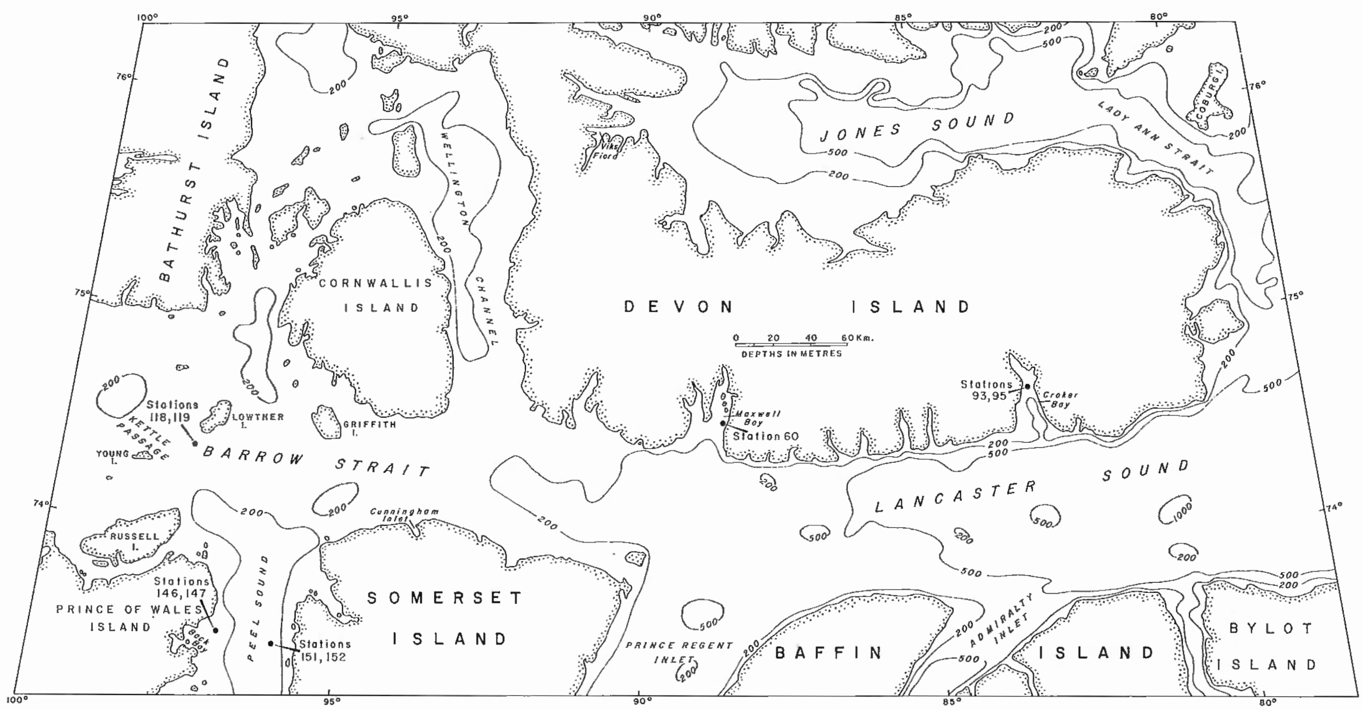

Figure 1. Location map, Parry Channel. Adapted from "Arctic Bathymetry north of 72°, 0° to 90° West" (Chart 896) and "90° to 180° West" (Chart 897), Canadian Hydrographic Service, 1967.

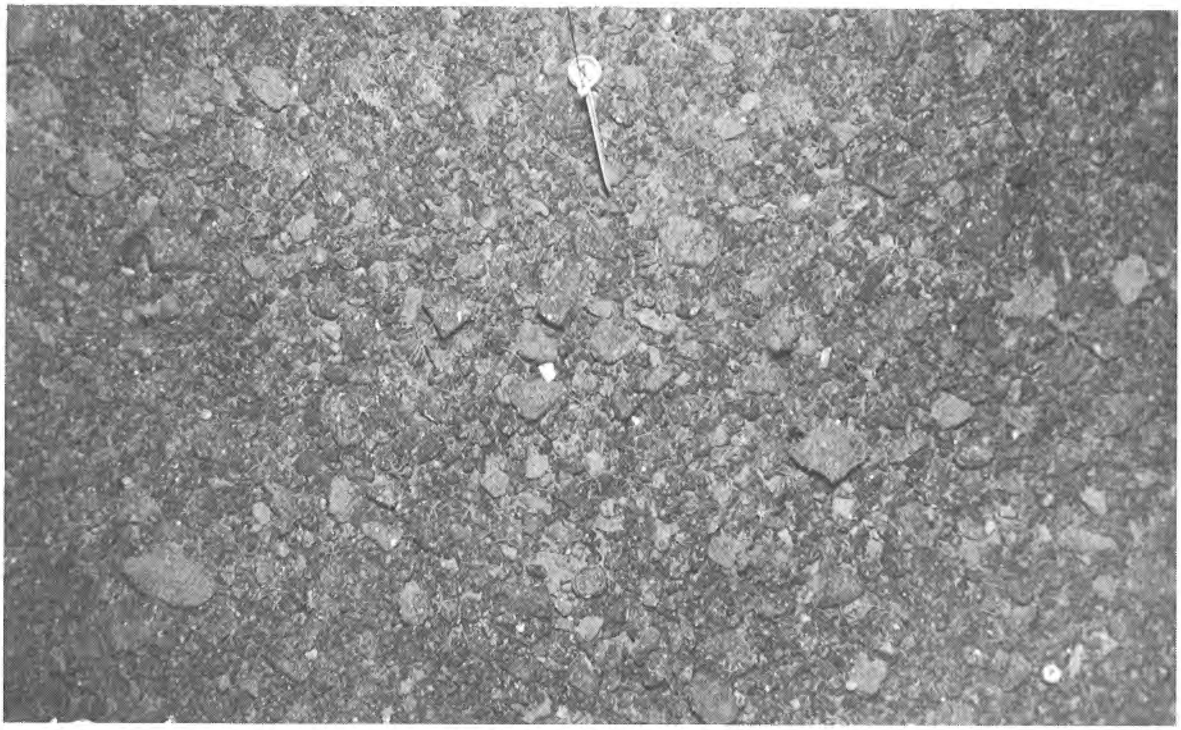

Figure 2. Detail of the bottom at Station 119, south of Lowther Island, water depth 122 to 125 m. Compass plus vane is 33.5 cm long. Some photographs at this station show a dominance of rock fragments <10 cm in diameter; others show the presence of rocks >20 cm long. August 28, 1974. (AOL photo No. 119-4)

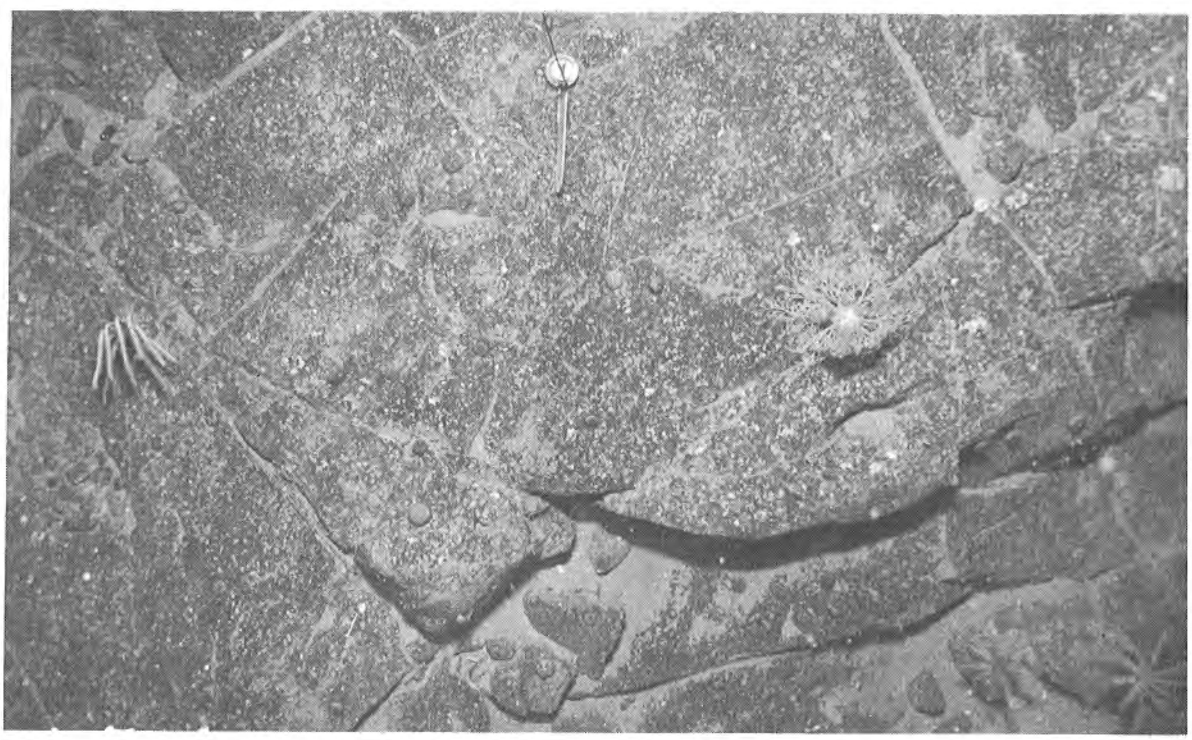

Figure 3. Well-jointed bedrock bottom at Station 147, east of Back Bay, Prince of Wales Island, water depth 112 to 114 m. Unconsolidated sediments occurred only in crevices or pockets in the bedrock. Scale as in Figure 2. August 30, 1974. (AOL photo No. 147-6)

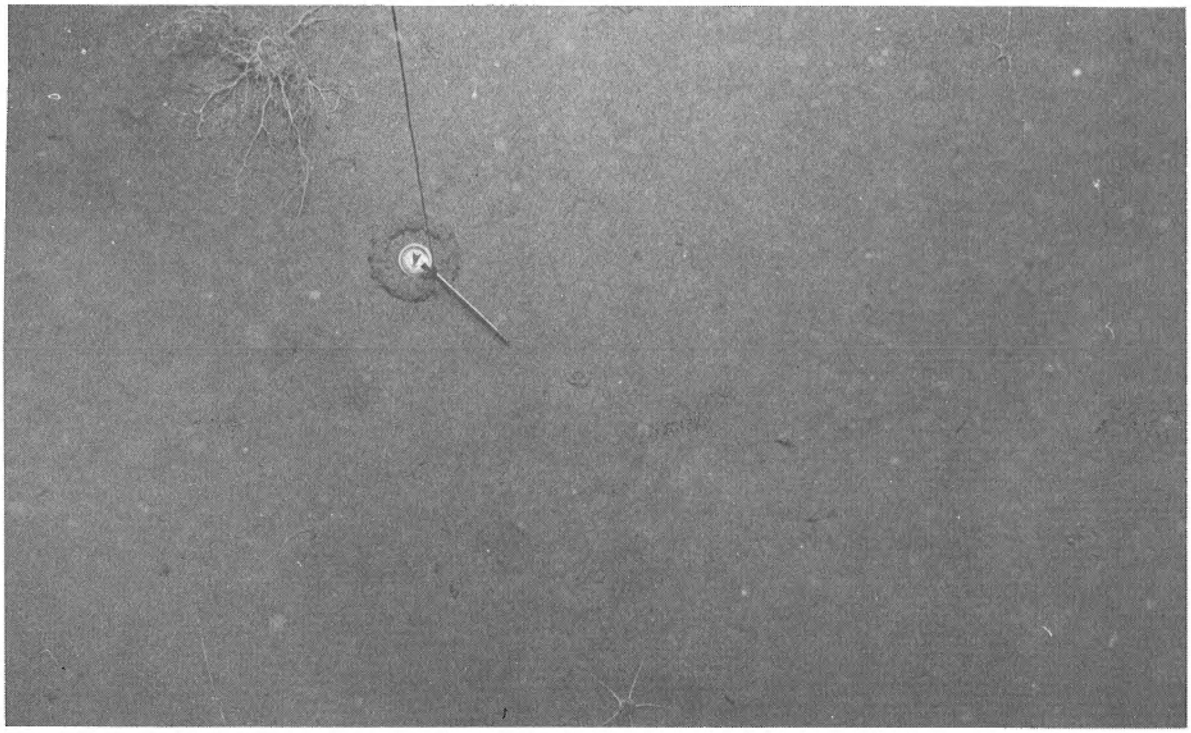

Figure 4. A silty clay mud bottom at Station 152, off the west coast of Somerset Island, water depth 290 m. Note how the compass has sunk into this soft material. August 30, 1974. (AOL photo No. 152-1)

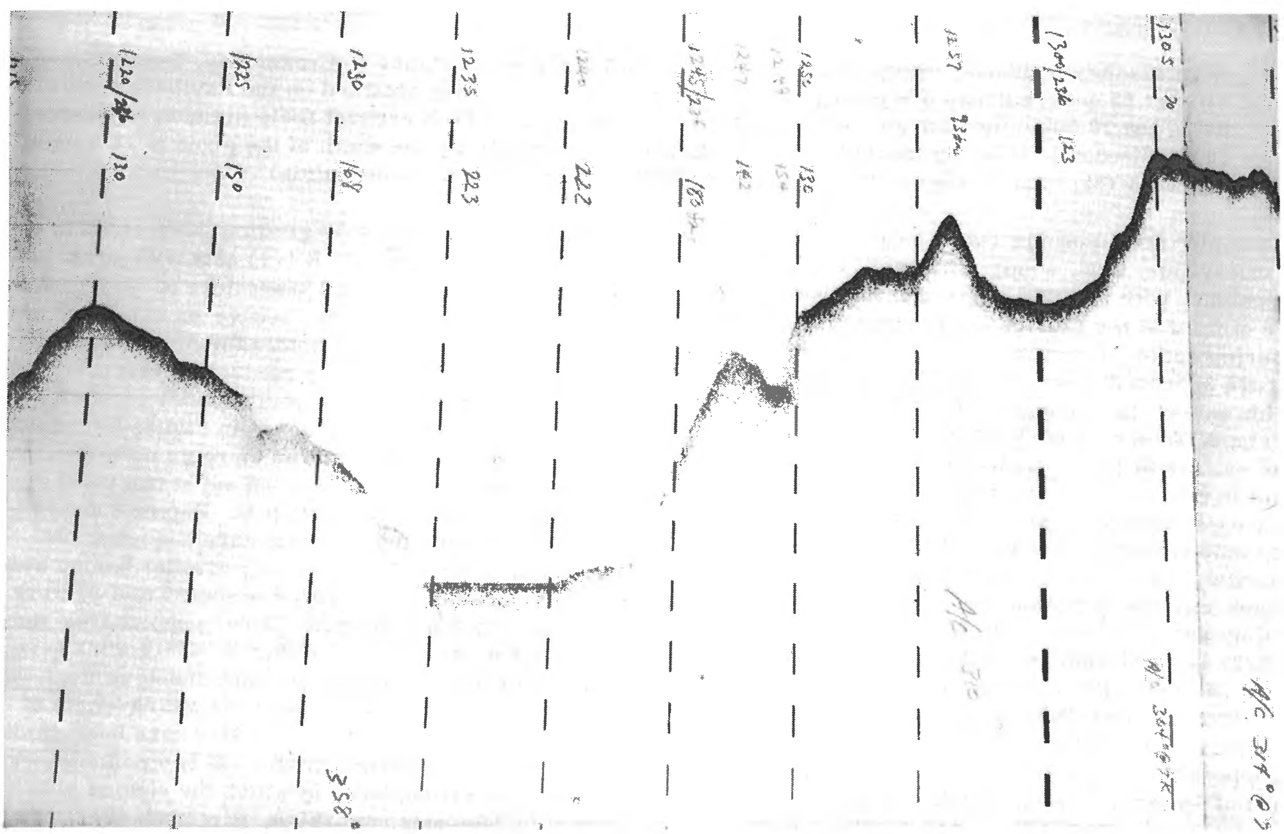

Figure 5. Bathymetric profile obtained en route northward in Croker Bay, Devon Island. Note layered sediment ca. 3.5 m thick (each vertical division is 20 fathoms = 36.6 m) in basin at depth of 222 fathoms (406 m). The distance represented by the width of the photo is 6.4 nautical miles (11.9 km). August 24, 1974. (GSC photo No. 202349-D, from a Kodachrome slide)

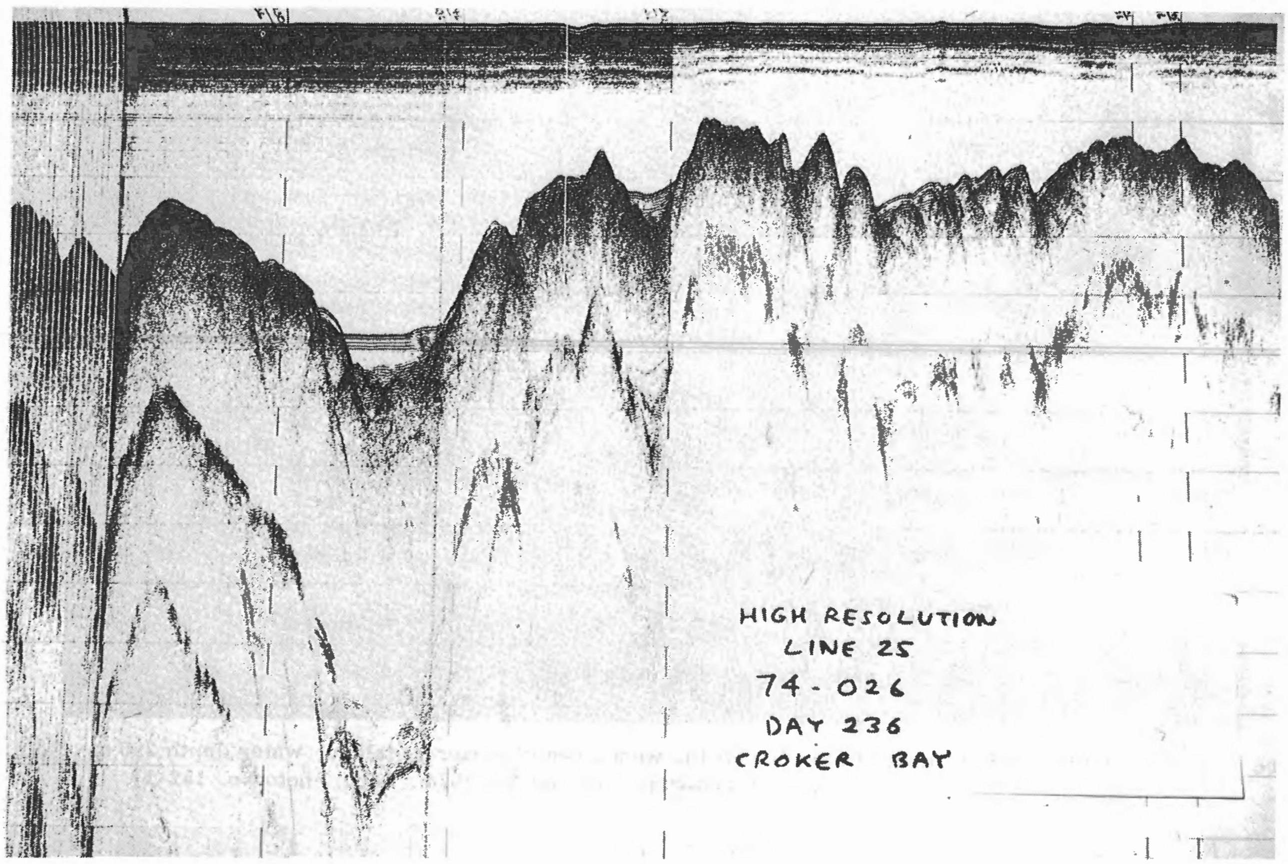

Figure 6. High resolution seismic record of the same basin as that shown in Figure 5, Croker Bay, Devon Island. At least 65 m of sediment are present in this basin. This record was obtained on the Raytheon recorder using the 10 cubic inch air gun and a short hydrophone array. Each vertical scale division represents 100 milliseconds of 2-way travel time. The distance represented by the width of the photo is 12.8 nautical miles (23.7 km). August 24, 1974. (GSC 202349-F, from a Kodachrome slide)

Shipek sampler at Station 118 (same location), is a highly calcareous, firm, sandy silty mud, grey (10YR 5/1) in colour, with pebbles admixed throughout. The absence of fines at the surface is presumably due to the scouring action of currents.

Figure 3, from Station 147 (73°33.5'N, 96°52.5'W) ca. 10 km east of the entrance to Back Bay, Prince of Wales Island, shows a well-jointed rock bottom at a depth of ca. 112 to 114 m, with only small pockets of sediment in crevices and depressions. The bedrock on the nearest coast consists of Ordovician and (?) Silurian dolomite and dolomitic sandstone (Blackadar and Christie, 1963). Only one cast out of three with the Shipek sampler at Station 146 (same location) brought up any sediment at all; i.e., a greyish brown (10YR 5/2) layer of medium- and coarse-grained sand ca. 3 to 4 cm thick, with pebbles and cobbles, which overlay silty clay and firm clay.

Figure 4, from Station 152 (73°31.5'N, 96°03.0'W) on the opposite side of Peel Sound ca. 13 km west of the coast of Somerset Island, illustrates another extreme in terms of bottom types. The sediment here, as seen in the Shipek sample taken at Station 151 (same location) in a water depth of 290 m, is a very soft, dark reddish grey (5YR 4/2) silty clay mud near the surface (0 to 3 cm depth), grading downwards to a semi-firm sticky grey (5YR 5/1) clay with a trace of silt (3 to 8 cm depth). A temperature of -0.3°C was recorded, immediately after recovery, at a depth of 5 cm in the sediment retained in the Shipek sampler.

The longest cores were recovered from the inner part of Croker Bay, on the southeastern coast of Devon Island. The basin shown in Figure 5 (222 fathoms - 406 m) was encountered en route northward up the bay, and coring was carried out at two nearby positions on the outward journey. Figure 6 shows more detail of the thick sedimentary sequence preserved in this basin as well as in smaller basins nearby. The gravity cores from Stations 93 and 95 were both close to 4 m in length. Three samples from the lower 2.5 m of Core 93 (74°45.8'N, 83°12.0'W) have been analyzed for their pollen and diatom content, and five samples spread throughout the entire length of Core 95 (74°45.7'N, 83°13.2'W) also have been studied.

Both cores contain a mixture of two pollen assemblages; one assemblage, in which the state of preservation suggests reworking, is of probable Tertiary-Cretaceous age, and the other comprises Quaternary pollen types (unpublished G.S.C. Palynological Report No. 74-6, by S. Lichti-Federovich). All samples also contain abundant marine diatoms. By contrast, a sample from 2.5 m depth, just above the base of the core from Station 60 (74°39.4'N, 88°34.2'W; water depth, 172 m) in east-central Maxwell Bay, southwestern Devon Island, contains an abundant, diversified pollen assemblage of Tertiary-Upper Cretaceous affinity; Quaternary pollen grains and diatoms have not been found as yet (unpublished G.S.C. Palynological Report No. 74-5, by S. Lichti-Federovich). This sample also has been studied by W.S. Hopkins, Jr., who concludes (pers. comm., 1974), "it would appear that the source area...was the Eureka Sound Formation, largely Lower Tertiary, with perhaps an addition from the uppermost Cretaceous part of the same formation."

These studies of pollen, although preliminary, are of interest because they suggest that Tertiary or Cretaceous rocks are present in southern Devon Island. Presumably these younger rocks are inset in the valleys leading into Maxwell Bay and Croker Bay, or they are present below sea level; in fact, the absence of Quaternary or Paleozoic pollen and the lack of marine diatoms suggest the possibility that the corer at Station 60 penetrated into undisturbed Tertiary-Cretaceous sediments. The available reports on southern Devon Island (Kurtz *et al.*, 1952; Glenister and Thorsteinsson, 1963; Christie, 1969) do not indicate the presence of rocks younger than Paleozoic near either area, although on the basis of seismic records, Lewis *et al.* (1974) suggested that softer (and younger?) sediments might underlie the northern part of Lancaster Sound, southeast of Maxwell Bay. The nearest reported occurrence of Cretaceous or (?) Tertiary rocks on Devon Island is south of Viks Fiord, some 90 km northwest of Maxwell Bay (Fortier, 1963).

Acknowledgments

The writers are indebted to Captain D. Deer, Chief Officer R. Gould, and the crew of *C.S.S. Hudson* for their efforts to ensure the success of the program, and to Dr. D.I. Ross, Chief Scientist, for his support. J.R. Horsman assisted with sampling between August 17 and 27 while Lewis was working with the barge in Cunningham Inlet (cf. Taylor and Lewis, this publication, report 138) and N.E. Fenerty, Head of the Photography Section at Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, made a particularly valuable contribution with his many excellent photographs of the sea bottom. Drs. S. Lichti-Federovich and W.S. Hopkins, Jr. kindly examined the Devon Island samples for pollen.

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103.

EVALUATION OF THE POTENTIAL USES OF EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-1) DATA FOR SMALL-SCALE TERRAIN MAPPING IN CANADA'S NORTH

Project 740074

A.N. Boydell
Terrain Sciences Division

Techniques of analysis of ERTS-1 data commonly fall into two broad classes: those which are concerned with the visual interpretation of photographic images derived from multispectral data, and those which use automated methods for multispectral analysis.

Among the projects of Terrain Sciences Division are several concerned with the small-scale mapping of landforms, deposits, and permafrost phenomena in the Canadian Arctic. These are part of an ongoing, systematic mapping program of the Division and are designed to provide a geological data base for land use planning and various aspects of engineering construction in the north. Preparation for projects of this type requires the compilation of preliminary terrain maps for use in the field from large numbers of high-altitude air photographs.

Objectives

The principal objective of this evaluation was to determine the extent to which a pre-field program terrain map of an area in the Arctic could be produced by rapid and relatively accurate methods, using ERTS-1 data. Such a provisional map could then provide the framework for a ground-checking program during the field season to follow. Meeting the objective would require that the boundaries between the terrain units could be defined accurately and, to a lesser extent, that the surface materials could be correctly identified.

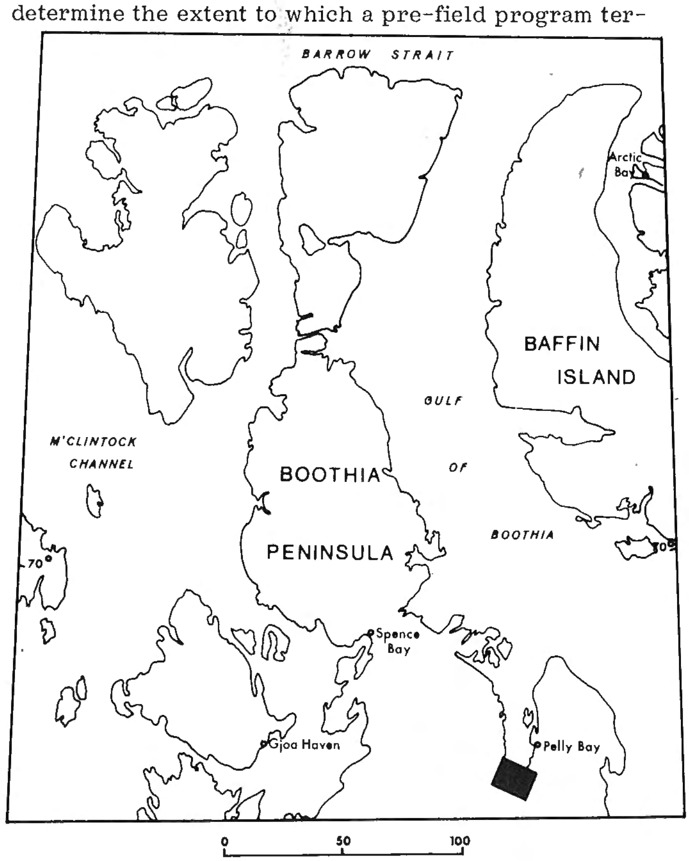

Figure 1. Regional setting of the study area (inset in black).

Selected Method of Analysis

The first group, concerning techniques of visual interpretation, was examined using black and white imagery on all four bands, pseudo-colour composites, and several methods of image enhancement using variations in assigned-colour densities. This group was discarded, not because it did not offer possibilities for terrain analysis, but because it could not generate sufficient information to construct a suitable terrain map.

The work, therefore, has been concerned with automated techniques of multispectral analysis using the Bendix Multispectral Analyzer Display (MAD) unit and PDP 10 computers at the Canada Centre for Remote

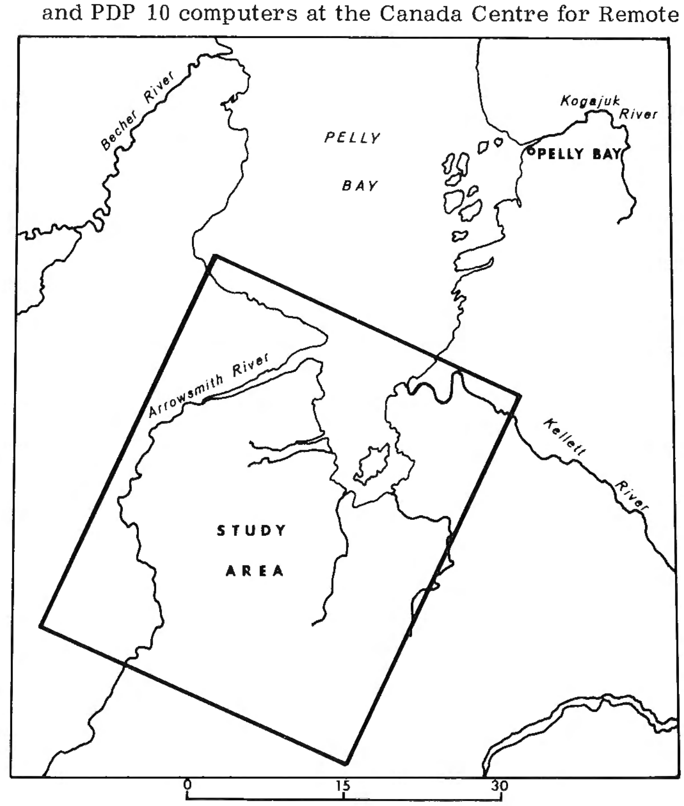

Figure 2. Location of the ERTS-1 project study area, Arrowsmith River, N.W.T.

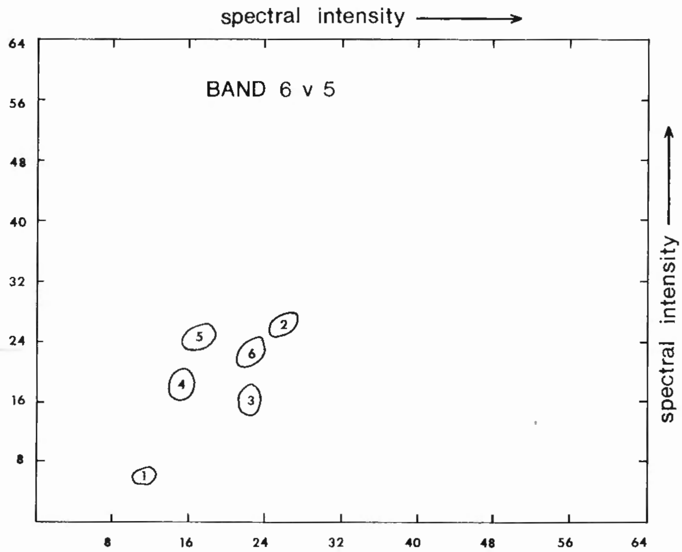

Figure 3. Class separability plot showing: (1) clear water; (2) marine silts; (3) silty water; (4) bedrock; (5) till; (6) gravel.

Sensing (for an explanation of the terminology used in this paper *see* Appendix I).

Methods

The criteria used to select the study area were those required by the technique to ensure reasonably valid data, that is: 1) low to moderate vegetation cover, north of the treeline; 2) snow-free terrain; 3) high quality of data in at least two bands, in this case, bands five and six. The area around Pelly Bay, N.W.T. (Fig. 1) was selected as it most nearly fitted the foregoing requirements and from that frame, a small area on the Arrowsmith River (Fig. 2) was used for the study.

Method of Analysis

The statistical methods used are those described by Shlien and Goodenough (1974) for automated terrain classification. Two assumptions were made concerning the validity of the data: 1) that any atmospheric distortion of the spectral signatures would be constant, and 2) that because of this, the spectral classes assigned to the terrain units would be internally consistent, that is, consistent within the area bounded by the ERTS frame.

The technique used was to display a selected portion of the ERTS frame in pseudo-colour on the Bendix and to train on areas of terrain, identified, where necessary, by reference to conventional air photography, with a software "cursor". It was found that using the cursor on a full-screen classification permitted a generalization of the probably impure terrain units (that is, representing a combination of several spectral signatures) which was more suited to pattern recognition than the more precise and purer breakdown of units provided by a computer printout of pixels.

We were able, by this method, to identify six units, and to add another unit for unclassified water areas. The units were: clear water with little or no silt content; water with a high silt content; marine silts; bedrock; till; gravel. From the class statistics a check was made on the validity of the classification at this stage by examining a plot of class separability (Fig. 3) which is a projection plot of the decision regions used by the classification program. Also examined was the divergence matrix (a value of about 50 shows that the classification was about 85% accurate for a particular pair of classes) and the confusion matrix, in which a set of synthetic data samples, having the same spectral intensities as the training set data, are run through the maximum likelihood classifier under the multivariate normal assumption (Figs. 4 and 5).

The results were displayed on full screen to check on possible unclassified areas. The additional water unit was noted, and at least one unclassified land unit. However, it was felt at this stage that the results were sufficiently promising to generate the map. The classified data were passed to the Electron Beam Recorder (EBR) to produce an image, and this was then enlarged to a more usable size for the field.

Field Checking

Field checking was carried out in mid-August 1974, using all-terrain vehicles supported by helicopter. The work consisted of checking the accuracy of the unit boundaries and the identification of materials on the ERTS map, supported by high-altitude air photographs and a topographic base map.

Results

A map of the Arrowsmith River area was compiled showing the actual disposition of surface materials, subdivided into vegetated and non-vegetated areas, and the relative concentrations of sediment in selected water bodies. Comparing this ground data map with the ERTS map, there was good agreement between

DIVERGENCE MATRIX

CLASS #	1	2	3	4	5	6
1	0.00					
2	1007.77	0.00				
3	574.20	216.71	0.00			
4	445.38	226.77	285.06	0.00		
5	1136.32	245.29	461.23	54.88	0.00	
6	660.87	9.17	60.95	127.52	172.14	0.00

LEGEND: 1 Clear water 2 Marine silts 3 Silty water
4 Bedrock 5 Glacial till 6 Gravel

Figure 4. High values in divergence matrix show good class separability.

CONFUSION MATRIX

	TRUE CLASS 1	2	3	4	5	6
0	0	0	0	0	0	0
1	100	0	0	0	0	0
2	0	86	0	0	0	9
3	0	0	100	0	0	0
4	0	0	0	100	0	0
5	0	0	0	0	100	0
6	0	14	0	0	0	91

Figure 5. Note the confusion between the marine silt (2) and gravel (6) classes. This lead to the suspicion that the gravel class was probably marine sand.

boundaries. Boundaries were most precise where there was minimal vegetation on at least one of the units being compared, for example, between unvegetated marine silts and other units, between unvegetated marine or alluvial sands and other units, and generally between bedrock and other units.

For the materials, the unvegetated marine silts were correctly identified, the original gravel class was, in fact, sand, and the original bedrock was generally bedrock, with or without sparse vegetation. However, as differences in vegetation in the original classification were not taken into account, the nature of materials underlying the vegetated areas proved difficult to determine. Most of the area classified as till was vegetated marine silts, some of it was vegetated marine sands, and a very small part, vegetated till. The unclassified land areas proved to be mostly sparsely vegetated marine sands which, to the north of the Arrowsmith River, showed up as having similar spectral signatures to some of the bedrock.

Despite these problems it was felt that, for the purposes of the evaluation, the original ERTS map was still acceptable, and that closer attention to detail would permit reclassification of the vegetated units in terms of significant plant communities and unit boundaries. Since the map was to be only preliminary, for use in the field-checking program, correct identification of the boundaries rather than the materials, was considered to be the prime requisite.

Using the ground data from the summer, the area was reclassified to determine whether differences in the vegetation supported by marine sands and marine silts would produce discrete classes. Using the cursor on full screen, nine units were established: high, medium, and low concentrations of sediment in water bodies, unvegetated sands, unvegetated silts, sparsely vegetated sands, vegetated sands, vegetated silts, and bedrock. Class statistics showed a better than 85% probability that the units were identified correctly.

Costs and Benefits

Concern with evaluating a technique which might replace much of our traditional use of air photographs requires some comments on the comparative costs and benefits of the two approaches. It would be unrealistic, however, to view these in terms of dollars and cents because of the current developmental nature of the research; rather, time will be discussed, both as it relates to computer use and in terms of user time applied to the job.

Computer Time

It is estimated that a full-frame classification (185 km^2) will use about three hours of computer time on the average. This will vary with the complexity of the classification in terms of both numbers of units and any modifications that might be required such as changes in lookup tables. Measured against the use of conventional air photographs, this is also a real cost to the user, which would not enter into the latter approach.

User Time

Disregarding the vagaries of computer systems, it is felt that the total time taken to generate a full-frame ERTS map should be about three to four days. Added to this would be a variable time factor of up to two weeks for processing the image on the EBR system, depending on how readily it could be accessed. If an area to be mapped is covered by parts of four ERTS frames, equalling about 32,000 km^2 (20,000 square miles), then three to four weeks should be allowed to produce the terrain maps. Comparing this with the traditional airphoto technique, coverage of an equivalent area should take three to four man-months, in order to classify the terrain and transfer the data to a suitable base map. The only real advantage in using the latter technique is that, with the addition of morphologic analysis, greater detail and more precise definition of the nature of the surface materials can be achieved.

It should be noted, finally, that the Bendix-PDP 10 system used on this project is not economically operational, largely because of its slowness, and time-sharing costs. Further research on this project will use the Image 100 Series system which not only has its dedicated computer but is also fully interactive, reducing both time and operational costs.

Conclusions

Programs of small-scale terrain mapping in the north may be enhanced by the use of automated techniques of multispectral analysis of ERTS-1 data. However, it must be stressed that the product is useful only as the starting point for other, more conventional mapping activities. It is felt that human experience and expertise alone determines the validity of the classification, and that this can be verified only by substantial ground checking.

While the use of ERTS saves time and effort in the early stages of a mapping program, there is a continuing need for conventional air photography to complement the ERTS data, and to identify areas requiring more detailed attention.

Further testing of the technique is required. There is a need to establish new training sets for each succeeding ERTS frame. The validity of the assumptions regarding the internal consistency of spectral classes within an ERTS frame must be tested. Can the vegetation and other inputs, such as slope effects, be rationalized to make the classification more precise? In the ongoing research program, these problems are being investigated in an attempt to apply the same methods for other, quite different, types of terrain in the Canadian Arctic.

Reference

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APPENDIX I

Bands 4, 5, 6, 7: Two sensor systems are carried in the Earth Resources Technology Satellite, a Return Beam Vidicon (RBV) unit and a Multispectral Scanner (MSS). The MSS covers four spectral bands:

*0.5 - 0.6	Blue-green = Band 4
0.6 - 0.7	Red = Band 5
0.7 - 0.8	Near infrared = Band 6
0.8 - 1.1	Near infrared = Band 7

*micrometres

Bands 5 and 6 have been found to be generally the most useful in terrain pattern recognition.

Class Separability: This is a projection plot of the decision regions used by the classification program. A point falling inside the region is assigned the theme corresponding to the region. The decision areas are ellipses since the maximum liklihood decision rule was employed under the multivariate normal assumption. The size of the ellipse is directly related to the covariance matrix of the class. The ellipse is centred at the means of the spectral intensities.

Lookup Tables: A listing, in the computer memory, of the statistics of spectral signatures from any of the four channels, that already have been used in the classification. This provides a rapid reference system by which a watch can be maintained on the validity of the data during classification.

Pixel: Each ERTS frame is composed of 2400 scan lines, each line being about 3200 picture elements long. The picture element is termed a pixel.

Pseudo-colour Composite: This is a photographic image which attempts to approximate to a true representation of the terrain, in colour. A red colour image can be made using Bands 4, 5 and 6, and a blue colour image is made using Bands 5, 6 and 7.

Software Cursor: The Bendix has an added capability for interactive graphics. It consists of a square/rectangular frame superimposed on the displayed image. The operator can adjust the dimensions of the frame and move it to any part of the screen. It will appear black on light coloured areas and white on dark areas. It is used, in the training procedures, to read into the computer the information contained within the cursor frame and hence to classify it.

104.

TERRAIN INVENTORY AND LAND CLASSIFICATION, BOOTHIA PENINSULA AND NORTHERN KEEWATIN

Project 740074

A.N. Boydell, K.A. Drabinsky and J.A. Netterville
Terrain Sciences Division

Terrain studies were carried out in the Boothia Peninsula-Rae Strait-Simpson Peninsula areas between 72° to 68°N and 88° to 96°W, an area of some 55,000 km^2. Terrain mapping was conducted by the authors and utilized helicopter support originating out of Fort Ross (Somerset Island), and the settlements of Spence Bay and Pelly Bay.

The objectives of the field component of this project were: 1) to undertake a terrain inventory of landforms and materials, including a granular resources survey, based on detailed ground checking of preliminary, photo-interpreted maps; 2) to study and record the characteristics of permafrost terrain and the distribution of ground ice with respect to sediment types; 3) to examine, where possible, the stratigraphy of the unconsolidated sediments, and other evidence of glacial and postglacial events, in order to describe the Quaternary history of the area; 4) to conduct a biophysical land classification survey in conjunction with C. Tarnocai, Soil Research Institute, Winnipeg (*see* this publication, report 118); 5) to evaluate the potential uses of Earth Resources Technology Satellite (ERTS-1) data for terrain mapping. Ground checking of the ERTS data was carried out in the Arrowsmith River (Pelly Bay) area and is the subject of a separate report (*see* this publication, report 103).

In addition, detailed studies of terrain and permafrost conditions were carried out in areas selected as being representative of their particular terrain units. These studies included detailed soils and vegetation inputs, surface drainage and surface temperature studies, temperature profiling in the active layer, and recording the character of the frozen sediments below the permafrost table. Some of the detailed studies were complemented by a limited, shallow-drilling program directed by J. Viellette (*see* this publication, report 120), and a hammer seismic program directed by J.A. Hunter.

The sampling program produced about 300 samples for testing the reactive properties of the sediments, the geochemical properties of the tills, granular resources documentation, and radiocarbon dating. Marine shells (mostly *Hiatella arctica*) from postglacial marine silts were collected at an elevation of 225 metres from an unnamed island in Pelly Bay (68°57'N, 89°58'W). This would appear to be the highest elevation from which postglacial shells have been collected in the Canadian Arctic. The shells have been submitted for dating.

Samples of Meerschaum (sepiolite?) were collected from outcrop in a fault valley to the east of Burwash Lake (68°55'N, 91°W). The Meerschaum appears to be confined to a zone of contact between Precambrian and Paleozoic rocks (*see* Heywood, 1961) and is contained between sharply-dipping bedding planes. It commonly exhibits crystalline inclusions and is of generally rather poor quality. Samples have been submitted for analysis.

Terrain Regions

For ease of description, the study area is divided into eight terrain regions (Fig. 1), distinguished by differences in surficial materials, physiography, and bedrock types. Elements of one region may be found as minor constituents of another. Most of the boundaries are gradational and have been drawn from field observations, photomosaics, and topographic maps.

Region 1

Till with a high content of carbonate rock detritus forms a thin (1- to 3-metres thick) mantle over gently-dipping dolomites, limestones, and sandstones throughout most of this region. About one half of the region is covered by old marine beach deposits, one to two metres thick. The beach deposits consist of carbonate

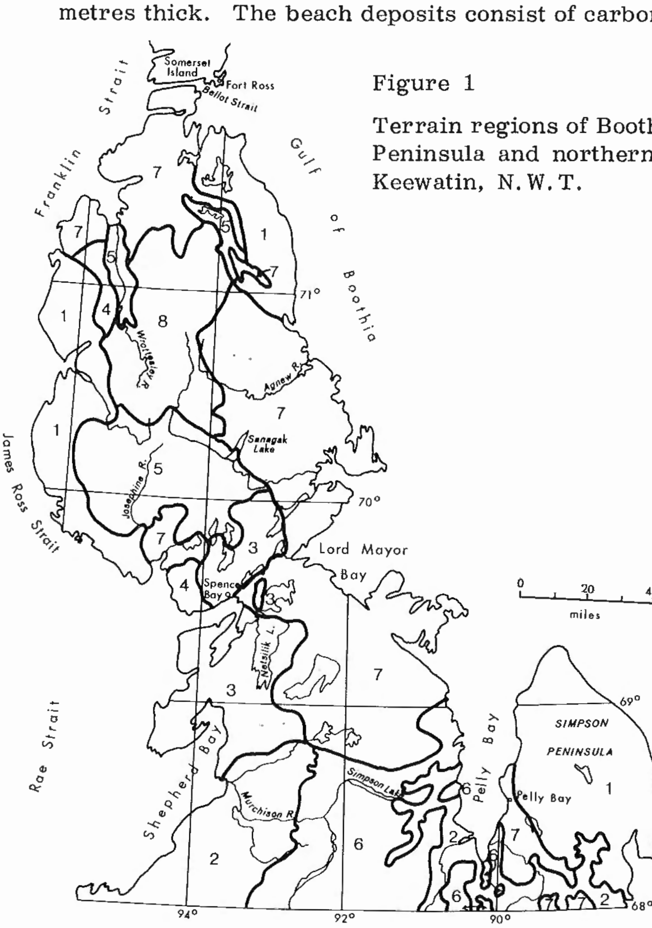

Figure 1

Terrain regions of Boothia Peninsula and northern Keewatin, N.W.T.

shingle or fine carbonate gravel, and commonly overlie Paleozoic bedrock. The remaining area consists of intensively marine-reworked till surfaces, with marine sediments in the lower lying areas. Terrain in this region has a generally low local relief of less than 10 metres.

Bedrock outcrops sporadically throughout the region, commonly as scarps, 10 metres or more in height, and extends laterally for several kilometres. The bedrock is predominantly thin bedded and should provide a ready source of rip-rap material.

The maximum thickness of the active layer is commonly less than one metre. Massive ground ice occurs in the form of vertical wedges in fine- and medium-grained marine sediments in low-lying areas. One small pingo occurs in marine silts within a depression on the northeast side of Simpson Peninsula.

Region 2

This lowland region consists primarily of thick (up to 10 metres) marine silts, clays, and minor amounts of sand. Deltaic sand and gravel, and ice-contact sand and gravel in the form of eskers and small kame knolls are scattered throughout the southern portion of the terrain region west of Murchison Lake. Low granitic hills and knolls form a minor constituent of the terrain, particularly near the boundary with Region 6.

Ground ice is a widespread and important component of the region and commonly occurs as massive lenses and blocky veins, forming a three-dimensional, lattice-like structure similar to that within fine-grained sediments of the Mackenzie Valley (*see* McRoberts and Morgenstern, 1973). Massive ice wedges occur in polygonal networks through much of the region and are particularly common and well developed where fine to medium sand, one to two metres thick, overlies marine silt or clay. The active layer is commonly less than 70 cm thick and low-angle skin flows are common along river channels.

East of Shepherd Bay, the terrain is flat to gently undulating. South of Pelly Bay, the region is restricted to broad valleys within an area of strong bedrock relief. Earth and vegetation hummocks with 10 to 30 cm relief are everywhere on the silts and clays, making ground travel during the summer months extremely difficult.

Region 3

The surface deposits and landforms in this lowland region consist mainly of till up to 10 m thick. Low, widely-spaced flutings and drumlins are common and reflect ice movement towards the northeast. Ice-contact sand and gravel deposits form a minor element of the terrain and occur as isolated knolls and ridges, or in localized belts, with hummocky relief commonly less than 5 m. Bedrock outcrops are prominent west of the settlement of Spence Bay, where the till forms a patchy veneer over low-relief granitic terrain. Paleozoic carbonate bedrock outcrops at widely scattered localities south of Netsilik Lake.

Wave modification of the surface forms has been extensive. Drumlins, eskers, and bedrock hills commonly are surrounded by marine sand or gravel beaches, or are capped by a lag concentrate of fine aggregate. Depressions commonly contain a thin surface layer of silty sand over the underlying till.

As in all the regions, this area is characterized by numerous mud boils and sorted circles. Frost cracks are well developed where sand forms the major lithologic component of the terrain. Ice-wedge polygons occur less frequently here than in the area to the south (Terrain Region 2). Permafrost commonly occurs at depths of one metre or slightly less.

Region 4

Till with a high content of carbonate rock detritus lies on granitic bedrock hills and in valleys throughout the two areas of Terrain Region 4. Thickness of the till deposits averages about 3 m. In the southern area (west of Spence Bay) the terrain is very irregular with local relief generally 50 to 100 m. In the northern area immediately west of Wrottesley River valley, granitic bedrock forms high, broad hills, and slope angles are generally lower (5 to 15 degrees) than in the area west of Spence Bay. In both areas frost action is intense; numerous mud boils, sorted circles, and stone stripes cover the till surface. The maximum depth of the active layer is about one metre.

Region 5

This large region contains variable thicknesses of till and ice-contact sand and gravel in the form of kame hills, terraces, and eskers. The drift cover is relatively continuous but thins towards the east and north. Large amounts of sand and gravel are located in the south and west. Limited areas of Paleozoic sandstone, dolomite and limestone outcrop southwest of Sanagak Lake as well as in the headwaters of Josephine River. Elsewhere in the region, frost-shattered granitic rocks appear as scattered, minor exposures.

The terrain is characterized by rolling hills and broad valleys, except in the sand and gravel areas where steep slopes abound. Local relief is commonly less than 50 m. Drainage is good except on low-angle till slopes where solifluction processes are active. A thin layer of black lichen commonly covers such areas, making them readily identifiable on low-level airphotos. These solifluctcd areas are water saturated, and are frozen at about 40 cm depth (in July). Elsewhere, intensive cryoturbation is evident in the till, resulting in sorted circles and stone nets. The maximum depth of the active layer is in the order of one metre.

Region 6

This region includes the central mainland in the southern part of the map-area, as well as smaller areas within Region 2 to the east. The Precambrian upland is of moderate relief with the highest elevation at 380 m a.s.l., south of Simpson Lake. This upland surface is dissected by the Murchison River—Simpson Lake drainage system.

Surface deposits are varied. A discontinuous veneer of "granitic" till decreases in thickness and cover from north to south, grading into a boulder-covered till veneer. Other areas of bouldery terrain consist of channelled outwash flats and ice-contact ridges associated with southwest-northeast-trending gravel eskers. Ground access in this area would be difficult.

Flat and intermittently-dissected terrain also forms a part of the southern region. It is composed largely of deltaic sands and other sands of marine origin. These sand plains are characterized by shallow thermokarst lakes and continuous moss/lichen cover, except where wind erosion has exposed the sediments. Although not numerous, these areas represent excellent sources of fine granular materials.

Almost all land below 228 m has been modified to some extent by marine wave action or overlain by marine deposits. Towards the marine limit, the boundary between the marine deposits and the underlying till is gradational. The Murchison River-Simpson Lake valley system has been partially infilled with marine sediments, mainly silts and clays, 10 to 15 m thick. Ground ice and terrain characteristics are as described for Region 2.

Region 7

The largest region in the map-area comprises the southern section of the Boothia-Somerset Arch complex. It consists of Precambrian granites and gneisses (*see* Blackadar, 1967) that have been greatly folded and dissected. Relief is greater in this region than elsewhere, with a maximum elevation of 591 m above sea level. This rugged upland area contains deeply entrenched river systems, particularly north of Agnew River, as well as fiord-like valleys such as those in the Pelly Bay area and in the area south of Bellot Strait.

Unconsolidated deposits are absent from much of the region and, where present, are commonly confined to valleys. Southwest of Bellot Strait, some till covers the upper plateau surfaces but is restricted to the western coastal zone. North of Agnew River, scattered talus slopes provide most of the unconsolidated materials in otherwise predominantly bedrock terrain. Scattered boulders on the upland surfaces are mostly frost heaved.

Granular resources are mainly represented by coarse, glaciofluvial gravels, scattered ice-contact ridges and eskers, and modern and raised marine beaches. Bouldery beaches, numerous along both east and west coasts, are commonly well developed in sheltered bays. North of Lord Mayor Bay, terraced glaciofluvial gravels are found in the major river valleys, which probably served as outlets for glacial meltwater. Coarse, bouldery deposits in the Agnew River valley present at least six, well-defined terraces, and extensive deltaic deposits along the northeast boundary of the region are 10 to 12 m thick. Postglacial alluvial sands occupy many of the valleys south of Agnew River, either as massive deposits up to 3 m thick, or as a veneer overlying till.

Region 8

The western extension of the Boothia-Somerset Arch complex on the mainland is represented by this relatively even-surfaced upland, lying between 300 m and 600 m above sea level. Although relief is generally low, deep, structurally-controlled gorges occasionally gouge the Precambrian surface to depths of up to 200 m.

Surficial deposits are present as an intermittent till veneer over the upland surface in the central part of the region and are confined mostly to broad, shallow valleys. Much of the upland surface is boulder covered. In the west and south, the till cover is substantially thicker, being generally associated with broad, sediment-filled, east-west trending valleys that form part of the Wrottesley River system.

Eroded glaciofluvial gravels, with local relief of up to 150 m, provide excellent sources of granular materials in the upper part of the Wrottesley River valley. Elsewhere, terraced stream gravels up to 5 m thick are common in the north-central part of the region.

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QUATERNARY GEOLOGY, NORTHERN STRAIT OF GEORGIA, BRITISH COLUMBIA

Project 740063

J. J. Clague
Terrain Sciences Division, Vancouver

A study of the surficial geology of the northern Georgia Depression was initiated in 1974. The prime objectives of this project are to establish a stratigraphic framework of unconsolidated Quaternary deposits in and around the northern Strait of Georgia, to determine present and past sedimentation patterns, and to reconstruct the Quaternary geologic history of the area.

Continuous seismic profiles, sediment grab samples, gravity cores, and underwater photographs were obtained during a cruise of the *C.S.S. Vector* in May and June 1974 (Fig. 1). Thirty-one seismic profiles, representing 600 line kilometres, were obtained with an air gun source of 16 cm^3 (1 cu. in.). These are augmented by 19 profiles (300 line kilometres) taken in 1973 with an 82-cm^3 (5-cu. in.) air gun. Two hundred grab samples were collected over a regular grid using a Shipek sampler. An additional 130 Shipek samples were taken from the tops of banks consisting largely of Pleistocene sediments. One hundred and eighty Shipek and Ekman grab samples were collected from the Comox Harbour area over a closely spaced regular grid. Nine gravity cores from 15 to 145 cm in length also were obtained.

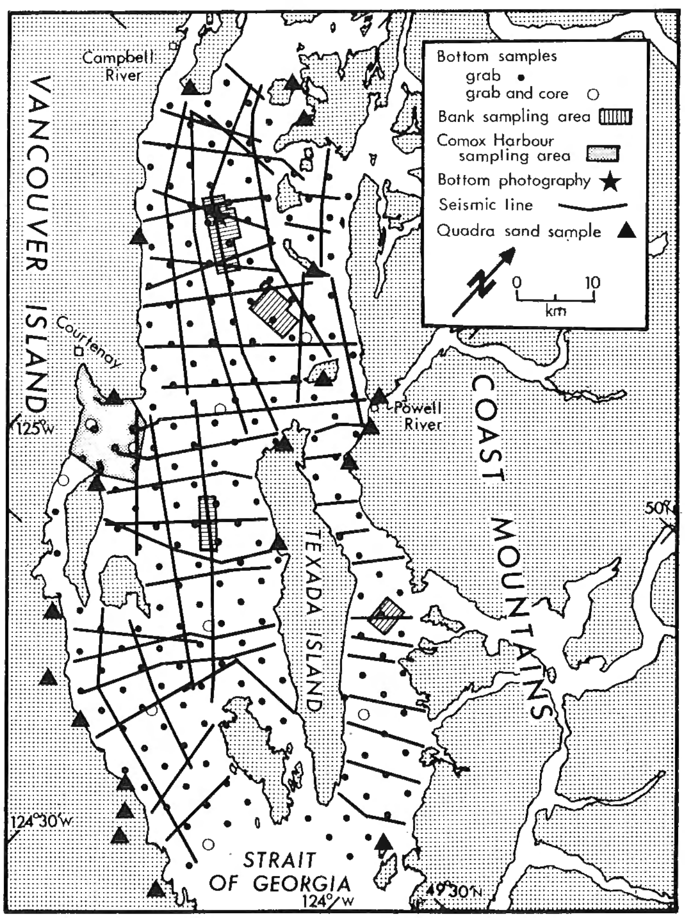


Figure 1. Location map showing sample sites and seismic profile lines. Only Quadra sample sites in the northern Georgia Depression are shown.

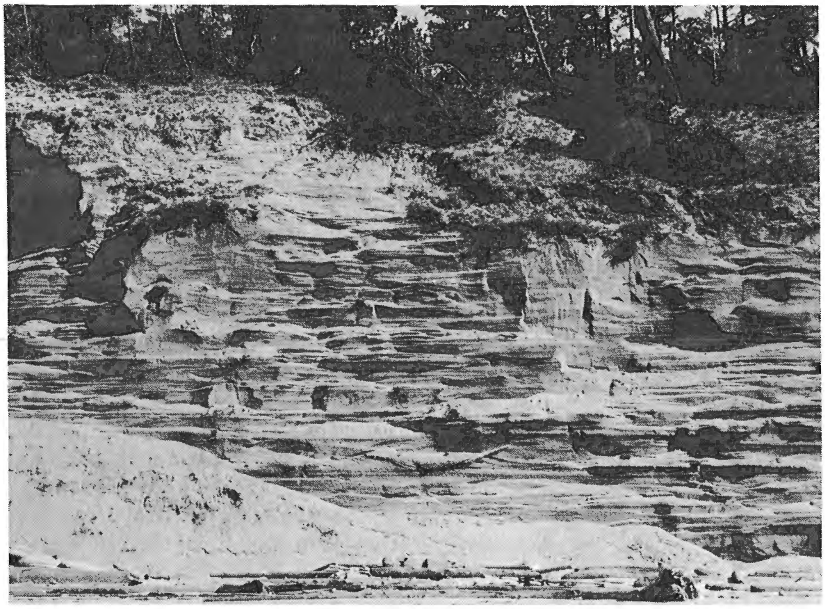
Exposures of stratified sediments predating the last continental glaciation (Fraser Glaciation) were investigated during the spring and summer of 1974. Quadra sediments, which were deposited during the Olympia Interglaciation, consist of marine silt and clay (commonly stony) and terrestrial silt, sand, and gravel (Fyles, 1963). The uppermost Quadra unit, consisting mainly of horizontally bedded, cross-stratified sand, is widely distributed in the Georgia Depression and in places is greater than 80 m thick (Fig. 2). The provenance and depositional history of this sand unit are currently under study. Eighty-six hydraulically equivalent Quadra and Holocene sand samples have been collected and prepared for mineralogic analysis. In addition, the texture and stratigraphy of major Quadra sand exposures have been examined. Paleocurrent data (axes of trough crossbeds) collected by Fyles and Clague (unpubl. data) have been analyzed statistically.

Preliminary Results

Bathymetric elements in the northern Strait of Georgia include ridges, troughs, and basins elongate in a northwest-southeast direction. This bottom topography has been produced by glacial erosion and Holocene deposition. Trough depths are locally greater than 350 m. Many islands are subaerial extensions of northwest-trending submarine ridges. On the Vancouver Island lowland bordering the northern Strait of Georgia, late Pleistocene and Holocene sediments overlie Upper Cretaceous rocks of the Nanaimo Group. The lowland on the northeast side of the study area is narrow or absent, and, except near Powell River, Quaternary sediments are thin. Bedrock here consists primarily of granitic rocks.

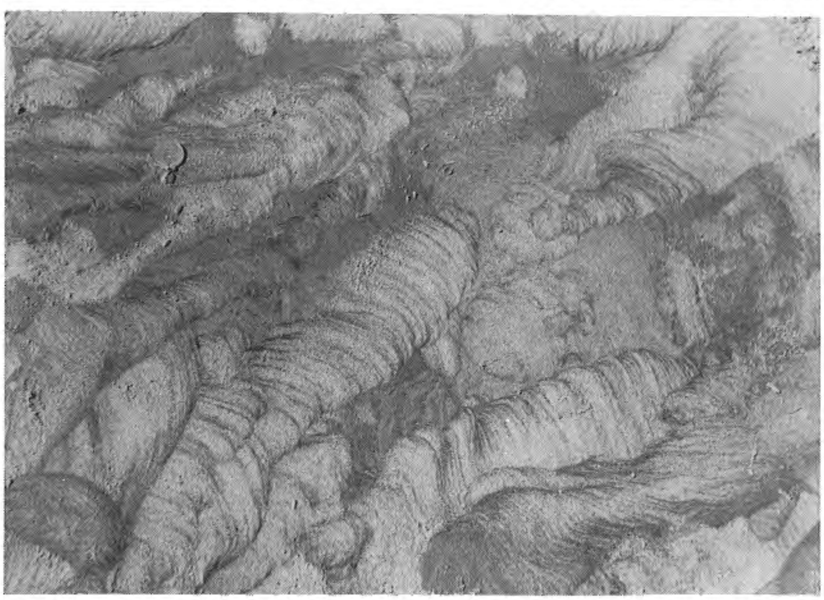
Holocene sediments in the northern Strait of Georgia were first described in detail by Waldichuck (1953) and Cockbain (1963) and include: (1) gravel, sand, and sandy silt; these coarse sediments occur on the flanks of submarine ridges and along the margins of the strait, and have formed from the erosion of older unconsolidated deposits; (2) clayey silt and silty clay; these are basin and trough sediments and are locally thicker than 175 m; sediment thickness and depth are strongly and positively correlated. The thickest and most extensive basin sediments are south of latitude

Figure 2. Quadra sand unit.



Cross-stratified, fine- to coarse-grained sand; Savary Island (49°56'N, 124°49'W).

Channel within Quadra sand unit; channel is cut in horizontally bedded, very fine-grained sand and is filled with fine-grained sand; North Thormanby Island (49°30'N, 124°01'W).



Bedding plane of Quadra sand showing trough crossbeds; Vancouver Island (49°17'N, 124°15'W).

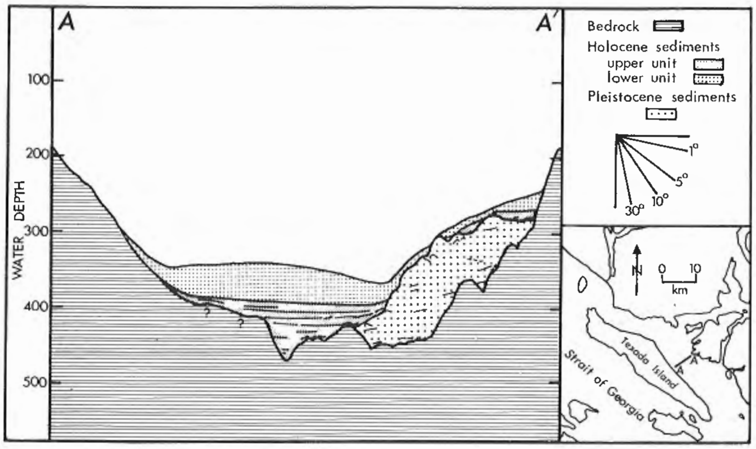


Figure 3. Selected seismic profile. Holocene sediments consist of an upper, seismically transparent unit and a lower unit with many seismic reflectors.

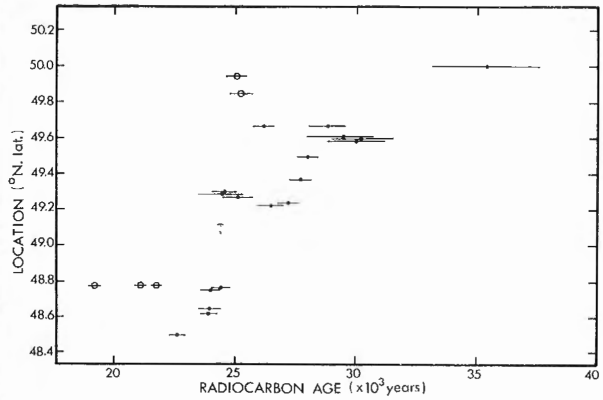


Figure 4. Relationship between Quadra radiocarbon dates and location. Dated materials are wood and peat within and below Quadra sand unit. Open circles are plots of upland samples from valleys bordering the Strait of Georgia; dots indicate samples from the Georgia Depression. Data from Fulton (1971, Table II).

49°30' and probably include detritus of Fraser River origin. The source of most Holocene sediments in the central and southern Strait of Georgia is the Fraser River (Tiffin, 1965; Pharo, 1972). However, north of latitude 49°30' there is no systematic decrease in basin sediment thickness or volume away from the mouth of the Fraser River, and seismic reflectors within basin sediments for the most part dip southeast. Although it is possible that some of this sediment is of Fraser River origin, much has probably originated through the erosion of older unconsolidated deposits and the transport of mud in suspension to the depositional site (Waldichuck, 1953). Rivers and streams flowing into the northern Strait of Georgia are, only locally, important suppliers of sediment.

Holocene basin sediments are divisible in many places into two units on the basis of seismic character and morphology (Fig. 3). The lower unit, characterized by numerous, horizontal, internal seismic reflectors, is confined to depressions. This unit overlies bedrock and chaotically-bedded or nonstratified Pleistocene sediments (drift?), and is overlain across a sharp, conformable (?) contact by seismically transparent basin sediments. Unlike those of the lower unit, the upper sediments drape over slopes rising from basins and troughs (Fig. 3). Sediments of this upper unit are thought to consist of silt and clay particles which are continually carried in suspension to the sea floor. The sites and rates of deposition are controlled by locally variable currents. Apparently, conditions have changed in the interval between deposition of the upper and lower basin units. Strong seismic reflectors within the lower unit indicate the sediments are stratified rather than massive. This stratification may have been produced by the periodic deposition of detritus from density currents. At the close of the Fraser Glaciation, drift covering steep slopes may have been gradually transferred in turbidity currents to deep basins. This process would continue until available drift was consumed in gravitational transfer and then would be replaced by the normal rain of dispersed fine particles.

Pleistocene deposits in the northern Strait of Georgia include diamicton and stratified sediments. They occur widely in the study area as erosional remnants, locally to several hundred metres below sea level and in excess of 550 m in thickness (the lower parts of such sediment piles may be Tertiary in age). Many islands in the northern Strait of Georgia and coastal areas bordering the strait consist of Quadra sediments overlain by Fraser drift. These sediments rest upon platforms of older Pleistocene deposits which, in large part, are below present sea level. Major unconformities occur within the sediment piles; thus the sequence of late Cenozoic depositional and erosional events is complex.

The Pleistocene sediments are remnants of a formerly more extensive fill in the Georgia Depression. Prior to the Fraser Glaciation, subaerial Quadra sediments were deposited on a platform of older Pleistocene materials. A major aim of the present study is to document the extent of this platform by determining the conditions under which the Quadra sand unit formed.

Radiocarbon dates from Quadra sediments indicate that the sand unit is progressively younger towards the south (Fig. 4). This is in agreement with paleocurrent data indicating south- to southeast-flowing currents during deposition. The dates further suggest that aggradation at any one site occurred in a relatively short period of time. For example, at latitude 49°16' sand at least 50 m thick was deposited after 24,500±500 years B.P. (GSC-108) but prior to glacial invasion of the area about 19,000 to 20,000 years ago. Some Quadra sediments in uplands adjacent to the Strait of Georgia were deposited in ice-marginal environments. For example, west of the study area (49°57'N, 125°36'W), Quadra sand a few hundred metres above sea level was laid down about 25,000±400 years ago (GSC-58) against an ice front to the east; presumably, ice filled the northern Strait of Georgia at this time. Yet, at about the same time, Quadra sand was being deposited in lowland areas of the southern Georgia Depression. It is probable, then, that the Quadra sand unit formed on outwash plains in front of, and in response to, glaciers advancing into the Georgia Depression during late Wisconsinan time. Available evidence provided by pollen and leaf imprints indicates that the sand was deposited under cool or temperate climatic conditions (Fyles, 1963, p. 37). However, the presence of ice-wedge casts internal to the sand unit suggests that, locally at least, frozen ground existed in the area during Quadra deposition.

The mineralogy of Quadra sands indicates derivation from granitic rocks north and northeast of the Strait of Georgia. However, there are regional variations in Quadra mineralogy. For example, at Vancouver (49° 16'N, 123°15'W) the Quadra sand unit consists, in part, of sediment eroded from late Cenozoic volcanic rocks outcropping about 70 km to the north (Mount Garibaldi area). Volcanic rock fragments (including glass), plagioclase, and clinopyroxene are especially common constituents. Volcanic detritus is even more abundant in underlying organic-rich, interstratified Quadra silt and sand.

The Quadra sand unit shows no systematic textural gradation areally in the Georgia Depression or vertically at an exposure. The sand unit throughout the depression consists largely of fine- to medium-grained sand; however, some upland sediments thought to be correlative with the Quadra sand unit are gravelly. Silt beds are most common at the base of the sands, but are by no means restricted to that position.

There is no evidence that the Quadra sand unit in the Georgia Depression was deposited as a series of small isolated bodies. Rather, the present patchy distribution is due in large part to the erosion of an originally more extensive body. Exposed Quadra beds are horizontal, uniform in character, and continuous over distances as great as 6 km. Strata on Savary Island (49°56'N, 124°50'W) correlate with strata 18 km distant on Harwood Island (49°51'N, 124°38'W).

It is tentatively concluded that the Quadra sand unit was derived in large part from the Coast Mountains and deposited progressively from northwest to southeast in the Georgia Depression in front of advancing glaciers during late Wisconsinan time. The unit was deposited on a platform of older marine, estuarine, and fluvial sediments. Although its original extent is not precisely known, the unit was more extensive than at present.

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SURFICIAL GEOLOGY, SEPT ÎLES - CAP CHAT

Project 710083

L. Dredge[1]
Terrain Sciences Division

Mapping of the surficial geology of parts of map-sheets 22 G and 22 J, north of the St. Lawrence River, was begun in 1971. Field work in 1974 was undertaken to complete mapping in several areas that formerly were not accessible, to obtain samples for the determination of basic properties of the glacial and post-glacial sediments, and to measure shear strength and penetration resistance of the materials.

Field work in 1974 confirms previous results reported in Geological Survey Papers 72-1A and 73-1A, with two exceptions:

1) Weathered bedrock is more extensive in the area than was reported in 1972. Anorthosite between Pentecôte and Port Cartier is weathered down to 4.5 m. Although the weathered layer probably predates the last glaciation, there is little indication of disturbance by glacial action below a depth of about 0.5 m.

2) Orientations of striae, grooves, and plucked forms near the coast in the southern portion of the map-area suggest that an early ice mass flowed from west to east between Godbout and Pointe des Monts, and then splayed slightly towards the northeast for a short distance. This flow probably was geographically restricted to the old St. Lawrence River channel, since no easterly trending striae or grooves were observed at high elevations. Evidence for a later major southerly flow is found over the entire field area.

[1]Department of Geography, University of Waterloo, Waterloo.

107. LE QUATERNAIRE DE LA CÔTE NORD DE L'ESTUAIRE MARITIME DU SAINT-LAURENT

Convention de recherche 1135-D13-4-1/74

Jean-Marie Dubois[1]
Division de la science des terrains

Localisation et accessibilité

Pendant l'été 1974, environ 525 milles carrés (1,360 km carrés) de terrain ont été couverts sur les cartes de Matamek Lake (22 I/5) et de Riviére-aux-Graines (22 I/6W). Ce secteur mesure 35 milles (56 km) le long de la côte entre la baie de Moisie et la rivière Manitou et s'étend sur une quinzaine de milles (24 km) à l'intérieur des terres. Cinq cantons se partagent la majorité de cette surface: partie est de Moisie, Blanche, Rochemonteix, Charpeney et Coopman. Il n'y a aucune agglomération excepté une zone de chalets et une station de biologie (exploitée par Woods Hole Oceanographic Institution, Mass.) à l'embouchure de la rivière Matamek.

La seule voie de pénétration pour véhicule est la route 138 en construction près du littoral. Cette route est carrossable jusqu'à la rivière au Bouleau et ouverte aux véhicules tout-terrain jusqu'à la rivière Sault-Plat soit une distance totale d'environ 25 milles (40 km). La majorité des cours d'eau étant difficilement "portageables" à cause des innombrables chutes et rapides dès l'embouchure, les excursions ont dues être menées soit à pied, soit en hélicoptère G-4 Bell.

Objectifs et utilité de la recherche

Avec la cartographie des formations meubles et des formes de terrain seront déterminés la nature, les caractéristiques, l'étendue, l'épaisseur et l'agencement stratigraphique des dépôts. Au point de vue géologique, le projet essayera de retracer l'évolution quaternaire de la région: déglaciation, limite maximale de la mer de Goldthwait, évolution littorale holocène. Au point de vue géotechnique, l'information se situera surtout au niveau des sédiments fins marins ou lacustres.

L'étude des caractéristiques physiques de la Côte Nord est devenue nécessaire à cause de l'imminent désenclavement routier dont elle fera l'objet. L'Office de Planification et de Développement du Québec ainsi que le Ministère de l'Industrie et du Commerce du Québec y prévoient un développement à très court terme.

Plusieurs organismes ont déjà demandé une collaboration pour des projets en cours: la morphosédimentologie de la rivière Matamek (Woods Hole Oceanographic Institution), la recherche de bancs d'emprunt granulaire pour la construction des chemins forestiers (Rayonnier Québec), la nature des dépôts littoraux en vue de la lutte contre la pollution des eaux (Mingan Underwater Service), la recherche de sites archéologiques d'après la géomorphologie (Ministère des Affaires Culturelles du Québec), et le relevé physique des rivières à saumons (Ministère du Tourisme, de la Chasse et de la Pêche du Québec) selon certains critères définis chez divers auteurs (Juurand, 1972; Leopold, 1968; Lagler, 1949).

Premiéres observations

Géologie et physiographie

Cette région fait partie de la province structurale de Grenville et la roche en place précambrienne est principalement composée de granite, de gabbro, d'anorthosite, de gneiss et d'un peu de migmatites et de mangérite.

Les Hautes Terres Laurentiennes s'élèvent vers le nord jusque vers 1,600 pieds d'altitude (485 m) et l'énergie moyenne du relief est de moins de 100 pieds (30 m) sur les 5 premiers milles (8 km) et de 100 à 250 pieds (75 m) sur le reste du territoire.

Le tracé des cours d'eau ainsi que la configuration de beaucoup de lacs sont commandés par des axes de faiblesse du substratum rocheux. Ces axes de fractures semblent souvent se poursuivre au large de la côte et souligner ainsi les tracés pré-glaciaires des cours d'eau qui devaient aboutir au système principal du chenal laurentien.

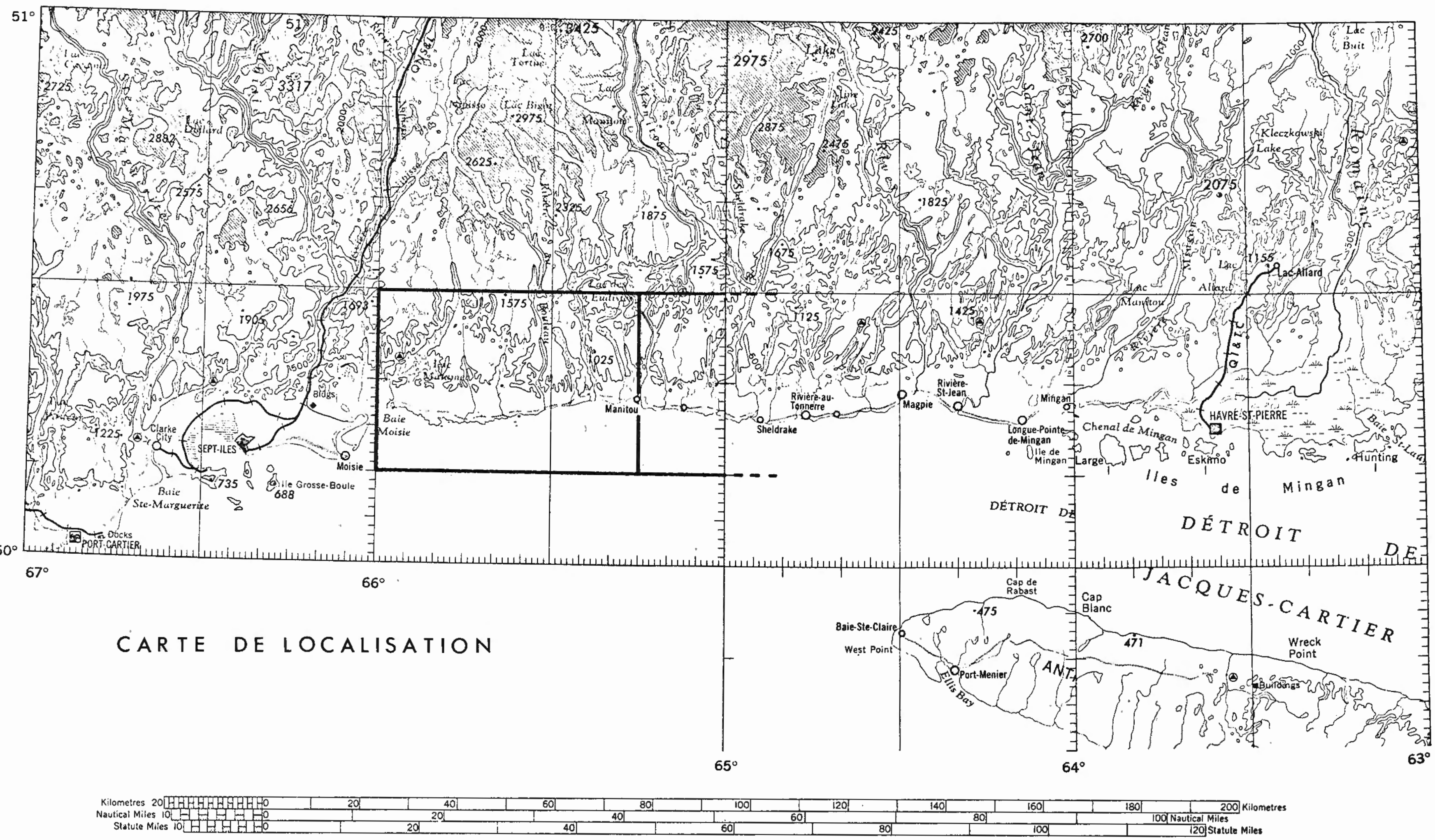
Répartition des dépôts meubles

La majeure partie de la surface est composée d'affleurements rocheux surmontés d'un mince sol. Les dépôts meubles sont concentrés le long des principales vallées, à l'embouchure ancienne ou actuelle des cours d'eau et dans quelques baies sur le littoral actuel. Aucun till et aucun sédiment typiquement fluvio-glaciaire n'ont été repérés; il y aurait cependant une possibilité d'en trouver dans la région du lac des Eudistes, au nord-est de la carte de Rivière-aux-Graines (22 I/6W), secteur qui a seulement été survolé en hélicoptère.

Des sédiments fins lacustres surmontés de sédiments fluviatiles se situent à des altitudes supérieures à 400 pieds (120 m) principalement sur la haute Matamek mais aussi dans les vallées de la Bouleau et de la Tortue.

En-dessous de cette altitude, les dépôts sont presque tous d'origine marine ou littorale. Ces sédiments fins d'eau profonde surmontés de sables et parfois de graviers estuariens ou littoraux se retrouvent jusqu'à une altitude un peu supérieure à 400 pieds; la limite maximum de la mer de Goldthwait à

[1]Université de Sherbrooke, Département de géographie, Section géographie physique, Sherbrooke, Québec.



CARTE DE LOCALISATION

cet endroit sera déterminée avec plus de certitude avec les prochains travaux d'analyse. Les mêmes sédiments sablonneux d'origine estuarienne, tels que décrits par Dredge (travaux en cours) se retrouvent dans la région soit associés à un complexe deltaique (rivières Matamek, au Bouleau et Manitou) ou soit sous forme de remplissages de vallées en-dessous de la limite de transgression marine. Généralement, ces sédiments possèdent un alios ferrugineux de 0.5 à 5.5 pieds (0.15 à 1.7 m) d'épaisseur en surface; cette carapace imperméable permet la formation de vastes tourbières caractéristiques de la Côte Nord.

A l'ouest du cap Cormoran, le littoral actuel ne possède pas de falaise et les plages sont surtout rocheuses; elles ne sont sablonneuses que seulement au fond de quelques petites baies et surtout à l'ouest de la rivière Matamek. A l'est du cap Cormoran, les falaises sont assez continues tant dans la roche en place que dans les sédiments fins marins (nombreux cas de glissements). Les plages y sont soit rocheuses, soit à blocs; des plages sablonneuses recommencent à apparaître vers la rivière Manitou. Presque tous les blocs des plages anciennes et actuelles sont d'origine locale.

Marques glaciaires

La majeure partie des marques glaciaires indique un mouvement qui s'est fait franc sud ou presque. Celles-ci ont été bien conservées surtout près du littoral actuel: stries, cannelures, quelques broutures, roches moutonnées. Des "crag-and-tail" et des cannelures géantes présentent un paysage assez spectaculaire entre la rivière au Bouleau et la rivière Tortue; plusieurs groupes de cannelures sont même visibles sur les photographies aériennes au 1: 15,840 et font jusqu'à 15 à 20 pieds (4.5 à 6.1 m) de profondeur et plus d'une centaine de pieds (30 m) de largeur.

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Project 620039

N.R. Gadd
Terrain Sciences Division

Through close co-operation of the Quebec Ministry of Natural Resources (M.R.N.) this project has been completed satisfactorily. Field work by the author commenced in 1962, and continued through 1965 with one preliminary paper (Gadd, 1964) completed. Subsequently, the project lapsed because the author was not able to return to the region for on-site verification of significant parts of the recorded field data.

More recently the activity of the Pleistocene geology section of M.R.N. in the Chaudière Valley region has emphasized a need for detailed maps of this area. Therefore during the 1974 field season, the author spent a period of six weeks in the field and at the Ministry in Quebec City in order to revise, to publication standard, previous studies of the St-Sylvestre area and to contribute by discussion and by the provision of maps and notes of other adjacent areas (Portneuf, Chaudière, St-Joseph) to the Quebec agency. As a result, the publication of maps of these areas is expected to be finalized at an early date as a co-operative enterprise by LaSalle (M.R.N.) and Gadd (G.S.C.). Specific study of late-ice flow directions and in particular of the delineation of northward ice-flow patterns have been prompted by recent discoveries of Robert Lamarche of M.R.N. in other adjacent areas. The results of these ice-flow studies have been made available to the author to enable a more comprehensive appreciation of late-glacial phenomena of the St-Sylvestre region in particular, and of the region as a whole.

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Project 700056

D.R. Grant
Terrain Sciences Division

Mapping of surficial deposits and landforms was carried out in the uplands and highlands plateau to complement earlier work in the southern lowlands (Grant, 1971a, 1972) and to complete coverage of the 4,000-square mile island for publication at 1:125,000 scale. Marked local differences in kind and thickness of surface materials were noted, in large part due to the greater relief, higher elevation, and more resistant rocks. As well, the pattern of glaciation has a significant external component in addition to dominant local centres, which, because of the varying relief, produced less extensive but locally more complex deposits.

In terms of originating processes the surficial geology of the island as a whole presents an intriguing and complex picture of glaciation and deglaciation in a maritime climatic area near the margin of a continent and an ice sheet. Evidence of both throughgoing 'Laurentide' ice action as well as of shifting local ice domes can be discerned amid the interlocking and overlapping patterns of ice-flow indicators. A great variety of glacial materials and landforms are present. Evidence of sea level changes includes deposits of the ongoing Holocene submergence as well as features produced during a pre-Classical Wisconsin high stand of the sea. Nonglacial deposits beyond the range of radiocarbon dating are relatively numerous, and are mingled with at least three similar occurrences of buried organic material that apparently indicate a readvance of the lowland ice about 10,000 years ago. Certain salient features and tentative conclusions are treated below.

Glacial Sequence and Surface Deposits

There are now a score of reliable indications of a unidirectional southeast flow of ice across the Gulf of St. Lawrence coast and across the plateau to the highest summits of the eastern escarpment. This trend parallels, and may correlate with that found over the Atlantic slope of mainland Nova Scotia and over eastern Prince Edward Island. All tend to suggest the passage of Laurentide ice. The Atlantic Provinces in general, however, are more characterized by divergent trends of other orientations, most of which signify the activity of independent local ice centres. In particular, southern and lowland Cape Breton Island was glaciated mainly by ice flowing first eastward then strongly northward during the maximal stage of the last glaciation (Grant, 1971b). The inferred Laurentide origin is difficult to reconcile with statements (e.g. V.K. Prest, pers. comm., 1974) that the Magdalen Islands, only 100 km up the inferred ice direction, were untouched by the last glaciation. The possibility of a pre-Classical Wisconsin age is rejected because the striated surfaces and the usually thin, single overlying till is fresh and commonly of western provenance. For example, reddish clay till from the Carboniferous red beds of the western lowlands are spread over parts of the plateau inland to the east. Following this problematical 'Laurentide' flow, the highlands and central plateau were the site of an ice cap that flowed radially to the sea. Westerly directed striations, including some that cross the southeast-trending ones, are found at numerous places along the Cabot Trail over the plateau south of Pleasant Bay, and along new forest access roads in the highlands near Margaree. As well multi-terraced outwash plains grade radially coastward in major valleys signifying shrinkage of an ice mass toward the interior. A boulder train of sulphide-rich erratics was intersected on three bush roads (46°27'N; 60°41'W) in the headwaters of Barachois River. The trend is southeastward like several nearby striations, but this effect equally could have been produced by flow in the southeast quadrant of the plateau ice cap.

Owing to the dense scrub forest and extensive bogs on the plateau, the nature and probable thickness of surficial deposits are difficult to infer in the absence of roads, but generally the medial summit areas are deeply weathered rock with intervening valleys having long smooth graded slopes underlain by up to 20 feet of layered sandy grus or granitic colluvium. In contrast, the plateau margins have large tracts of scoured outcrops, with several extensive areas of fluted and undulating till, giving rise to the Baddeck Lakes, Wreck Cove and French Lakes, Cheticamp Lakes and Pembroke Lake. The till areas do not appear to correlate with any one rock type, but have a polymictic lithology and hence may be remnants of a more extensive till sheet produced by the overriding ice sheet.

The relative age of the 'Laurentide' ice-flow pattern and the north and northeast pattern stemming from the lowland-centred ice cap to the south, is largely unresolved. Along the Atlantic coast between Skir Dhu and Cape Smoky, a thick till and glaciofluvial sequence includes a lower till of dominantly basic igneous lithology perhaps emplaced by eastward flowing ice crossing the large diorite area in the interior, overlain by pink granite boulder till and gravel, possibly deposited by coastwise-moving ice drawing upon the granite intrusions localized near the escarpment.

Deposits along the west coast bear upon this problem. Between Inverness and Pleasant Bay, scores of cliff sections and borrow pits reveal a complexly interlayered, and not altogether consistent, sequence of tills, gravel, and colluvium. The strata may reflect the interplay of Laurentide ice impinging on the coast from the Gulf, of island ice moving northward along intermontane valleys from the southern lowland centre, and late remnant ice retreating to upland sources. An early episode of ponded water along the escarpment may be inferred from a discontinuous basal unit of red clay with rare dropped stones, that is well exposed at Grand Etang. This member may have ceramic potential, at least for the local cottage industry. An unusual red stony pelite member, in most cases less than 1 m thick, is commonly encountered overlying all other materials, and gradually descending in elevation from Margaree to Cheticamp. Significantly, it is seen to wrap around till and gravel knolls, with a sharply defined upper limit. The material tentatively is believed to have originated as a mud-flow diamicton that issued perhaps from an ice-marginal body of meltwater ponded in the Margaree basin by coastwise-moving ice that channelled it along the coastal lowland.

Pre-Wisconsin Sub-Till Marine (?) Bench

Discontinuously exposed around the entire island, is a conspicuous level surface that truncates hard and soft rocks alike, and is commonly overlain by thick Wisconsin tills and outwash, as well as by buried organic deposits beyond the range of radiocarbon dating. This bench has little or no relief, stands at an elevation of 6±2 metres, and in most places is veneered with cobbles and boulders having the roundness, sorting, and stratification of beach gravel. An obvious explanation is that it marks a marine planation surface dating from the last interglacial when sea level was slightly higher than at present.

No systematic variation of elevation is yet discerned, but this aspect has to be treated carefully because of the variety of random sections across the presumably gently seaward-sloping surface. Perhaps the concordance of the feature to modern sea level gives some indication of the degree of crustal equilibrium attained since the last glaciation. A notable departure, however, occurs at Aspy Bay where it can be followed continuously for several kilometres south from Cape North to the Aspy Fault zone where, over a few hundred metres, it reappears on the south side at twice its average elevation. No higher benches are known so, taken at face value, this discontinuity could mean relatively recent movement on the flank of the Aspy evaporite-carbonate basin.

A Late Wisconsin Glacial Readvance

Four occurrences of subtill peat and wood are now known from the eastern Bras d'Or Lake basin; they appear to indicate a significant readvance of the lowland ice mass ca. 10,000 years ago. The exposures are near the head of East Bay (10,300±150 years; GSC-1578), at Benacadie Point (11,670±170 years *in* MacNeill, 1969), and two new sites at Wilhausen Point near Englishtown. Hopefully, these latter two will be dated to support the contention that Maritime ice responded like that in Fennoscandia during the Younger Dryas stadial.

This event gives new meaning to the peat deposit on Port Hood Island dating 10,250±250 years (Y-762) that is buried by an unsorted diamicton-type sediment interpreted as a till emplaced during a late readvance (Hickox, 1962). The overlying sediment has been referred to as colluvium generated by a climatic deterioration 10,000±11,000 years B.P. (Terasmae, 1974). This may correlate with the glacial readvance in Bras d'Or Lake basin. Indeed, colluvial mantles and long graded soliflucted slopes are characteristic of the west coast of Cape Breton, and may date from some specific period of periglacial weathering.

However, the interpretation and inferred age of the buried organic deposits around the Bras d'Or Lake is complicated by the widespread distribution, especially along the north side of East Bay, of thick sequences of tills, colluvium, sand and gravel, and interbedded peats and related organic beds, two of which have given 'greater than' radiocarbon dates. The rolling topography on these accumulations has been carved out by northeast-moving ice. Additional dates and pollen analyses are needed to correctly position the several buried organic beds in the Wisconsinan.

In summary, the reconnaissance inventory of surficial geology throughout the island has served to identify the nature and origin of most covering materials and relief features for land-use considerations, and has in the process brought to light a variety of excellent exposures recording important new aspects of past sea levels and the nature of glaciation near the periphery of the Laurentide Ice Sheet.

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110. SURFICIAL GEOLOGY AND SEA-LEVEL CHANGES, L'ANSE AUX MEADOWS NATIONAL HISTORIC PARK, NEWFOUNDLAND

Project 690065

D. R. Grant
Terrain Sciences Division

A park has been recently established at the terminus of the Northern Peninsula, to preserve the site and environs of a Norse settlement dating ca. 1000 A.D. Following on-site Quaternary studies (Grant, 1974) in conjunction with bryological analysis of the covering peat layers by M. Kuc of Terrain Sciences Division (*see* Kuc, this publication, report 124) the author became a participant in a multidisciplinary biophysical inventory of the 32-square-mile park area. The team, co-ordinated by P.E. Skydt, National Parks, Halifax, consists of L.M. Cumming, Geological Survey, Ottawa (bedrock geology), F.C. Pollet, Canadian Forestry Service, St. John's (vegetation aspects), and P. Gimbarzevsky (assisted by P. Addison on photo-documentation and drainage) Forest Management Institute, responsible for integration of all parameters on a common land base.

Utilizing previous field observations at the site together with a knowledge of the Northern Peninsula as a whole, early in 1974 a map at a scale of 1: 6,000 was prepared by airphoto interpretation showing terrain units and geomorphic features differentiated and identified to 3-m diameter. This portayal of the physical substrate subsequently was used as a base document in the field for the bedrock and vegetation mapping phase. The main field effort involved 3 days of helicopter traverse, supplemented by observations along outlying roads, and sampling and measurement of low-level raised strandlines.

The terrain is essentially a mosaic of rock, bog, and sediment. A rolling to rugged rock surface with a relief of 20 to 30 m contains extensive infillings of late-glacial marine sediment deposited when level was 60 to 100 m higher than at present, although the aggradational levels probably have no particular eustatic sea level significance. The material filling the basins is inferred to be a shell-bearing stony pelite deposited by floating ice, judging by road-cuts through similar terrain to the south. The relatively impervious sediment, the lateral extent, and the basinal setting account for the continuous cover of muskeg 1 to 3 m thick. Within one kilometre of the present shoreline, however, the marine cover takes the form of discontinuous terraces and flights of beach ridges festooned between rock knobs. These sandy, cobbly deposits in contrast, support mainly low shrubs, greatly facilitating mapping and reconstruction of former water levels.

In concert with L.M. Cumming, bedrock exposures were examined inland and on all offshore islands. Numerous aerial observations of the attitude of fracture planes and stratification were made to illustrate the influence of bedrock fabric on terrain patterns. Exposed rock, including lichen-covered surfaces, is distinguished from shrub and tree-covered rock where outcrops may be found but are not visible from the air. Rock, thinly mantled by marine sediment, is recognized by the muted expression of structural fabric. A weathered rock category, characterized by mammillary fields of shingly fragments, was found to have originated by frost action on an unmapped fissile silty phase of the Maiden Point Sandstone. The eastern part and a large area offshore is underlain by 'mélange' - a chaotic jumble of mixed lithologies in blocks of virtually all sizes, with structures of greatly discordant orientation, produced by fragmentation along the sole of a thrusted sheet of the earth's crust. As rock is at the surface over less than one-third of the park area, the aerial observations, including structures visible through shallow water offshore, will make possible an improved portrayal of 'sub-crop' lithologic distributions.

Most of the park consists of muskeg-covered plains underlain by fine-grained deep-water sediments deposited during higher postglacial sea levels. Flow slides in the low terraces at Canards Cove suggest underlying clayey sediment. Only rare beach lines are evident on inland slopes owing to the bare rock substrate, the inferred thinness or absence of till and other source materials, and to the quiet-water conditions that existed because of the shelter of an island-studded coastal environment that prevailed during the relative fall of sea level from 130 to 30 m, 11,000 to 8,000 years ago. A few large beach complexes of varied lithology near the main highway probably originated by re-sorting of sporadic till deposits, though none are recognized per se within the park. Two prominent terraces rise behind the site at 4 to 6 m, and 12 to 14 m, with a large intermediate berm at 10.5 m. The lower terrace on the edge of which the Norse buildings are situated is found repeatedly in numerous coves several kilometres west; its edge is a scarp that can be followed throughout the region, commonly as a bluff in rock. Below this terrace is a narrow fringe of about 5 beach berms which, at the site, form a massive spit terminating at Colborne Point arranged in an elongate triangle enclosing a former lagoon into which many minor hooked spits extended.

Additional radiocarbon dates on shells in these raised beaches, and several dates on the peat bog that laps over the lower berms below the occupational terrace, now permit a tentative chronology of shoreline formation. Earlier, Grant (1974) had extrapolated the age of the lower terrace as being immediately pre-Viking, based on dates of shore features at similar elevation on Strait of Belle Isle, 40 km west. However from altimetry of the same terrace along the southern Pistolet Bay, the low strandlines are now known to tilt upward to the west (toward the Labradorean ice centre). For this reason, any given level at L'Anse aux Meadows will be older than a shoreline at the same elevation farther west. Minimum ages for the occupational terrace come from the onlapping bog that yielded basal dates as old at 2,500 years B.P. (GSC-1987, 2055, 2059, 2071, 2076). Peat from a bog pond on the terrace dated 3,890±110 years B.P. (T-500). One of the lower beach ridges at elevation 1.5 m a.s.l. contained *in situ Mytilus edulis* dating 2,170±130 years (GSC-2086).

The age determinations are still too few to provide anything more than a starting point for the chronology. However, an approximation of the age of each of the shoreline features can be made, based on the premise that on a coast that is rising by postglacial rebound, such as here, shore-level marks would be undifferentiated unless there were independent movements of sea level to lengthen the residence time of the sea surface at its contact with the land. The great variety of development of the shore features - broad, separated terraces and beach ridges of differing spacing and amplitude - probably therefore reflects the influence of eustatic fluctuations. These have been variously portrayed by Morner (1971), Fairbridge (1961), and Ters (1973). In particular, the freshwater peat/marine clay alternations in the Netherlands have yielded a well-dated series of marine transgressions (Jelgersma, 1961). These horizontal landward excursions of the shoreline here will be considered analogous to periods of relatively faster eustatic rise, and will be the basis for the following correlation, subject to the slight time shift explained by Bloom (1974): "...upward tectonic movement subtracts from the eustatic transgression effect. (Beach) growth will cease when the rate of eustatic rise declines and becomes less than uplift rate. Hence, (beach) crests in rapidly rising areas, will appear somewhat older than the culmination of eustatic rises...." In other words, a beach ridge or terrace is produced when the uplift curve is tangent to the sea level curve, i.e. when the rates of change are equal and in the same sense, when there is little or no movement of the shoreline. In terms of a single transgression, this period occurs during the maximal flood, rather than at the culmination.

Examining the published curves of eustatic fluctuation cited above, and tying the chronology to the few existing dates, the occupational terrace is found to correlate with the Calais IV transgression, 4,500 to 4,000 years B.P. Marine water receded from the terrace and peat spread over it by 3,900 years B.P. The 10.5 m shoreline correlates with the Calais III surge ca. 5,200 to 4,900 years B.P., and the upper terrace at 16 m correlates with the Calais II, ca. 6,500 to 5,800 years B.P. The lower terrace was truncated on its seaward margin and a berm constructed at its toe by the Dunkirk 0 eustatic rise ca. 3,500 years B.P. Finally, the 3 to 4 berms commonly found between this level and the modern berm, at 2 m, 1.5 m, and 1 m above high tide, probably would relate to the Dunkirk II, III, and IIIa transgressions dating ca. 1,800, 1,100, and 600 years B.P. High tide level during the Norse occupation 1,000 years ago was therefore 1.5 m or less above present mean sea level. Assignment of individual low-level berms to specific recent eustatic events is, of course, difficult because of the addition of similar-appearing storm berms, more related to short-term climatic effects. Further dating of shells from some of these low but persistent strandlines is hoped to refine the correlation. During the last century, worldwide sea level has been rising noticeably, as proven by tide gauges, and probably accounts for the local truncation of the older low-level berms.

A perennial problem at the site is the spring flooding of Black Duck Brook, caused by deep snow over the lower flood plain and drift ice clogging the stream mouth. Alleviation of the destructive effects on the excavations might be achieved by a diversion to the adjacent drainage basin. The catchment of the stream itself is about 1 km^2, compared to more than 5 km^2 for Black Duck Pond, its headwaters area. Black Duck Pond is at + 18.7 m elevation whereas the level of neighbouring Skin Pond is + 20 m, separated by a low divide of peat at + 21.4 m. If the peat and gravel-floored outlet of Skin Pond, for a distance of 80 m downstream, was deepened to the same level as Black Duck Pond and the divide breached, Black Duck Brook would be relieved of all but a small proportion of the present flood stress.

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SURFICIAL GEOLOGY, GEOMORPHOLOGY, AND TERRAIN DISTURBANCE, CENTRAL ELLESMERE ISLAND (49 C, D, E, F, 59 D)

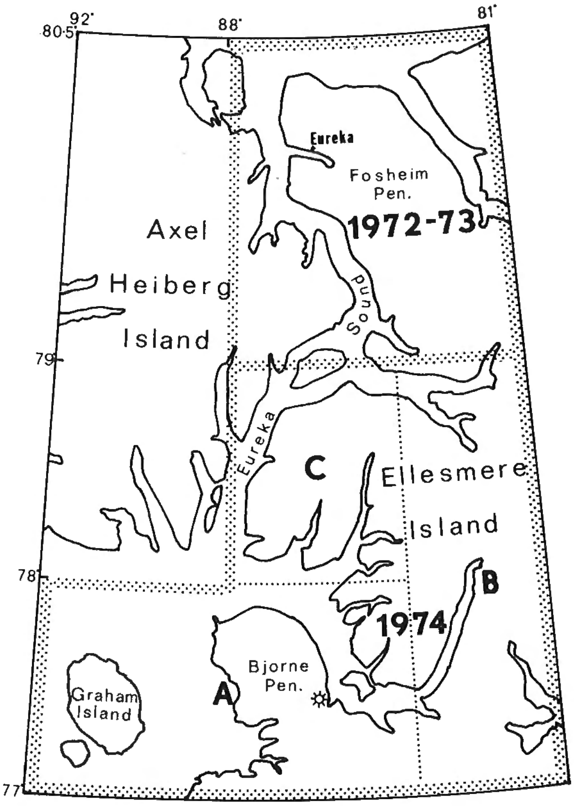
Projects 720081 and 720082

D.A. Hodgson and S.A. Edlund
Terrain Sciences Division

Field work in southwest Ellesmere Island and Graham Island (Fig. 1) was continued in the same manner as in the 1972 and 1973 field seasons (*see* Hodgson, 1973) with the addition of observations on vegetation by S.A. Edlund. As vegetation and surficial materials are closely related, integrated mapping is of mutual value, and can lead to a combined presentation of the two most important factors in land use management. Much of the time was spent examining the surface characteristics and associated plant communities of the weathered mantle of some 30 bedrock formations, as well as areas of preglacial gravels, glacial moraine, and postglacial marine deposits.

Activities were moved to Eureka for a ten-day period to re-examine disturbed sites, particularly the revegetation of the old airstrip near Eureka, and to core with a prototype JKS 300 drill/auger (*see* J. Veillette, this publication, report 120). The assistance of H.R. Balkwill (helicopter support at Eureka) and Panarctic Oils (aircrew accommodation at Bjorne airstrip) is acknowledged.

Maps showing surface materials, including a vegetation component, for the areas surveyed from 1972 to 1974 are expected to be placed on open file early in 1975.



1972-73: maps compiled from airphoto interpretation and ground traverses

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C. airphoto interpretation only

1974: base camp

Figure 1. Extent and reliability of surficial material mapping under project 720081.

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QUATERNARY GEOLOGY AND TERRAIN INVENTORY, KANANASKIS LAKES, 82 J, EAST OF THE CONTINENTAL DIVIDE, ALBERTA

Project 740095

Lionel E. Jackson, Jr. [1]
Terrain Sciences Division

Work was begun on the mapping of terrain units and the investigation of the Quaternary geology within the Kananaskis Lakes map-sheet (82 J), latitude 50°00' to 51°00', longitude 114°00', and west to the continental divide. Approximately half of the study area was mapped during the 1974 field season. The mapped area includes the Kananaskis and Spray River drainage basins and the parts of the Highwood, Sheep, and Elbow drainage basins within the Rocky Mountain Front Ranges and Rocky Mountain Foothills.

In addition to mapping, extensive sampling of surficial deposits was carried out both for the determination of the engineering properties of terrain units and investigation of the origin and provenance of the terrain units.

Preliminary interpretation of field-derived data indicates the following tentative conclusions:

(a) Rapid and efficacious slope processes have removed most glacial deposits from hilly and mountainous terrain units. The properties of the surficial deposits mantling these sloping upland areas are dominated by the nature of the underlying parent material. Glacial and related deposits generally are confined to the larger river valley bottoms and other low-lying areas.

(b) Where glacial deposits are preserved, they are composed entirely of material of Cordilleran origin - sandstone, shale, limestone, dolomite, and quartzite.

(c) Morainal deposits commonly rest on bedrock or gravels and presumably represent the last advance of mountain ice to affect the local area in which the deposits are preserved. Only at scattered points are a succession of two distinct sets of Cordilleran glacial deposits found within the area mapped during the 1974 field season.

(d) Erratics of Lower Cambrian quartzite of a type found in place only in the main ranges of the Rocky Mountains were observed in the most recent till which is discontinuously preserved across the Rocky Mountain Foothills. The presence of the quartzite content of this till can best be explained by a southeastward deflection of glacial ice originating in the Bow River valley north of the study area.

(e) Although no clasts originating from the Canadian Shield were noted as components of the tills observed within the mapped area, erratics of Sheild origin were found within the foothills belt up to elevations of 1,400 m (4,700 feet) in Cordilleran-originating outwash. This appears to indicate that older advances of Laurentian ice were able to penetrate farther west and to higher elevations within the Rocky Mountain Foothills than during the last glacial episode.

A TECHNIQUE TO FACILITATE AIRPHOTO INTERPRETATION

Project 730086

D.E. Lawrence and D.R. Grant
Terrain Sciences Division

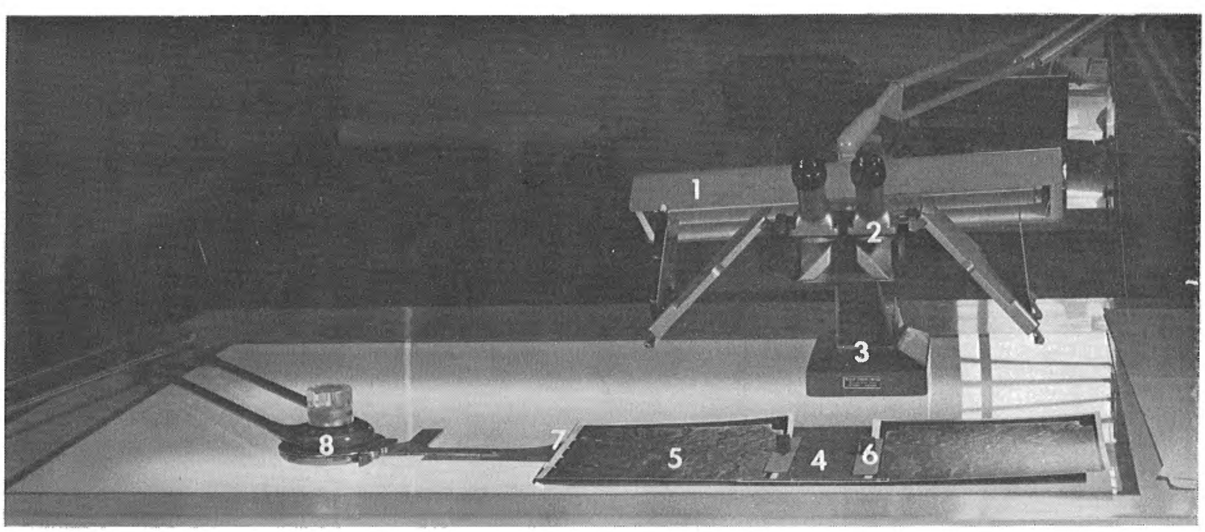
Airphoto interpretation is the principal method of analysis in the regional evaluation of surficial geology and terrain classification. The requirement of scanning large numbers of photos by stereoscope is time consuming. The techniques and associated equipment described were devised to speed up airphoto interpretation using stereo images, while at the same time minimizing eye strain and improving the quality of interpretation.

The technique permits stereo airphotos to be scanned as a pair without constant readjustment of individual photos or movement of the stereoscope. This is accomplished by means of a platen to which the airphotos are aligned and held in place with magnetic clips. The platen is attached to a commercially available drafting machine which permits the platen to be moved while at the same time keeping it orthogonal with respect to the stereoscope.

In this particular case the stereoscope used is a Wild mirror stereoscope model ST.4 attached to a cantilevered-type stand. The type of stand permits easy access to, and movement of, the photos and platen which would be more difficult should the standard support legs be attached. The platen is approximately 28 by 10 inches and is fabricated from No. 23 gauge (U.S. Standard) galvanized sheet metal with nylon skid pads attached to the underside to facilitate movement. Magnetic clips are used to hold the airphotos in position. A groove on the extreme left of the platen permits initial positioning of the left-hand photo. After alignment of the stereo pair, magnetic clips are used to hold the photos in place. The platen is attached to the drafting machine by a key which fits the keyway of the particular instrument being used. Unfortunately, each brand of drafting machine has its own particular design of keyway which makes it difficult to attach the platen to different makes of drafting machines. This can be overcome by having removable keys which may be changed to suit the particular drafting machine available.

The method of alignment of photos and use is as follows:

1. After a suitable work area is selected, preferably with a strong, evenly distributed source of light, the drafting machine is attached to the table and the platen to the drafting machine. Alignment of the stereoscope with respect to the platen is necessary. Loosen the locking head of the drafting machine and bring the platen parallel to the stereoscope. Lock the head of the machine.
2. Place the left photo against the positioning groove on the left of the platen and place one of the magnetic clips along the right-hand edge of the same photo.
3. Position the right-hand photo roughly on the platen and adjust it so that a stereo image appears.



1. Light source
2. Mirror stereoscope
3. Cantilevered stand
4. Platen
5. Airphotos
6. Magnetic clips
7. Positioning groove
8. Drafting machine

Figure 1. Photo showing the arrangement of equipment.

4. Move the platen in order to view a portion of the photo near one corner. Adjust, using the highest magnification occulars, until a good stereo image of that portion of the photo is obtained.

5. While using a map pin or other suitable sharp object as a pivot, on the right-hand photo on a point which is "in stereo", move the platen so as to view a portion of the image in the opposite corner of the photos. Rotate the photo around the pivot point until the position of best stereo image appears. Use the magnetic clips to position the right-hand photo in place. The photo pair is "locked in" and now the platen may be moved to any convenient position for scanning or viewing and the magnification of the occulars may be changed without disturbing the stereo image. No further adjustment is required.

The advantages of the above system of stereo viewing and scanning are numerous:

a) Reduction of eye strain: once properly aligned, the photo pair is in stereo on all portions of the photos no matter how much or how frequently the pair is moved. It is not necessary to move the stereoscope at any time.

b) Time saving: photo alignment is required only once for each stereo pair.

c) The method is convenient and rapid. Conventional equipment (a mirror stereoscope, a drafting machine, an easily fabricated platen, and several magnetic clips) are the only requirements. The method may be easily learned and used with facility.

d) The scanning ability of much more sophisticated and expensive equipment (e.g., scanning stereoscope) is duplicated without the cost.

Acknowledgments

The authors wish to thank Mr. G. Meilleur of the Geological Survey's Instrument Development Shop for the suggestion of the use of a conventional drafting machine as the method of preserving orthogonal alignment between the photos and stereoscope and for fabricating the prototype platen.

DIRECTION D'ÉCOULEMENT DES GLACIERS DU PLEISTOCENE DES CANTONS DE L'EST, QUEBEC

Project 740094

Guy Lortie[1]
Division de la science des terrains

La région étudiée est comprise entre les latitudes 45°45' et 46°45', et les longitudes 70°00' et 72°30'. Elle englobe les cartes topographiques suivantes: 21 E 11 à 16; 21 I 1à 12, 16; 31 H 9, 16. La région à l'est de la rivière Chaudière n'a fait l'objet que d'une reconnaissance rapide.

Cette recherche régionale a eu pour but premier de délimiter la distribution des polis glaciaires indiquant les mouvements nord, ouest, et est de la calotte glaciaire résiduelle du tardi-glaciaire (Lamarche, 1971, 1974; Gadd *et al.*, 1972). Compte tenu de la dimension considérable du territoire à couvrir, notre approche du problème s'est essentiellement centré sur l'examen des polis glaciaires et le comptage des blocs erratiques. Ces deux critères nous ont permis de définir, d'une part, les directions d'écoulement de la glace et leur chronologie relative, et d'autre part, l'extension maximale du transport des blocs erratiques par le mouvement nord dans les régions d'Asbestos et de Thetford-Mines.

Directions d'écoulement

L'étude des polis glaciaires des Cantons de l'Est révèle trois "groupes" des directions d'écoulement: 1) sud-ouest et ouest (SW, W); 2) sud-est, plus ou moins variable (SE); et 3) nord, nord-est, et ouest (N, NE, W).

(1) Le systéme SW n'est observé qu'en peu d'endroits, surtout dans la région de Richmond et de Windsor. Il s'agirait d'un mouvement antérieur au mouvement SE.

Un système W, aussi antérieur au mouvement SE, est présent dans les régions de Richmond, Windsor, au sud de la rivière Saint-François et plus à l'est, dans les régions de Stoke, North Hill, et Mont Aylmer. Ses limites sont mal connues, mais sa distribution vers l'est est nettement plus étendue que le système SW.

McDonald (1967, p. 75) estimait que ce système "...formed...during the early part of glacial phase II". (glaciation Chaudière de McDonald et Shilts (1971)).

(2) Le système SE reste le plus constant et le plus généralisé dans les régions parcourues. Les dépôts meubles reliés à ce mouvement ont fait l'objet de cartographies de détail le long de la frontière internationale et dans la Beauce. Sa stratigraphie est bien connue.

(3) Le système N, avec déflection vers l'est ou l'ouest, se retrouve dans la plupart des Cantons de l'Est. Sa limite sud est approximativement, d'ouest en est, Richmond, St-Gérard, St-Romain, St-Hilaire de Dorset, Bolduc, Rivière Metgermette, St-Louis de Gonzague, St-Camille et Lac-Frontiére; sa limite ouest suit le relief appalachien depuis Richmond jusqu'à Arthabaska, St-Norbert et Plessisville; sa limite nord fait de même, jusqu'aux confins des Basses-Terres du St-Laurent, depuis Laurierville à Ste-Agathe-de-Lotbinière; on retrouve ce système à l'est de la Chaudière, à Ste-Marguerite, à Lac-Etchemin, à St-Philémon. Sa limite est nous est inconnue. Ce système Nord tend à dévier vers le NE-ENE dans les régions de Laurierville, de Ste-Marguerite, de Ste-Hénédine et de St-Magloire, soit dans les secteurs nord et est de sa distribution géographique.

Un deuxième système W recoupe tous les autres systèmes dans la région d'Asbestos. Sa distribution est nettement plus restreinte. Sa limite ouest pourrait être Kingsey-Falls, St-Félix-de-Kingsey; sa limite nord, Bennet, Ste-Hélène-de-Chester, Warwick; sa limite est, Vimy Ridge, Mont Caribou; sa limite sud se confond avec le système W antérieur.

Environ deux cents comptages de blocs erratiques ont été faits autour d'Asbestos et de Thetford Mines. Les résultats préliminaires confirment l'écoulement des glaces vers le nord dans ces régions. Ils indiquent aussi que les zones les plus au sud touchées par ce mouvement, en terme de transport glaciaire, seraient les massifs granitiques situés entre les lacs Aylmer et St-François. Il nous apparaît enfin probable que ce mouvement ait été plus vigoureux et de plus longue durée à Thetford Mines qu'à Asbestos.

Conclusions préliminaires

L'ensemble des observations nous suggère trois séquences, en terme d'écoulement glaciaire, dans les Cantons de l'Est: (1) vieux mouvements SW et W d'âge incertain (probablement till Chaudière); (2) mouvement SE au Wisconsin (till Lennoxville) et (3) mouvement N suivi de mouvements latéraux W et E au tardi-glaciaire.

La seule distribution des polis glaciaires indiquant le mouvement N a été très sous-estimée: elle occuperait au moins le double de la surface suggérée (Gadd *et al.*, 1972). La limite nord de la distribution des polis du système N se situant à la bordure de complexe morainique Highland Front, ou encore à l'intérieur même des dépôts cartographiés comme tels; on doit envisager: (1) l'existence d'une zone de contact entre le complexe Highland Front et les dépôts associés à l'écoulement nord; (2) la probabilité que certains dépôts du Highland Front aient été, en fait, mis en place par les glaces s'écoulant vers le nord, et vers l'ouest.

Par ailleurs, il est encore trop tôt pour savoir si ou encore à quel point la calotte glaciaire résiduelle formait une masse homogène débordant la vallée Chaudière jusqu'à Lac-Frontiére. Il est possible que l'écoulement nord ne se soit pas produit en un seul

[1]Université McGill, Département de géologié, Montréal, Québec.

mouvement qui aurait impliqué tous les Cantons de l'Est. La région à l'est de la Chaudière, et celle comprise entre les rivières St-François et Chaudière ont pu s'écouler à des moments légèrement différents. L'hypothèse reste à préciser.

Seule une cartographie de détail est en mesure de résoudre ces problèmes. Cela est particulièrement vrai pour les régions longeant la frontière Canada-E. U. à l'est, et sur lesquelles nous n'avons que peu d'informations géologiques.

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115. SURFICIAL GEOLOGY MAPPING: MORRISBURG-WINCHESTER AREA (PARTS OF 31 B, G)

Project 740068

S.H. Richard
Terrain Sciences Division

Field investigation and mapping of the surficial geology of the Morrisburg (31 B/14) and of the east-half of the Winchester (31 G/3) map-areas has been completed. Part of the Morrisburg map-sheet was mapped by E.B. Owen (1951) as part of the Geological Survey of Canada's St. Lawrence Seaway investigations. In both areas the unconsolidated Quaternary deposits are well developed in surface extent and in thickness over the Paleozoic limestone and dolomite platform. The bedrock outcrops mainly along the western margin of the Morrisburg map-area and small tabular uplands and ridges are also common north of Chesterville and north of Finch in the Winchester area.

Glacial deposits make up at least two-thirds of the land surface of the Morrisburg area and about three-quarters of the Winchester area. They occur mainly as an undulating to moderatly rolling mantle of grey, calcareous, silty, compact ground moraine - mainly derived locally - covering flat-lying bedrock. The till plain is especially extensive in the southern and eastern parts of Winchester map-area and in the eastern and central parts of Morrisburg area. In the western and southern parts of Morrisburg map-area the till plains are fairly small in extent, with the higher knolls of till being separated by shallow basins filled with marine sediments. In adjacent areas to the south and east, P. MacClintock and J. Terasmae have called this till "Fort Covington till", and defined it on the basis of its composition, colour, matrix, origin, and a fabric which indicates deposition by a well defined ice lobe (Ottawa-St. Lawrence ice lobe) that advanced across the map-area from the northwest (MacClintock and Stewart, 1965; Terasmae, 1965).

In the part of the study area between Berwick and Avonmore in the north, Dunbar and Williamsburg in the west, and Morrisburg and the St. Lawrence River in the south, most fresh exposures in ground moraine have revealed the presence of fossil marine shells in the matrix of the glacial till. A fresh road-cut and borrow pit in an area of north-south oriented drumlins, which extend between Avonmore, Finch, and Osnabruck Centre and the Long Sault Islands, also revealed the presence of fossil marine shells in the matrix of the till to depths of 8 to 10 feet. At another locality in a gravel pit one mile south of Newington, fossil shells of the marine molluscs *Hiatella arctica, Macoma balthica, Balanus hameri* and *Balanus crenatus,* were found in the matrix of till that is adjacent to deformed beds of fossiliferous beach gravels and is overlain by undisturbed fossiliferous beach gravels and sands. Fossil marine shells incorporated and disseminated throughout the matrix of the surface ground moraine also were found in fresh exposures opened in a newly dug roadside drainage ditch at a site located two miles west of Apple Hill in the northern and central part of the Cornwall map-area.

In his 1965 report, Terasmae (1965, p. 19) referred to evidence of a post-Fort Covington ice-advance but did not attempt to correlate it with ice advances in other areas (p. 35). The findings outlined above in the eastern part of the Winchester and Morrisburg map-areas strongly support Terasmae's findings from the Cornwall map-area. The drumlins containing shells and mapped around Newington and Finch are the western and northern extension of a drumlin field identified and mapped by Terasmae in the Cornwall map-area. They likely originated in the way suggested by Terasmae (1965, p. 19) i.e. remoulding of till by a post-Fort Covington ice readvance that superimposed them on the pre-existing ground moraine. This fossiliferous thin till and the drumlins associated with it appear to be distinctive enough as a unit to be given a stratigraphic name. "Newington till" and "Newington ice readvance" would seem to be logical names to propose, however, the unit will not be designated formally until the extent and nature of this unit are known more completely and the included organic material has been dated.

Postglacial marine sediments deposited by the Champlain Sea, following the withdrawal of the Wisconsin ice, are less widespread than the glacial deposits and they make up slightly more than one quarter of the land surface of the map-areas. The most important of these in area and size are grey, massive, calcareous, fossiliferous marine clays and silts which were laid down in long, sometimes narrow, erosional depressions and wider basins developed in flat-lying Paleozoic limestones and dolomites. The deposition of these marine clays and silts has resulted in a subduing of a good part of the local relief up to an elevation of 275 feet a.s.l. in the south and to an elevation of 220 feet a.s.l. in the north. These deposits form gently sloping clay plains whose surfaces are primary surfaces of marine sedimentation. The most extensive areas of these deposits occur in the valley of the South Nation River and of its tributaries. The southern limit of the horizontal, burgundy-red beds that are found in the upper part of the marine clays and silts of the Russell and Thurso map-areas has been determined to lie approximately one mile south of the village of Crysler in the valley of the South Nation River.

In western and southern parts of the Morrisburg map-area, the marine clay plain is mantled by a thin sand cover varying from five to ten feet in thickness and surrounding completely all the small isolated areas of till plain located between South Mountain in the north and Port Johnstown in the south. This area was named the Edwardsburg sand plain by Chapman and Putnam (1940).

Marine sands are present in the Winchester map-area but are of much lesser extent and occur mainly in the northeast between Berwick and Moose Creek. The sand cover is very well sorted, medium to fine grained, and commonly shows no well developed bedding. It is grey in colour when exposed in fresh deep cuts but commonly weathers to an orange-buff near the surface. In many places it is highly fossiliferous, yielding large quantities of shells of *Macoma balthica* and *Hiatella arctica*. These sand features were developed as successive shallow water offshore bars and shoreline beaches during regression. In the Morrisburg area this sand unit is found from the elevation of 300 feet in the south down to an elevation of 240 feet in the north. In the till plain areas east of Berwick in the Winchester map-area, the sand occurs mainly between the elevations of 325 and 235 feet a.s.l. Fossil marine shells recovered from the lowest of the sandy shoreline beaches at an elevation of 235 feet a.s.l., 3 miles east of Crysler, will be submitted for radiocarbon dating in order to date the last stand of the Champlain Sea in this area. The Ottawa River delta, which lies a few miles to the north, is graded to this same approximate elevation, and hence this should also date the construction of that feature.

During withdrawal of the Champlain Sea the washing and reworking of the ground moraine built several fossiliferous gravel beach ridges along the higher parts of the emerging glacial topography. Most of these features lie between elevations of 350 and 250 feet.

Following emergence, a large number of marshes and peat bogs developed where swales of the undulating and uneven ground moraine were poorly drained. In the eastern part of the map-area these areas of marshes and bogs are so well developed that they commonly make up half of the total land surface.

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116. QUATERNARY GEOLOGY - TERRAIN INVENTORY LYTTON MAP-AREA, BRITISH COLUMBIA (92 I/SW)

Project 740066

J.M. Ryder[1]
Terrain Sciences Division

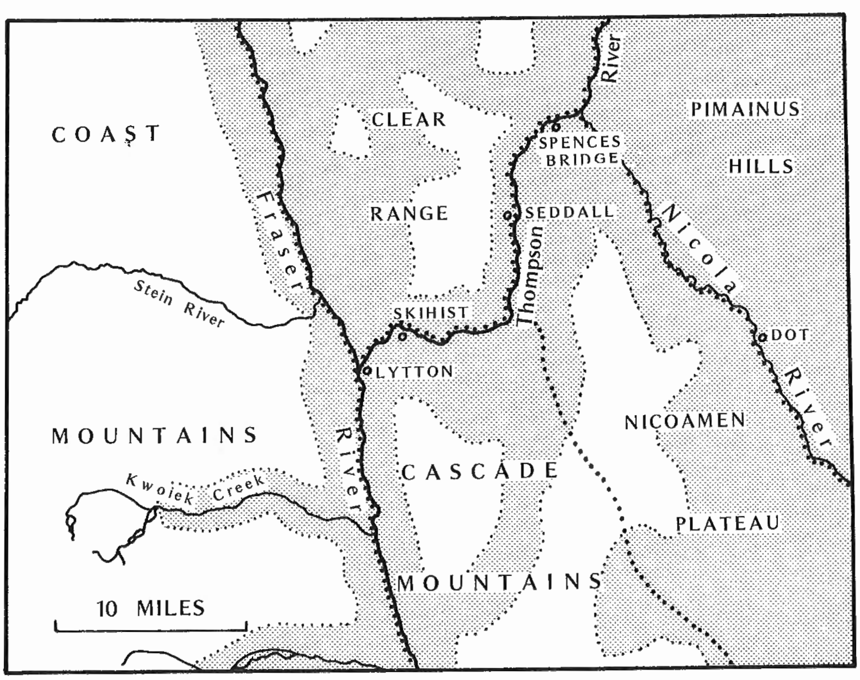
The Lytton map-area extends across the geologic and climatic boundary zone that separates the Coastal and Interior systems of British Columbia. Thus the physical features of the region that result from the interplay of lithologic and atmospheric factors are transitional. They range from the humid, nival conditions of the Coast Mountains, exemplified by the Kwoiek Peak area in the southwestern part of the region, to the semi-arid valley floors of Thompson and Nicola rivers. The relief of the area is rugged, and consequently altitude imposes an additional control that fragments and diversifies the climatic and geologic zones.

During the summer of 1974, field mapping at a scale of 1: 50,000 essentially was completed for all parts of the region that are accessible by road. This includes the valleys of the major rivers and most of their larger tributaries and segments of the upland and alpine terrain (Fig. 1). Earlier field reconnaissance of alpine areas and detailed stratigraphic studies of Quaternary valley sediments, together with airphoto interpretation, will be utilized in the completion of the terrain mapping and analysis.

The map-area may be broadly subdivided into physiographic regions for the purpose of describing the terrain, surficial geology, and Quaternary history (Fig. 1).

The terrain of the Coast Mountains is characterized by extreme ruggedness, steepness of slopes, and great range of relief. The landforms are well developed features of alpine and valley glaciation. In general, postglacial slope reduction by weathering and mass wasting has had relatively little effect on the granodiorite of this area. Pleistocene cirques, modern glaciers, slopes currently being modified by nivation and rock glaciers display a strong preference for locations with northern or northeasterly aspect. Small, fresh morainic ridges occur within 2 km of present glacier termini, and indicate that a phase of more extensive glacierization ended recently. At intermediate elevations, avalanche cones, alluvial cones, and talus slopes are the most common depositional forms. Blankets of bouldery drift and colluvium are restricted to gentler slopes of valleys and cirque floors.

The Cascade Mountains are distinguished from the Coast Mountains by their generally lower and relatively rounded summits and ridges. They were overridden during the last Pleistocene glaciation. Cirques are common, but have not contained cirque glaciers since prior to the time of the overriding ice. Most surfaces below timberline and cirque floors are covered by drift and colluvium. Extensive rock outcrops are restricted to the steepest slopes and areas of high elevation.



Area covered by field mapping

The portion of the Interior Plateau that lies within the map-area includes part of three physiographic subunits: Clear Range, Nicoamen Plateau, and the Pimainus Hills area of Thompson Plateau. The Clear Range has been deeply dissected by steep, short tributaries of Thompson and Fraser rivers. Most of this region consists of steep valley-side slopes. The Pimainus Hills are an undulating upland with gentle slopes and less than 300 m of local relief; but with precipitous dissected margins bordering Thompson and Nicola valleys. The Nicoamen Plateau consists of rolling upland areas separated by deep valleys of creeks tributary to Nicola River. These three areas were overridden during the last Pleistocene glaciation by ice moving southeastwards across the Clear Range and Pimainus Hills, but flowing more directly southwards across Nicoamen Plateau. Large areas of plateau surface

[1]Department of Geography, University of British Columbia, Vancouver.

and valley-side slopes are drift (chiefly till) covered, indicating that there has been little postglacial erosion of bedrock. In general, only the steepest slopes, prominent areas of high elevation, and arid south-facing slopes are the sites of rock outcrops. The character of the till (texture and lithology of clasts) is closely related to the nature of the underlying bedrock. For example, a distinctive bouldery sandy till overlies granitic rocks of the Guichon Creek batholith in Pimainus Hills.

Within the map-area, Fraser Valley is a steep-sided, fault-controlled trench. Quaternary sediments within the valley are as much as 150 m thick. They are structurally complex and vertical and lateral facies changes are common within most depositional units. At least two glacial episodes are recorded, although basal till is rare in extensive river-bank sections. It appears to have been replaced by a heterogeneous gravelly drift - possibly as a result of winnowing of fines by considerable volumes of meltwater washing through and around stagnating ice. A late-Pleistocene proglacial lake occupied Fraser Valley and extended at least a few miles up Thompson Valley. Lake silts and sands are unconformably overlain by fluvial gravels of a later phase of aggradation. During the final deglaciation of the area, ice in Fraser Valley may have been maintained by a glacier emerging from the Kwoiek Valley. In other tributary valleys, sediments were aggraded against this late Fraser Valley ice.

The valleys of the Thompson and Nicola rivers generally are similar to those of the Fraser Valley with respect to morphology and the distribution of surficial deposits. Valley side slopes are more gently inclined and the depth of incision of the rivers into the Quaternary valley fill decreases upstream. A thick (150 m) two-phase sequence of outwash gravel in the Thompson Valley between Seddall and Skihist (Anderton, 1970) is overlain by till of the last glaciation. To the north of Spences Bridge, the youngest till overlies glaciolacustrine silt which in turn rests upon an older till. Postglacial lakes (cf. Fulton, 1969) extended throughout the Thompson-Nicola system upstream from Seddall. Rhythmically bedded silt, resembling the South Thompson Silt (Fulton, 1965) occurs in the Nicola Valley near Dot. Drift terraces in tributary valleys at higher elevations mark the sites of earlier ice-marginal lakes.

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THE LARGE INTERDRIFT BEDROCK BLOCKS OF THE CANADIAN PRAIRIES

Project 740089

A. MacS. Stalker
Terrain Sciences Division

The 1974 field season saw the commencement of a detailed and systematic study of the large masses of bedrock found lying between tills and other drift in the southwestern part of the Canadian Prairies. The aim of this project is to map the locations of these blocks, describe them in more detail than has been done to the present, and if possible to explain their origin and to determine how they were brought to their present locations. These blocks have importance for surficial stratigraphy and correlation, and, if they were transported by ice, for the information they may supply about the movement of glaciers and the mechanics by which glaciers incorporate, transport, and deposit large masses of bedrock.

The writer has recorded many of these large, buried bedrock masses during past study of surficial deposits on the Prairies; other workers have done the same. They have been mentioned in published reports, however, only incidental to descriptions of other features (Johnston and Wickenden, 1931, p. 31-34; Stalker, 1963, p. 5-6, 12, 21; 1972, p. 69-72). The description of the large mass found along Oldman River northeast of Taber by Johnston and Wickenden remains the most complete, and their discussion of the character and stratigraphic position of that mass is, to a large extent, applicable to all these large masses. They called it an interglacial deposit, mainly because it was hard to conceive how such an enormous block could be transported to its present location, but undoubtedly it consists of a large mass of bedrock plucked from one of the nearby formations. They state (p. 32, 33):

> "The interglacial deposits at Driftwood bend on the Oldman River are unusual in character in that they consist, in large part, of a soft sandstone containing lignite and bentonitic clay. In places quartzite river gravels derived from the mountains to the west are exposed at the bottom a few feet above river level and rest on bedrock. Above these are stratified silts 6 to 10 feet thick and the lower boulder clay which averages about 75 feet in thickness. The upper boulder clay (overlying the interglacial deposits) is about 40 feet thick in the central part of the sections on the east side of the bend....
>
> The interglacial sands are exposed for nearly a mile along the east side of Driftwood bend and average 30 feet in thickness.... The interglacial series as a whole is much disturbed and in places the beds are minutely folded, owing probably to movements induced by the pressure of the overlying till sheet or of the ice-sheet itself and by the alternate expansion and contraction of the bentonitic clay in the beds, on wetting and drying. Sliding of the beds may also have been caused simply by the greasy character of the clay layers."

They then go on to discuss the origin of this "interglacial series", which they conclude is an alluvial flood plain deposit despite the presence of the brown to black, good quality lignite and the bentonite beds. Though the beds might be considered much disturbed for interglacial deposits that had formed in place, they appear to have suffered remarkably little contortion if they are considered to have been moved to their present site by a glacier or by some other means. Later, Stalker (1972, p. 71), in describing the same block, estimated its maximum thickness at 85 feet, and suggested that it might extend over more than 10 square miles and weigh as much as 1,000,000,000 tons. At present the dimensions of the block are uncertain, but it is still the largest known of these intertill bedrock masses. The 1963 report by Stalker gives a general discussion of these masses (p. 5-6), and reports on the ones at the Wolf Island (p. 12) and Kipp (p. 21) sections. The latter, though thin, cuts through the middle of the drift exposed along the river bank for more than a mile.

During the summer of 1974 most attention was directed towards the large block along the east bank of Oldman River within the city of Lethbridge. Its outcrop stretches south-southeast from NE. ¼ of lsd. 6, sec. 1, tp. 9, rge. 22, W. 4th mer. to NW. ¼ of lsd. 1, sec. 36, tp. 8, rge. 22, W. 4th mer.; from there south the bank becomes overgrown and the bedrock mass, if present, hidden. Though its further southward extent is unknown, it is probably not great. Not only is this block easy of access, but the exposures along the river bank, in gullies reaching back from the bank, and fresh cuts made for approaches to the new bridge being built across Oldman River near Laundry Hill in Lethbridge, gave excellent opportunity to study the eastern continuation of the block for a few hundred feet into the bank, to confirm that it was, in general, horizontal, and to give a preliminary estimate of its size.

The block outcrops on every knoll between gullies for a distance of one and a half miles along the valley edge, and also along the sides of most of the gullies until the rising gully floor truncates the mass; in some cases this was a distance of more than 300 feet. Exposures of bedrock lying in drift were also seen at a few points on the far (west) side of the river valley, about one half mile distant, but those may not be parts of the same block. Tills, gravels, and silts are found both above and beneath it. A typical, though simplified, section from the north side of the approaches for the new bridge, on the east side of the valley in lsd. 7 and 8, sec. 36, tp. 8, rge. 22, W. 4th mer., and towards the south end of the exposed bank, is given below. Much of the section, particularly near the top, may have been disturbed by slumping or contortion, and so the exact thicknesses and sequence are not certain.

	Thickness (feet)
Lake deposits, partly varved	10
Till, light brown	35
Silt, mostly massive	20
Till, light brown, loose	8
Gravel, medium, poorly sorted	12
Till, light bluish-grey, hard, compact	35
BEDROCK MASS	45
Till, dark grey, columnar	15
Till, light grey, compact, columnar	20
Overgrown	60
Level of Oldman River	—
Total thickness	260

The overgrowth near the base probably hides more till and the bed of Saskatchewan gravel and sand that elsewhere directly overlies bedrock. The interdrift bedrock mass consists mostly of dark, bentonitic clay or shale, or of white, poorly indurated sandstone, and a minor amount of ironstone. The mass is thicker here than farther north, and the 45-foot thickness at this location is about the maximum present anywhere. Its average thickness would be about 15 feet. The original weight of the part of the mass investigated would have been about 3,000,000 tons; since much of it has been removed by river erosion and as the block extends an unknown distance south and east of the exposed portions, the original weight of the full block must have been vastly greater. Indeed, if the remnants of the far side of the valley belonged to it, the original weight was at least 25,000,000 tons.

The investigation showed that the mass was nearly horizontal, that it was singularly thin considering its lateral extent, and that many parts of it displayed remarkably little disturbance for a block of comparatively weak rock that had been transported into place, whether by a glacier or by other means. These are features apparently common to all the blocks, and at present they cannot be explained.

All the interdrift bedrock masses studied in southern Alberta appear to lie between the same till sheets and to have been moved into place at about the same time. If so, they represent an unique event here, and the blocks form a useful marker horizon. In addition, the ones studied in southern Alberta are confined to the preglacial course of the Oldman-South Saskatchewan River system. Whether this is fortuitous, or whether there is a simple logical explanation for it, or else whether it is merely because the best exposures in the region are along that system with the blocks in reality being much more widespread, cannot be decided at this time.

The writer would recommend that the term "erratic" not be used, at present, for this type of bedrock mass.

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BIOPHYSICAL STUDY OF THE BOOTHIA PENINSULA AND NORTHERN KEEWATIN

Project 740074

C. Tarnocai[1] and A.N. Boydell
Terrain Sciences Division

Boothia Peninsula and a portion of northern District of Keewatin (north of latitude 68°), an area of approximately 64,000 (25,000 square miles km^2), was surveyed for a biophysical study. A.N. Boydell provided the landform/materials input and C. Tarnocai covered the soils and vegetation, as well as delineating the ecoregion. This paper contains the preliminary results of the soil, vegetation, and ecoregion studies.

In 311 stops along helicopter traverses, information was obtained relating to soils and vegetation, and soil samples and plant specimens were collected. Detailed studies also were carried out on 8 sites (approximately 1 day per site). On these sites detailed soil studies were conducted using an electric hammer. With this tool a soil trench was extended into the perennially frozen portion of the soil to a depth of approximately 1.5 metres. In addition to this, foot traverses (total of approximately 60 miles or 100 km) were carried out where soil or vegetation changes took place due to changes in elevation or parent material. Here again, the soils and vegetation were examined along the traverse. All these field activities resulted in the collection of 117 soil samples, 40 soil moisture and ice content core samples, 11 14_C dating samples (of cryoturbated organic matter) and approximately 150 plant specimens. In addition, 319 vegetation analyses were obtained to form the basis of a description of the vegetation.

Ecoregions

The ecoregion represents similarities of climate as determined by the vegetation, soils and, to some degree, the permafrost condition, which then produce specific ecosystems on material having similar properties.

The southern portion of the study area is designated by the ecoregion symbols Lf[2] and Lm (*see* Fig. 1) and represents the low (continental) arctic condition. There is continuous vegetation cover (except on bedrock and eroding surfaces). Its northern limits coincide with the northern limit of some ericaceous species (*Ledum decumbens*, *Vaccinium Vitis-idaea* and *V. uliginosum*) and also with the tussock-forming *Eriophorum* species. Some willows up to 30 cm high are also present along the river valleys. Soils in the Lm region are mainly Brunic Turbic Cryosols and Gleyic Turbic Cryosols which have developed on marine silt and are associated with hummocks and tussocks.

Region Lf, however, which is associated with a higher elevation and acid till materials, is dominated by Brunic Turbic Cryosol and bedrock, while on marine deposits in valleys it is associated with hummocks and tussocks and dominated by Brunic Turbic Cryosol and Gleyic Turbic Cryosol soils.

The rest of the ecoregions, identified by the primary letter M, represent mid-arctic island conditions. These regions are characterized by sparse vegetation cover, active cryoturbation, weak soil development, and greater wind disturbance, especially along the sea coast and at higher elevations. The largest region is Mt which generally occurs at higher elevations. It is composed mainly of Precambrian bedrock with continuous vegetation occurring only in small, wet areas. Soils are Regic Turbic Cryosols on calcareous till except in the northern portion where, due to the more favourable parent material, some Bm horizon development is found.

In the coastal regions (Ms, Mn, Mj, Mp, and Ma) the vegetation cover is absent to moderate. In general, the extreme coastal strip is unvegetated, except in wet areas, with vegetation cover increasing as one moves inland. Ecoregion Mj represents a unique situation. It is a higher plateau and is almost completely unvegetated and extremely sorted, resembling a polar desert condition. Soils in these regions are very weakly developed and strongly cryoturbated (Regic Turbic Cryosol).

A small protected lowland north of Spence Bay is indicated as having a somewhat moderate climate. Here, outliers of low arctic vegetation, dominated by ericaceous species, are found on southerly slopes. Some willow shrubs up to 30 cm in height also are present.

Soils

All soils in the study area encounter the permafrost table within 1 m (control section) and are classified as Cryosols. Cryosols developed on marine silt and silty clay materials are associated with earth hummocks having a Bm horizon in well to imperfectly drained condition. High ice-content materials, pure ice, and cryoturbated organic-rich horizons are present in soils associated with this hummocky terrain.

Soils on till materials are also Cryosols. Brunic Turbic Cryosols occur on acid till (ecoregion Lf) in association with circles and stripes. On moderately calcareous till as far north as Sanagak Lake and Agnew River in ecoregion Mt and Mk are found mainly Regic Turbic Cryosol soils, but the northern portion of Mt is dominated by moderately calcareous reddish till. Here, Brunic Turbic Cryosol also occurs. In the coastal regions (ecoregions Ms, Mn, Mp, and Ma)

[1]Soil Research Institute, Winnipeg.

[2]lower case lettering is used in Figure 1 to differentiate between units but otherwise has no special significance.

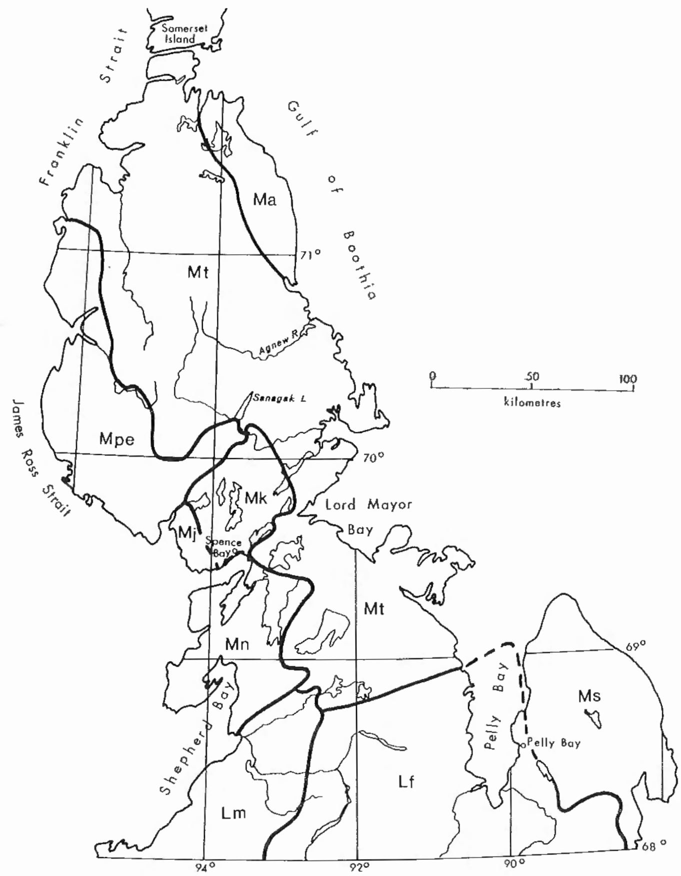

Figure 1. Ecoregions of Boothia Peninsula and northern Keewatin (preliminary map).

strongly calcareous till materials were found and weak soil development was noted. These soils are strongly cryoturbated Regic Turbic Cryosols.

On coarse materials (sands and gravels) where ice-wedge polygons are common, the soils are Brunic Static Cryosols and Regic Static Cryosols. Along polygon trenches, strong cryoturbation was found associated with well developed ice wedges.

Organo Cryosols are a very minor group of soils in this area. They are found mainly in very small wetlands associated with recent alluvial plains. Here, peat layers (fen peat) very seldom reach greater than 30 cm in thickness and, in all cases, have layers of alluvial material included. In ecoregion Lm, on very wet areas, some peat deposits were noted. These were continuous peat deposits (fen peat) without mineral layers.

Vegetation

Three basic vegetation habitats were identified in the study area. The rockland and cryoturbated vegetation is characterized by little or no vegetation cover and the tundra and wetland vegetation by moderate to continuous vegetation cover. Further separation of these vegetation habitats into vegetation types is as follows:

1. Rockland and Cryoturbated Vegetation
   a. Rock desert types
   b. Solifluction slopes and strongly cryoturbated types
   c. Gravelly and sandy types
2. Tundra Vegetation
   a. *Dryas* tundra types
   b. Ericaceous tundra types
   c. Shrubby tundra types
   d. Tussocky tundra types
   e. Wet tundra types
3. Wetland Vegetation
   a. Fen peatland types
   b. Marshland types

Further subdivision into vegetation type and description and species composition will be carried out after the analysis of field data.

The northern limit of the ericaceous vegetation is represented by *Ledum decumbens, Vaccinium Vitis-idaea* and *V. uliginosum.* This coincides with the northern limit of the continuous vegetation cover and the low (continental) arctic climatic situation. A number of species found in the area had not been reported previously in the literature.

In the winter of 1974-75 the biophysical maps of the area will be prepared. On these maps the three basic components of the environment-landform, vegetation and soils will be identified in a climatic (ecoregion) framework.

119. MODIFIED CRREL ICE CORING AUGERS

Project 730019

J. Veillette
Terrain Sciences Division

The standard USA-CRREL auger, now produced by the Geotest Instrument Corporation has been subjected to numerous modifications by a variety of users. Originally designed to be turned by hand, it is also adapted to a variety of power sources ranging from light, portable engines to heavy truck or track mounted drilling equipment for sampling frozen soils free of coarse-textured material.

Irrespective of the power source used, the auger is limited to short core runs (6 to 10 inches) when used in the vertical position with the barrel completely below ground level. This limitation is due mainly to:

1) Limited room for storage of cuttings between the walls of the hole and the outside diameter of the tube.
2) Tendency for cuttings in certain soils to develop solid rings between the auger flights and prevent further upward movement.

The USA-CRREL auger produces a 3-inch core and drills a 4 3/8-inch hole. Smaller versions of various lengths producing cores as small as 1½ inch and powered by small engines are used in the Division. The main reasons for their use are:

- faster penetration rate in low temperature permafrost,
- reduction of linear speed of travel at the cutting edge, reducing melting of ice, which could induce binding,
- reduction in surface area to minimize changes of binding the barrel in the hole,
- extended terrain coverage.

A further modification to provide additional storage room for cuttings and permit a longer core run is described here. The auger was designed to be used with the J.K.S. 300 drill. Figure 1 illustrates the dimensions of the auger. The main addition consists of steel deflectors located near the top of the barrel at 180 degrees to each other and used to divert excess cuttings through openings in the barrel into the inside of the tube.

All CRREL augers in use, whether factory made or machined tools, have similar geometrical configurations. Consideration of the geometry of the barrel described here illustrates the volume limitations of the auger. To produce a 2-inch core, the cutting edge has to remove a ring of material of 3½-inch outside diameter and 2-inch inside diameter. A small amount of clearance required inside the tube plus the thickness of the tube itself accounts for additional lost space. To this must be added the volume lost by about 9 feet of double helical flights made up of a metal strip. About 163 cubic inches of available space for cuttings is left between the barrel and the walls of the hole. Assuming the disturbed soil in the form of cuttings would occupy the same volume as *in situ*, only 24 inches of advance at the cutting edge would produce enough cuttings to fill up the available space. Since densities are much lower in the loose state (cuttings) than *in situ*, it follows that, in practice, an advance of 24 inches is generally impossible without compressing the cuttings, which in turn induces binding. For design purposes an arbitrary loose density, half the density *in situ*, was assumed for loose cuttings. Based on this assumption an 18-inch run would leave twice the amount of available space between flights and inside the tube as the material occupies *in situ*.

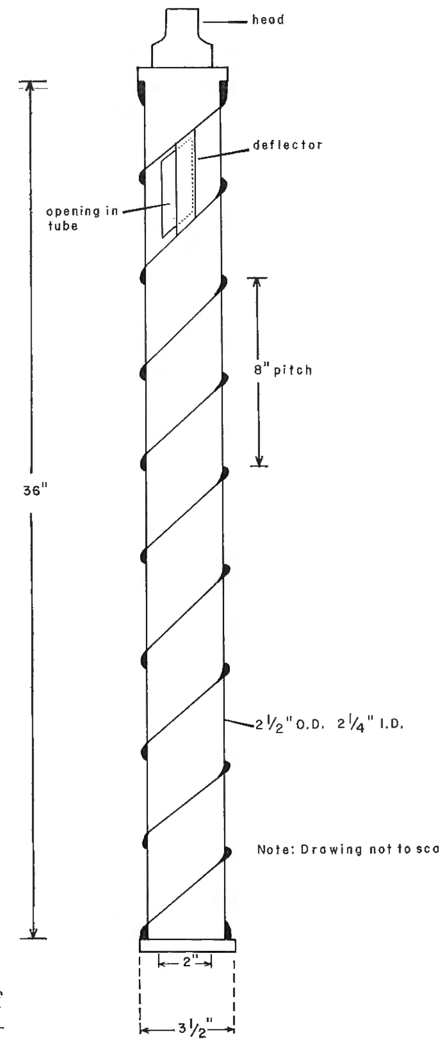

Figure 1. Modified CRREL barrel.

Results

The auger was thoroughly tested during summer 1974 in a variety of permafrost soils in the Arctic Islands. Runs up to 15 inches were secured using the full storage capacity of the barrel. The experiment was never pushed to the extent where serious binding of the barrel might have occurred. Cut-off rotational pressures observed on the hydraulic gauge were established for safe procedure, and average runs were in the vicinity of one foot. Shorter runs were made in soils, with a tendency to develop "mud rings" between the flights. Movement of cuttings was facilitated by oiling the barrel outside surface between successive runs. There is an indication that the loose density of cuttings could be even less than half the *in situ* density. Best results were obtained in friable material such as ice, frozen sand and gravelly sands. Slightly inclined holes using longer barrels with additional storage room should be tested.

HELICOPTER PORTABLE DRILL FOR HIGH ARCTIC PROGRAMS

Project 730019

J. Veillette
Terrain Sciences Division

Shallow permafrost coring was conducted during summer 1974 on Banks Island, in co-operation with J.S. Vincent (Project 740065), on Ellesmere Island with D.A. Hodgson (Project 720081), and on Boothia Peninsula with A.N. Boydell (Project 740074). While providing some subsurface data for these areas, the main objective of the drilling program was to test under field conditions a new helicopter portable drill, the J.K.S. 300. Such factors as portability, mechanical performance, maintenance needs, and operation costs were assessed.

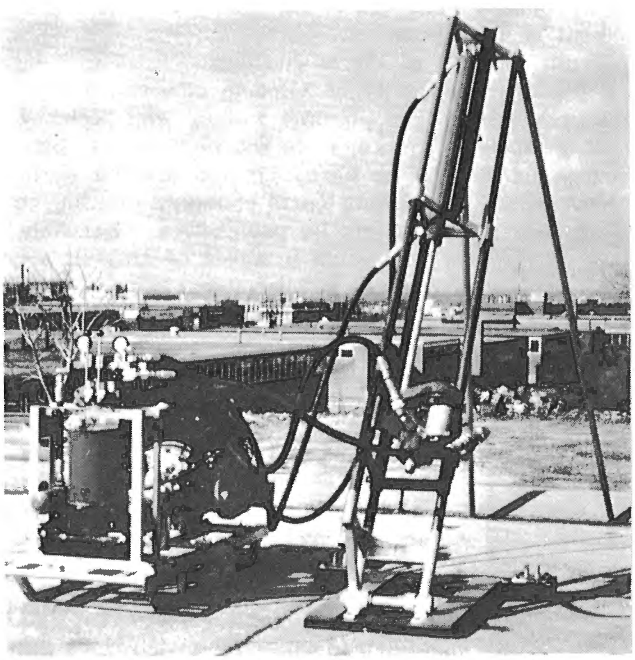

Figure 1. J.K.S. 300 core drill.

Ground temperature probes, installed in the fall 1973 in the vicinity of Thompson, Manitoba, are read weekly by the personnel of the Division of Building Research, National Research Council of Canada.

During fall 1973 research was initiated with the objective of locating or developing a helicopter-portable drill tailored to Division sampling needs in remote permafrost areas, such as the Arctic Islands. Guidelines were established in order to meet the following requirements:

1) Bridge the gap between larger helicopter-portable drills such as the Heli-Drill, and smaller light portable drills such as the Haynes ice cover, and Winkie diamond drills.

Positioning large portable drills in the high Arctic may cause serious logistics problems, and is not always economically feasible. Large helicopters with great fuel consumption are necessary to move such drills, which add considerably to the operational costs. On the other hand, light portable coring machines have depth and core diameter limitations. Production output is commonly low in terms of footage below a certain depth, and manual labour involved is commonly greater than for larger drills.

2) Adaptability to small fixed-wing aircraft and helicopters available for Arctic charter.

Helicopters for most Arctic work are single-engine turbine types, with block speeds in excess of 100 mph and fuel consumption in the order of 20 gallons per hour. Sling load capacity for these aircraft varies from about 900 to 1,200 pounds. The proposed drill was considered in relation to this type of heli-

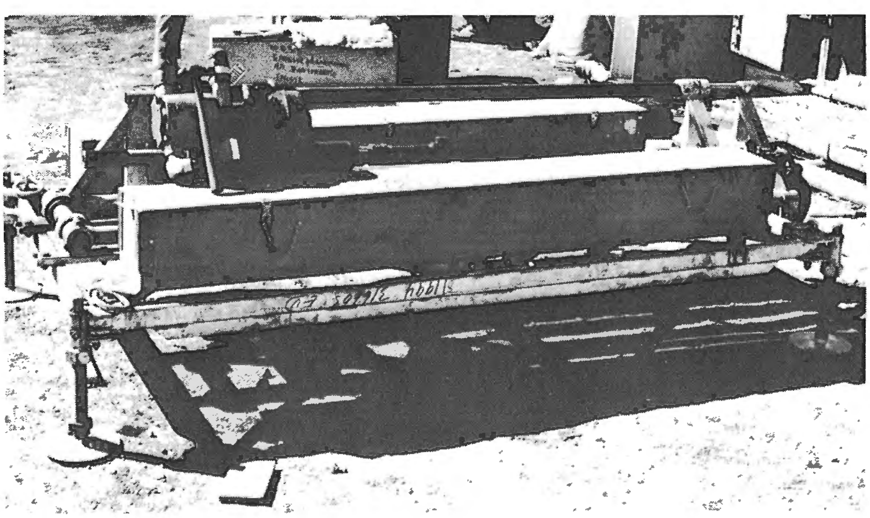

Figure 2. Platform with retracted drill mast.

Figure 3. Moving the power unit.

Figure 4. Moving the platform andmmast.

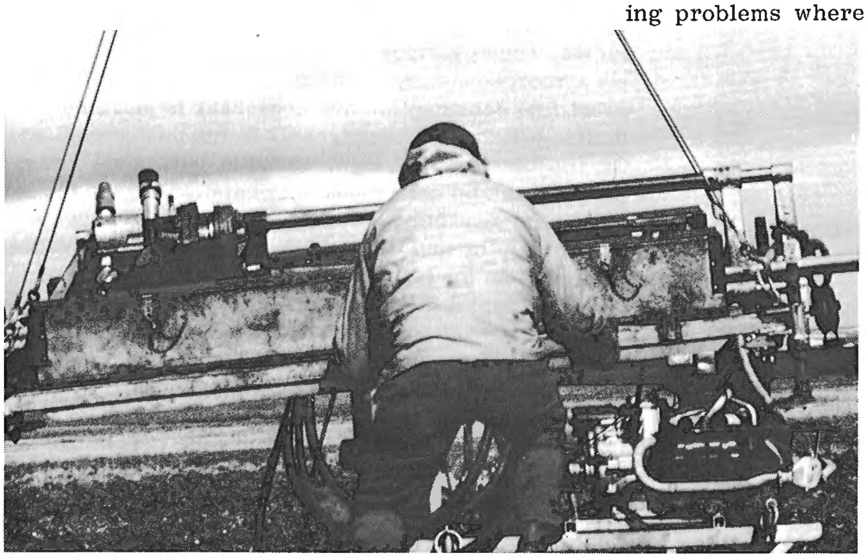

Figure 5. Positioning the platform and mast.

copter. Different varieties charter at similar rates, and cost about half as much as those required to move larger portable shothole drills such as the Heli-Drill.

Fixed-wing aircraft are used mainly for positioning of drilling equipment to a new base of operation. A prerequisite for the drill was that it could be easily carried in such aircraft as twin and single Otters with a minimum of disassembling, and smaller aircraft such as a Beaver DHC-2 when taken apart.

(3) Ability to function both as an auger and a diamond drill.

This feature was considered a highly desirable asset for operations in remote permafrost areas. The use of augering techniques, such as the CRREL barrel, greatly facilitate field operations and produce excellent core quality. When such techniques fail, diamond drilling, using a circulating fluid cooled below 0°C, permits the recovery of undisturbed core samples (Hughes *et al.*, 1973; Hvorslev and Goode, 1963). Unconsolidated frozen soils free of coarse-textured material also can be cored using the diamond drill with circulating water provided rapid rates of penetration can be maintained. Best results are obtained in "hard" permafrost (low temperature) using double tube core barrels. To perform both functions, a range of spindle speed, varying from about 30 RPM to 1000 or more with high torques in the low range, are considered essential.

(4) Flexibility for coring programs.

The majority of diamond drills are designed with little thought given to frequent assembly and disassembly. In mineral exploration, drills commonly are positioned at the same location for prolonged periods of time. Division coring objectives may require daily movement. Consequently, the structure of the proposed drill had to be such that assembly time could be kept at a minimum.

(5) Depth capacity of 100 to 200 feet.

The depth of the majority of holes in connection with surficial geology mapping, gas pipeline routes, and highway construction in permafrost terrain is in the order of 20 feet. However, greater depths may be necessary for specific engineering problems where positioning costs of heavy drilling equipment might be prohibitive. Borehole instrumentation in areas of difficult access also could become feasible.

(6) Simple design, availability of replacement parts.

Field operations in the high Arctic are impaired by enough problems without adding the burden of complex equipment. Simplicity of operation and design was considered essential.

J. K. S. 300 hydraulic drill

The above mentioned considerations led to the choice of the J. K. S. 300 diamond drill designed primarily as a light mineral exploration drill. Field testing of the prototype on bedrock holes, under both winter and summer conditions, has been carried out by the manufacturer since January 1973. Following modifications resulting from these field tests the prototype was considered ready to be evaluated for Divisional drilling requirements.

All of the drill working components are hydraulically driven (push, pull, and rotation) which permits a close control of the drilling operation. The complete drill assembly consists of two separate components, the power unit and the drill frame-head unit (Fig. 1).

The hydraulic circuit is a closed-loop design, which reduces the amount of oil needed to operate the circuit and consequently the total weight of the power unit. Hydraulic system pressures up to 3,000 psi can be used. A heat exchanger keeps the oil at working temperature. For augering purposes a hydraulic low-speed motor (39 lb.) can be adapted to the drill head in a matter of minutes, permitting the necessary low spindle speeds and high torques required for such work. For diamond drilling a high speed motor (18 lb.) can be substituted. The motors are interchangeable and are supplied in a variety of output shaft RPM. For a circuit pressure range of 1,000 to 2,500 psi with low speed motor, a torque output of 2,200 in.-lb. to 8,000 in.-lb. can be developed depending on the gear ratio used. For the same circuit pressure, the hydraulic cylinder will show a pushing range of 4,900 to 12,000 lbs. and a lifting range of 3,400 to 8,500 lbs.

The circuit pressure will vary with the HP input; electric and diesel power sources can also be used.

Power Unit	Weight (lbs.)	Drill Frame Head	Weight (lbs.)
No. 126 Volkswagon Industrial Engine 44 BHP	280	Mast and hydraulic cylinder	250
Hydraulic pump and circuit with skid	387	Drill head	140
Total	667		390

Field procedure

To permit short assembly and disassembly time, the drill frame was mounted on a light (195 lb.) reinforced rectangular tubing platform ($3\frac{1}{2}$ by 7 feet) designed to sustain loads up to 2,000 lbs., (Fig. 2). Jack screws at each corner of the platform allowed the levelling of the assembly. Plywood boxes were secured to the platform for drilling tools and accessory equipment. A common procedure was to sling the power unit and then position the platform at a reasonably close distance so that hydraulic hose connections between the two units could be facilitated. Figures 3, 4, and 5 illustrate the positioning operation. With the mast erected in vertical position, drilling could be resumed (Fig. 6). Typical time required for a 5-mile move of men and drill, including assembly time, is about 1 hour.

Drill Performance

To ensure greater terrain coverage, the holes drilled during summer 1974 were limited to maximum depth of 20 to 30 feet. Drill performance indicates that much deeper holes could be cored with little difficulty. Mechanical performance of the drill was excellent and lost time due to breakdown was practically nil. The procedure adopted for operating with the power unit separated from the platform eliminates a source of vibration. On the other hand, the non-anchored light platform limits both the pushing and feeding capabilities of the hydraulic cylinder. Although this is of minor importance when using the CRREL barrel, using higher down pressure is desirable for some diamond drilling situations.

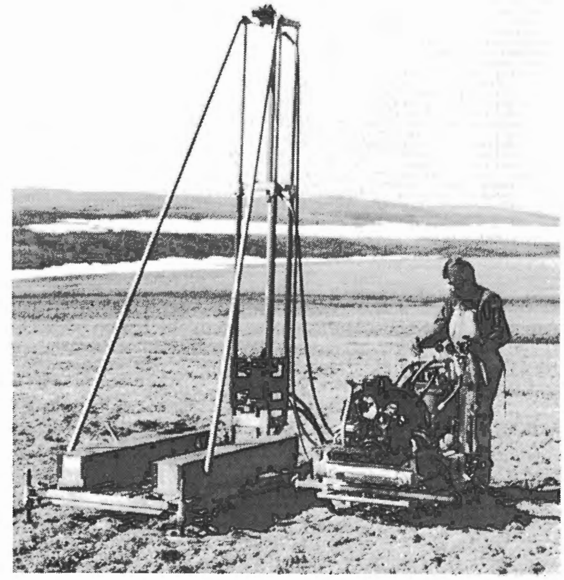

Figure 6. Drill in operation.

Coring

Most of the coring was done using a modified CRREL barrel (*see* reports on modified CRREL ice-coring augers in this volume). A limited amount of diamond drilling was done with both N-size double tube swivel type barrels and non-coring pilot type bits, using water as drilling fluid. This approach, while useful in providing rapid stratigraphic information, should be confined to drilling operations using a chilled fluid when detailed subsurface information is required.

The co-operation and ingenuity of Mark Nixon, Terrain Sciences Division, for the field testing period is greatly appreciated. The technical help of Mr. J. Durrel, formerly of Woolex Exploration Ltd. of Calgary, and personnel of J.K. Smit Diamond Products, Toronto Division, was most valuable.

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SURFICIAL GEOLOGY INVENTORY, BANKS ISLAND, DISTRICT OF FRANKLIN

Project 740065

J-S. Vincent, C.M. Tucker and S.A. Edlund
Terrain Sciences Division

Introduction

Recent oil and gas exploration on Banks Island has created a need for detailed information on the unconsolidated deposits, landforms, permafrost, ground ice, organic cover and the geomorphic processes responsible for terrain modification. To this end, the project was designed to obtain data which would aid in the implementation of Territorial Land Use Regulations and be pertinent to engineering construction, petroleum exploration and related activities. A base camp was set up in the central part of the island close to a lake situated 93 km northwest of Johnson Point. The camp provided facilities for up to 14 persons at one time.

A Bell 206-B helicopter was used for air traverses, while the Honda A.T.C.-90 and inflatable Canova boats were the mode of transport for shorter surveys. Logistical support, including aircraft (Twin Otter and Bell helicopter) was efficiently provided by the Polar Continental Shelf Project at Tuktoyaktuk.

This year's effort consisted mainly of:

1) identifying and obtaining general information on the various unconsolidated lithological and stratigraphic units;

2) gathering quantitative data at critical sites;

3) attempting to understand the recent geological history of the island;

4) identifying and describing the various processes acting on the lithologic units; and

5) obtaining information on the vegetative cover of specific landforms and formations; this was conducted by S.A. Edlund.

Mapping

Investigations of the different lithological and stratigraphical units were carried out in order to provide ground base information essential for completing a preliminary airphoto interpretation and design of an extended map legend this winter. The identification of a series of units based on textural, morphological, and genetic attributes, as well as relevant active and fossil processes was initiated. Adequately defining some map-units posed numerous problems. For example, much of the Banks Island surface is completely blanketed by a thin layer of solifluction debris which hinders identification of underlying material. This problem is compounded by the fact that there are very few available sections, especially in the area described in Fyles (1962) and Craig and Fyles (1960) as not glaciated during the Classical Wisconsin. Another problem involves the presence of extensive areas of surficial unconsolidated Cretaceous and Tertiary sediments and consolidated Devonian bedrock (Fig. 1). While it is possible to identify these formations, commonly it is difficult to subdivide them into their various lithological facies which respond differently to specific processes and disturbances. This is particularly true for the Eureka Sound Formation of Maastrichtian-Eocene age (Miall, 1974 and Fig. 2). A third difficulty lies in the identification of Pre-Classical Wisconsin tills. Since these tills commonly are composed of reworked unconsolidated Cretaceous and Tertiary sediments, problems arise in separating them from their source material and chronologically ranking them.

Based on current research it is possible to construct a textural and morphological map of the island; however, further detailed observation is needed before a complete understanding of genesis and chronology is attained.

Site Descriptions

In order to identify the lithologic units and acquire information for the extended map legend, detailed site descriptions were completed at critical locations. This involved gathering data on texture, types and dimensions of landforms, slope, drainage, permafrost and ground ice, as well as processes involved. More systematic site descriptions will be carried out next year when the preliminary airphoto interpretation has been completed.

In order to obtain subsurface data, a small-scale drilling program in fine sediments was attempted using a CRREL barrel with a Haynes powerhead. An extensive drilling program was carried out under the supervision of J. Veillette (*see* Veillette, this publication, report 120). A total of 19 holes were drilled in varying lithologies along the river which flows from the base camp lake east to the Thomsen River, and around the elbow-area of the Bernard River. Although the main purpose of the drilling program was to test prototype equipment, a great deal of useful core data was obtained. Hammer seismic and resistivity data were collected near the Veillette drill sites by a party supervised by the Resource Geophysics and Geochemistry Division. The purpose of this research was to make areal correlations in conjunction with the drill site results. Further subsurface information will be obtained from the analysis of samples removed from seismic shotholes drilled by Elf, Deminex and Panarctic oil companies. These samples have already been described by personnel at the Institute of Sedimentary and Petroleum Geology in Calgary.

Pleistocene History

From the detailed studies of materials, landforms, and available sections, substantial information relating to the Pleistocene history of the island was

Figure 1

The Devonian plateau along M'Clure Strait east of Cape Vesey Hamilton. In this area the surface is devoid of Pleistocene material except for local patches of thin till. Note the badland-type erosion and the talus made up of frost-shattered sandstone arranged in a sorted step pattern. (August 8, 1974.) 202672-E

Figure 2

Badland-type erosion in the Eureka Sound Formation, 35 km from the mouth of and on the north side of the Muskox River. In the zone bordering the river, the Eureka Sound surface lacks Pleistocene deposits and is composed of interstratified beds of sand, clay, and carbonized wood. Photographed facing east July 2, 1974. 202672

Figure 3

View of the north slope of the Masik River valley, 16 km east of the mouth. The slope consists of Cretaceous Christopher shale overlain by till and/or sands and gravel of, as yet, undetermined origin. The active layer detachment failures and related gullying are typical of Christopher shale. (July 23, 1974.) 202672-B

Figure 4.

Large solifluction lobes at Cape Vesey Hamilton, M'Clure Strait. The lobes are composed of frost-shattered slabs of Devonian sandstone derived from the escarpment shown in the background. (August 8, 1974.) 202672-D

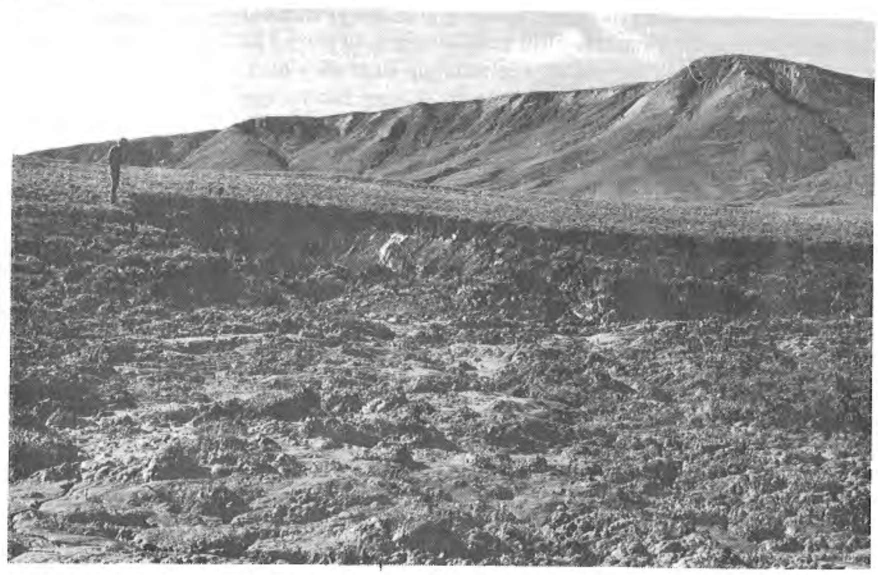

Figure 5

View to the west of a thermokarst hollow and valley wall of the Thomsen River just north of the mouth of the Muskox River. The valley wall is composed of Christopher shale overlain by Hassel sands and by a thin layer of Kanguk red shales and cindery material. The hollow is located in colluvial material. Note the exposure of massive ice on the backwall. (August 6, 1974.) 202672-C

Figure 6

Small section on the east side of the Thomsen River about 52 km northwest of Johnson Point. The section has been exposed by the melting of massive ice which is visible near the bottom and underlies 18 cm of till and 3 m of varved glaciolacustrine silts and clays. An ice wedge is also visible to the left of the shovel. The varved clays were deposited in a lake situated between a morainal ridge, which possibly marks the western extent of the Classical Wisconsin, and ice retreating to the east. (July 10, 1974.) 202672-A gathered. Major events are understood, but the exact chronology has not been determined. It is expected that resultant ^{14}C age determinations of wood and organic material collected this field season will supply much new information. Similarly, dates on material recovered by R.J. Mott (*see* Mott, this publication, report 125) from organic cores in lakes located in key areas may yield important data. Investigations from the past summer have recorded several till sheets thought to be either Classical Wisconsin or older; however, more research is required before full understanding of these till sheets and various glaciations is gained.

Processes

Major processes affecting the different lithologic units were investigated. Studies revealed that processes vary significantly in rate, degree, and type with changing lithologies (Figs. 3 and 4). This is especially apparent from mass movements on the slopes of the older unconsolidated geological formations. Particular attention was paid to relatively widespread eolian deposits (*see* Pissart, this publication, report 134). Ground ice is widespread in Pleistocene deposits and thermokarst is an important factor in recent landscape evolution (Figs. 5 and 6). Fluvial and coastal processes are being investigated by T. Day (*see* Day, this publication, report 127).

Vegetation

In conjunction with surficial geology mapping, plant communities were studied on a variety of substrates. Broad correlations between vegetation types, surficial materials, and geomorphological features are being drawn. Several eolian deposits were inventoried in greater detail as to plant species and their abundance.

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122. GLACIAL GEOLOGICAL INVESTIGATIONS IN NORTHWESTERN GREENLAND

Project 670031

W. Blake, Jr.
Terrain Sciences Division

Introduction

Part of the 1974 field season was devoted to an examination of glacial and marine deposits on Saunders Ø (Island) and Carey Øer (Islands), northwestern Greenland. Both areas were deemed worthy of investigation in view of published reports (Krinsley, 1963; Bendix-Almgreen *et al.*, 1967), particularly because of possible similarities to the sequence of unconsolidated deposits exposed on Coburg Island (Blake, 1973), on the opposite side of northern Baffin Bay (Fig. 1).

Saunders Island

Saunders Ø was reached by boat from the village of Dundas, some 25 kilometres to the east, and observations and collections were made between July 26 and 30. A camp was established at Uvdlisaitut at the apex of an area of raised beaches on the north coast of the island. The shingle beaches and the underlying marine and glacial deposits are inset into a broad bay carved into the Upper Red member of the Narssârssuk Formation (Fig. 2). Davies and Nicol (1963, p. 34) noted

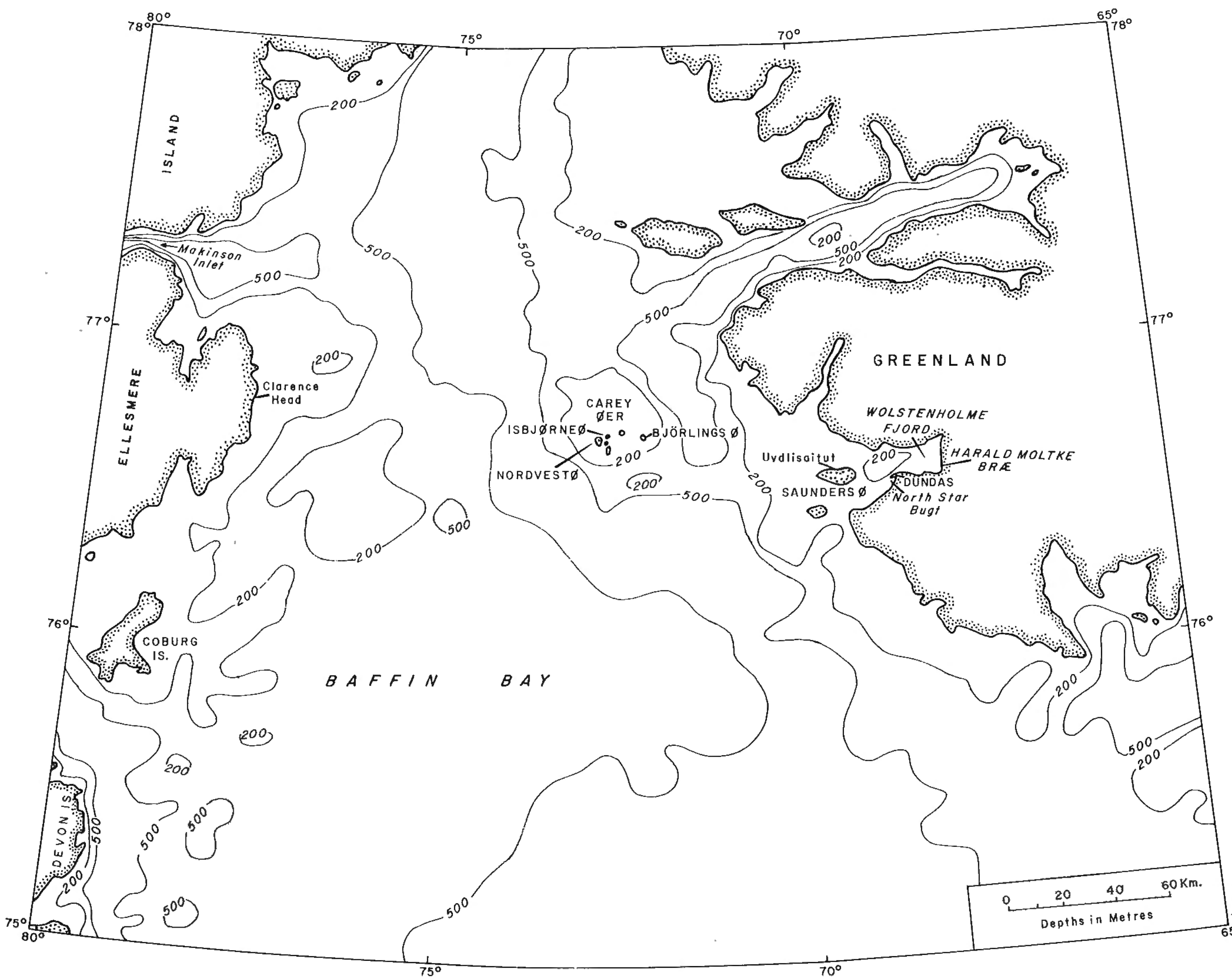

Figure 1. Location map, northern Baffin Bay. Adapted from Chart 896, "Arctic Bathymetry north of 72°, 0° to 90° West", Canadian Hydrographic Service, 1967.

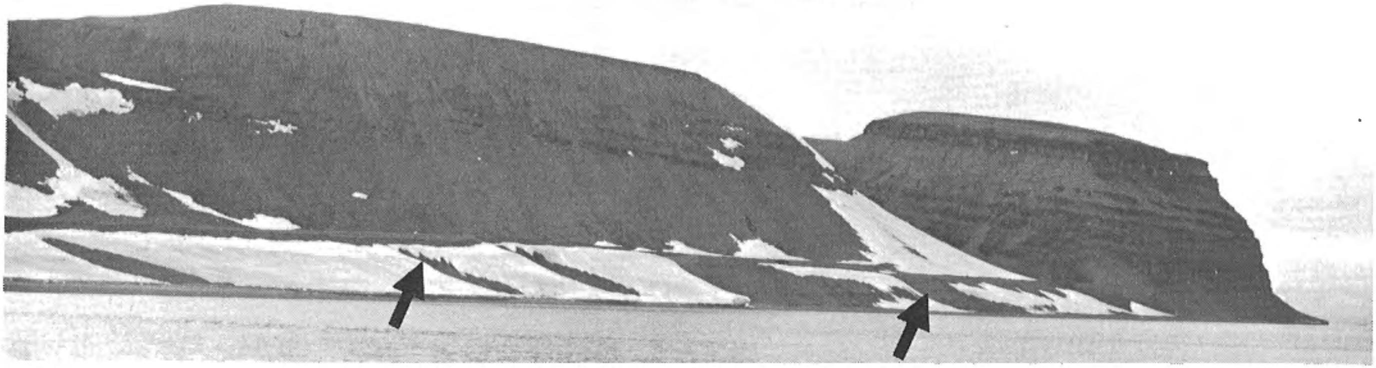

Figure 2. View west-southwestward along the north coast of Saunders Ø. Note gentle dip eastward of unconsolidated strata. Solid arrows indicate locations of the two sections where collections were made. July 30, 1974. (GSC 202657)

that "the upper red beds are a cyclical alternation of red siltstone, gray dolomite, and gray-green sandstone." Much of the coast of Saunders Ø is characterized by cliffs, but the deposits at Uvdlisaitut are situated where several rivers draining the inland plateau (much of it about 30 m in elevation) enter the sea.

Krinsley (1963), in describing the stratigraphy of coastal exposures west of Uvdlisaitut as a result of field work on Saunders Ø in 1953, reported 15 m of marine till overlain by 15 m of stratified marine sand and beach shingle. Shell fragments of the marine pelecypods *Mya truncata* and *Hiatella arctica*, collected from a zone in the marine till at an elevation of 4.5 m, were dated as being > 32,000 years old (W-75; Suess, 1954). The same age was obtained for fragments of *Mya truncata* (W-74) from the top of the marine till unit. Shells of the same species from a zone at 24 m, in the middle part of the overlying marine sand, were 8,570 ± 200 years old (W-72; Suess, 1954).

As a result of his investigations Krinsley (1963, p. 62) concluded that:

> "Any fluctuations of the front of the north lobe between 32,000 and 8,500 years ago must have been north of Saunders Ø and North Star Bugt, for the following reasons: (1) There is no apparent unconformity between the marine till (> 32,000 years old) and stratified sand (8,570 ± 200 years old) at Saunders Ø. The change in facies is transitional. (2) There is no indication of glacial reentrants, nor are there any intersecting marginal channels at Saunders Ø. No stratigraphic or topographic evidence was found to suggest that Saunders Ø had been glaciated during the last 32,000 years. (3) Immediately north and south of North Star Bugt one till rests directly on bedrock. This till is locally covered with marine sand that was deposited in shallow water 8,500 ± 200 years ago."

Evidence collected during the writer's examination of two sections west of Uvdlisaitut indicates that the history of glaciation and marine transgression is considerably more complicated than that envisaged by Krinsley. At the western section (ca. 28 m high as determined by levelling) the mollusc-bearing bouldery till exposed close to sea level is overlain by a sand unit several metres thick, from which two large whale bones were extracted at an elevation of ca. 9 m. This sand unit becomes coarser upward, and at the eastern section (ca. 21 m high) the gravel at an elevation of ca. 11 to 12.5 m was found to contain abundant fragments of *Mytilus edulis*. The shell-bearing, dark reddish grey (5Y 4/2) gravel is overlain by similar material, non-fossiliferous, which becomes increasingly compact and richer in fines upward, and this unit, which is 0.5 to 1.5 m thick and contains angular boulders, is interpreted as being a till. It is overlain in turn by an olive (5Y 4/3), clay-rich layer with shells, by a thin bed of shell debris, and by a reddish brown (5YR 4/3) sand with abundant paired valves of *Mya truncata* as well as some paired valves of *Hiatella arctica* and a few individuals of *Macoma calcarea* and *Clinocardium ciliatum*. Above this unit, the marine sediments become increasingly coarser toward the beach shingle at the top of the section.

The age of a sample consisting of seven intact and paired valves of *Mya truncata* from the reddish brown sand unit at the 13.5-m level has been determined to be 8,010 ± 80 years (GSC-2079). Presumably the underlying mollusc-rich zones, above the thin till unit, are closer in age to the 8,570 ± 200 years (W-72) value reported by Krinsley (1963), but until additional dating is carried out we cannot be sure that any of the postglacial strata on Saunders Ø are as old as the deposits on the north side of Wolstenholme Fjord. Radiocarbon age determinations on the north side of Harald Moltke Brae (Glacier) — 9,000 ± 350 years (L-216A; Goldthwait, 1960) for marine shells and 9,880 ± 500 years (M-723; Crane and Griffin, 1959) for marine algae — indicate that innermost Wolstenholme Fjord was free of glacier ice by 9,000 years ago.

The situation on Saunders Ø appears similar to that encountered on southeastern Coburg Island, where a variety of marine and glacial deposits are preserved. The uppermost fossiliferous bed which predates the last glaciation, at an elevation of 5.7 to 6.0 m, is characterized by the presence of *Mytilus edulis* shells which are > 38,000 years old (GSC-1425; Blake, 1973). Above the *Mytilus*-bearing horizon is a non-fossiliferous unit of sand, gravel, and cobbles believed. to have been deposited during the last glaciation; the lowest postglacial shells overlying the non-fossiliferous

Figure 3. View westward at the head of Wreck Bay, Isbjørneø, Carey Øer. Note size of boulders in emerged beaches. Scale is given by man standing (open arrow) on rock promontory in lower left corner. Strata containing *Hiatella arctica* outcrop on steep slope behind him. The solid arrow indicates the highest boulder beaches in this locality at ca. 40 m, and the diamond shows an example of peat mantling slopes and summits; note the typical development of ice-wedge polygons. August 9, 1974. (GSC 202658)

zone are barnacles 8,940 ± 110 years old (GSC-1426; *Balanus balanus*) at an elevation of slightly above 7.0 m. Farther north, near Clarence Head on the east coast of Ellesmere Island (Fig. 1), *Mya truncata* shells at 27 to 30 m are 8,980 ± 160 years old (GSC-1572-2). An earlier determination, utilizing the single largest valve from the same collection, gave an age of 9,770 ± 330 years (GSC-1572; Blake, 1972).

The Carey Islands

Approximately 24 hours were spent on Carey Øer (Islands) on August 9 and 10. The writer was given the opportunity of making this brief reconnaissance while C.S.S. Hudson was carrying out a series of geophysical traverses in the vicinity. A landing was made first at Wreck Bay on the eastern side of Isbjørneø. Much of the summit of Dark Head, at the northern end of this island (cf. Wordie, 1938), was found to have a mantle of peat. A similar organic cover occurs on nearby slopes and hilltops (Fig. 3), although palsa-type peat deposits such as those described by Bendix-Almgreen *et al.* (1967) for nearby Nordvestø were not observed. The peat, in which *Dicranum* sp. is the main component and *Dicranum elongatum* is frequent according to M. Kuc (unpublished G.S.C. Bryological Rept. Nos. 295, 296), is at least 35 cm thick, and in general it was frozen below a depth of 17 cm. Ice-wedge polygons have developed in the organic cover giving it a characteristic pattern, but in places on the summit the present-day vegetation and part of the underlying peat have been removed by deflation.

Strikingly well developed boulder beaches exist at the head of Wreck Bay south of Dark Head, and they extend to ca. 40 m a.s.l. (Fig. 3). Although the beaches themselves are composed of far too massive gneissic boulders to be likely places for driftwood or molluscs to occur, erosion at the shore has revealed that fossiliferous unconsolidated deposits several metres thick underlie the boulders. Not enough time was available, unfortunately, to make large-scale excavations in the unstable, steep slope where these strata outcrop, but beds of sand containing both shell fragments and intact pelecypods are present. The size, thickness, and misshapen nature of *Hiatella arctica* valves, which characterize part of the section, suggest that these pelecypods are 'old'; i.e., they are typical of the type of shells which predate the last glaciation. Shells of similar-appearing, thick, *Hiatella arctica* from a compact shelly unit on Coburg Island below the *Mytilus* horizon are > 40,000 years old (GSC-1062), and in both localities a few fragments of *Mya truncata* and of a scallop, probably *Chlamys islandicus*, are also present. In addition, it would appear that till is present in the section, judging by the quantity of angular boulders of various sizes interspersed among finer materials. Some of the shells may well derive from till, but the exact stratigraphic sequence is not clear.

On Nordvestø a landing was made in a bay at the southern end of Markham Beach, on the eastern coast of the island (cf. Wordie, 1938). Boulder beaches are well developed here also, although in general they are not composed of such massive rocks as are the beaches at Wreck Cove, Isbjørneø. A collection composed nearly entirely of *Balanus balanus* was made in a shore exposure of sand and gravel; the site was at an elevation of ca. 1.5 m above high tide level and 1.0 m below the surface of the beach (as determined by levelling). These shells are believed to be of postglacial age, but a radiocarbon age determination is not available as yet.

Much work remains to be done in deciphering the glacial history of Carey Øer, although it seems certain that at some time the islands have been overridden by ice. As early as the last century Chamberlain (1895a, p. 219) stated, in regard to these islands after visiting Bjorlings Ø, "They are very notably abraded by glacial action coming from the north. Striae are still preserved upon them at heights of 500 feet above the sea." In another report Chamberlain (1895b, p. 169) referred to "glacial groovings on the summit of the southeastern island." Likewise, Bendix-Almgreen *et al.* (1967, p. 12) noted, after visiting Nordvestø, "Near the summit of the island are several small outcrops which were truncated, planed and smoothed by glacial action." Erratics of limestone, shale, sandstone, quartzite and dolomite have been reported by these authors as well as by Koch (1928), and additional examples were collected on the dolerite of Dark Head, Isbjørneø, at the time of the writer's visit. Some of these erratics occur above the limit of marine submergence, which Bendix-Almgreen *et al.* (1967) place at ca.80 m on Nordvestø. Although it is difficult to know when the erratics were emplaced, the fact that striae and grooves are preserved at high levels on Carey Øer suggests that they were inscribed during the last glaciation; otherwise it seems likely that they would have been destroyed by frost action.

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123. POLLEN ANALYSIS OF ICE CORE SAMPLES FROM THE DEVON ISLAND ICE CAP

Project 690064

S. Lichti-Federovich
Terrain Sciences Division

Introduction

An earlier study (Lichti-Federovich, 1974) indicated that pollen analysis of snow samples from the upper 0.5 m of the Devon Island Ice Cap (Fig. 1) reflected seasonal variation in the pattern of deposition. On the basis of that encouraging finding, and with the background of glacier palynology from other parts of the world (Vareshi, 1942; Godwin, 1949; Krenke and Fedorova, 1961; and Bortenschlager, 1970), it was decided to analyze the pollen of meltwater samples recovered during thermal drilling of the Devon Island Ice Cap in 1973. The samples were taken and made available by Drs. R.M. Koerner and W.S.B. Paterson of the Polar Continental Shelf Project, Department of Energy, Mines and Resources.

Field Methods

Cores were recovered with a thermal drill which yielded 14 litres of meltwater for each 1.5 m depth of drilled ice. The meltwater was drawn continuously into a melt tank, from which it was drained into a precleaned, stainless-steel pressure tank. The water then was filtered through 5 μ pore-size triacetate metricel filters. Each filter represented a core increment of 1.5 m depth. The meltwater tank was rinsed out each day with a litre of ethyl alcohol.

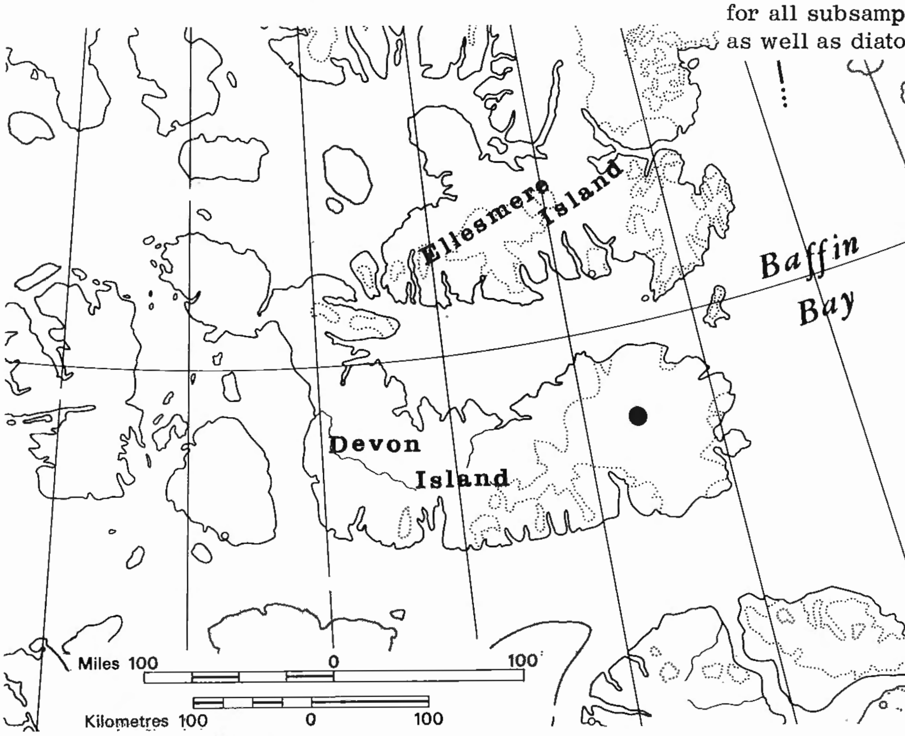

Figure 1. ● Location of sampling site on Devon Island.

Laboratory Methods

All handling and processing of the samples in the laboratory was done in a specially constructed chamber of sealed plexiglass connected to an aircleaning unit (Fig. 2).

To further reduce the possibility of contamination, a simplified processing technique was adopted as follows:

1. Treat 10 minutes with acetolysis mixture (9 parts acetic anhydride: 1 part H_2SO_4) at 100°C.
2. Wash in glacial acetic acid and centrifuge.
3. Wash in filtered distilled water and centrifuge.
4. Mount residue in glycerine for microscopic examination.

Pollen grain diameters in Betula were measured during the routine counting, and while it is recognized that the values are greater than the true dimensions because of swelling in glycerine, the relative proportions of different size groups might well indicate the relative amounts of shrub and tree types. The degree of preservation of the grains was recorded on an arbitrary scale, following Havinga (1964). The numbers of grains which could not be identified, because of poor preservation or fragmentation, were recorded for all subsamples. Totals of moss and fungal spores as well as diatoms were noted.

Results

Table I summarizes the sample depths, the amounts of meltwater, and the approximate age estimates based on ice-flow considerations (R.M. Koerner, pers. comm.). Four samples were filtered and made available for pollen analysis, but only samples 1 to 3 have been analyzed for inclusion in the present report.

Samples 1, 2, and 3 yielded 5, 6, and 2 filters respectively, and the detailed pollen and other analyses of these filter samples are presented in Table II.

The two filters from sample 3 gave low pollen totals (12 and 14 respectively, the six filters from sample 2 yielded pollen counts ranging from 67 to 179, and sample 1 gave filters with the highest pollen totals, from 50 to 463.

There is a broad trend in the

Table 1

Sample Number	Filter Numbers	Sample depth (m)	Meltwater (litre)	Age - approx. years B.P.
1	168 - 146 to 172 - 150	258 - 259.8	72.8	2,900 - 3,100
2	184 - 162 to 188 - 167	282 - 284	70.2	6,000 - 8,000
3	197 - 176 to 197 - 177	292 - 294	13.9	12,000 - 50,000

Table II

Totals of pollen and other microfossils from ice samples from the Devon Island Ice Cap

Sample Number	Filter Number	Approx. Age yrs. B.P.	*Alnus*	*Betula*	*Picea*	*Picea* (fragment)	*Pinus*	*Pinus* (fragment)	Conifer (fragment)	*Quercus*	*Populus*	*Fraxinus nigra*	*Salix*	*Corylus*	*Myrica*	Ericaceae	Cyperaceae	Gramineae	*Urtica*	*Artemisia*	Ambrosiae	Tubuliflorae	Compositae
1	168 146	2900–3100	260	95	2	7	6	3	2				2		1	2	4	3	1	4	4		
	169 147		2	11		2				1			1					2		3			
	170 148		64	28	1	1	1	1	2				3					2		4	1		2
	171 149		94	82		1		3	1				1	1	1		2		1	3	1		
	172 150		161	93			2	1			1		3	2	1	3	2	4		6	3		
2	184 162	6000–8000	57	6														2		1	1		
	184 163		5	1																1			
	185 164		77	14			3	1					1					1		3	1		
	186 165		64	5			1						3			2				4		1	
	187 166		107	30	1		2	1	2				2		1	4	1	2		3	2	1	
	188 167		35	1		1							2		1		2	2		1			
3	197 176	12,000–50,000		4		2						1								2			
	197 177		1	6		1	1													4			

Sample Number	Filter Number	Approx. Age yrs. B.P.	*Chenopodium*	Polygonaceae	Ranunculaceae	*Ranunculus sulphur.*	*Saxifraga*	Rosaceae	*Dryas*	Leguminosae	*Scrophularia*	*Valeriana* (fragment)	*Lycopodium obscurum*	*Cryptogramma*	*Pteridium*	Polypodiaceae	Pteridophyta	Musci	Pollen-Spore sum (exclud. oxid. grains and fungal spores)	Unidentifiable pollen grains (oxid. or fragm.)	Fungal spores	Pennales - Diatoms	Centrales (fragm.)
1	168 146	2900–3100		1			3	1					1	1		1		56	463	64	8	1	3
	169 147						1				1							5	50	30	4	10	3
	170 148		1	1			2											14	130	17	12	8	1
	171 149			3	1		3											19	219	45	5	4	8
	172 150			1		1	2										1	19	308	45	8	4	4
2	184 162	6000–8000																4	73	28	7	4	3
	184 163																	1	8	3	10	2	3
	185 164																	19	122	27	8	9	4
	186 165						2	1		1						1		8	95	22	6	14	3
	187 166		2	1	1		2		1						2			10	179	47	9	38	4
	188 167			1	1			1								1		7	67	12	4	30	2
3	197 176	12,000–50,000																1	12	3		1	7
	197 177											1							14			4	5

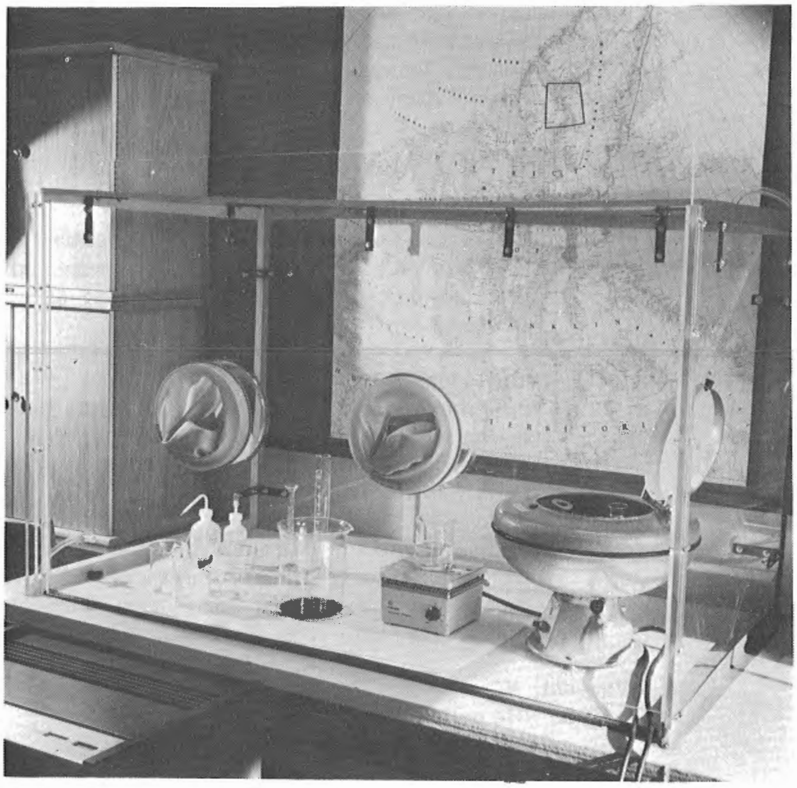

Figure 2. Special processing chamber to eliminate contamination.

relative frequencies of the main pollen types in relation to depth. The lowest sample (3) shows a preponderance of dwarf birch (30 to 40 per cent) associated with low frequencies of spruce and non-arboreal pollen types; the six subsamples from sample 2 yield a spectrum dominated by alder (54 to 78 per cent), associated with shrub birch (8 to 16 per cent) and low frequencies of willow and other non-arboreal pollen types; the uppermost sample (1) has 20 to 30 per cent of birch pollen with a wide range in pollen size, plus about 50 per cent alder and low frequencies of *Pinus, Myrica, Corylus, Salix,* Ericacea and non-arboreal types.

A notable feature of all the pollen assemblages is the very low frequency of pollen types of local or even regional origin, with the exception of filter samples 197-176 and 197-177 where the total numbers are very small.

Discussion

The spectra from all levels are dominated by pollen from distant sources. This result is in striking contrast to the data from the surface snow layers of the Devon Island Ice Cap (Lichti-Federovich, 1974), which indicated relatively high percentages of sedge, grass heath, and willow pollen types, all local tundra plants. Also, a preliminary analysis of a core of peat from the Truelove Lowland of Devon Island (Jankovska and Bliss, 1972), with a basal radiocarbon age of 2,450 ± 90 years (I-3231), shows relatively high proportions of pollen of local or at least regional origin.

It would be expected, from knowledge of the deglaciation history of the area (Blake, 1970; Barr, 1971), that the lowest samples analyzed here would yield little pollen of local or even regional origin, since land surfaces had not emerged before about 9,500 years B.P. The earliest dated terrestrial peat from the area is a sample from the base of a deposit on the Truelove Lowland with an age of 6,900 ± 115 years B.P. (S-428; Barr, 1971). Accordingly, the paucity of pollen of tundra affinity in the spectra from samples 2 and 3 can be explained in terms of the absence of adjacent tundra sources. However, if the estimate (Table I) of the age of sample 1 is accurate, it might be expected that it would give higher values for local pollen (especially Cyperaceae, Ericaceae and Gramineae). It is possible that the size of the ice cap might have been influential in this respect, since a large surface would have produced a local atmospheric circulation predominantly away from, rather than towards, the ice cap, whereas incoming ice masses would be from the upper levels and would be expected to be carrying long-distance pollen.

The results show a remarkable correlation with parts of the pollen stratigraphy which has been developed for the western low-arctic of North America (Hopkins, 1972; Ritchie, 1972). These results indicate a major pollen zone boundary at about 10,000 years B.P., separating the older assemblage of dwarf birch with non-arboreal types from the younger assemblages dominated by spruce and later alder pollen. Table II illustrates the interesting similarity in trend.

The near absence of pine, together with the broad stratigraphic pattern referred to above, suggest strongly a western origin for the pollen assemblages. Such an origin is concordant with modern air mass circulation in the Arctic (Hare and Hay, 1974).

These preliminary findings (Table II) suggest that further studies of the pollen spectra in the Devon Ice Cap cores would be of interest, and illustrate the possibility of developing stratigraphic correlation between different sites.

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PALEOECOLOGICAL INVESTIGATIONS OF THE NORSE SETTLEMENT SITE AT L'ANSE AUX MEADOWS, NEWFOUNDLAND

Project 690044

M. Kuc
Terrain Sciences Division

Introduction

As a result of field studies and laboratory investigations, paleoenvironmental information is presented here in support of archeological investigations being carried out by the National Historic Parks and Sites Branch, Department of Indian and Northern Affairs. This work is a continuation of archeological research begun in 1960 at L'Anse aux Meadows (H. Ingstad, 1963, 1964, 1969, 1971; A.S. Ingstad, 1970; Morrison, 1971; Pohl, 1972).

The site is on the raised beaches at Épaves Bay near L'Anse aux Meadows ($51^{o}35'41"$N and $55^{o}32'06"$W) and was settled by Norsemen around the year A.D. 1000. The main function of the author's field work was to interpret the biostratigraphy of the organic deposits in the area between the Norse houses on the upper beach and the present shoreline (Fig. 1). Field work was undertaken in August and September 1973, and laboratory work was carried out in October 1973 and from June to October 1974. Samples of the deposits examined have been submitted to the Geological Survey of Canada.

Materials and Methods

The environmental information presented in Figures 1 to 4 was deduced from the following sources: (a) a vegetation map; (b) a map of surficial bioproducts and habitats; (c) airphotos; (d) nine monoliths of organic deposits collected from the archeological trenches; and (e) observations of tides. Herbarium materials, three cross-sections of sod walls of the Norse houses, and the pictorial documentation are not dealt with in this report.

Nearly 1,390 pounds (wet mass) of bioproducts were examined macroscopically, about 460 pounds were separated into fractions and analyzed microscopically, and 103 pounds were preserved as monoliths glued to plywood and illustrated by diagrams. Special attention was given to cuttings made by man on wood, to indicators of the former position of the shoreline (remains of marine algae, shells, and halophitic plants occurring in shore detritus), and to the rates of growth of the biomass under xeric, mesic, and hydric environments. The chronology of events is based on radiocarbon age determinations (*see* below and Fig. 3). The correlation of organic strata and their relationships with accumulation basins (Figs. 2 and 3) are based on block diagrams.

General Stratigraphy

The bedrock of this area represents resistant Maiden Point Formation sandstone, greywacke and "mélange" (*see* Cumming, this publication, report 2). These rocks form cliffs and underlie boulder clay of glacial origin. Well-rounded sand, gravel, and boulders (both foreign and local rocks), mixed with transported components (amber, pumice, lignite, bog-iron ore, limestone, etc.), are the main materials of the beach deposits. These occur as three distinct generations of raised beaches (Fig. 1; *see* Grant, this publication, report 110) on which organic strata developed. These strata were examined in detail in order to reconstruct the biomes and former habitats. They are as follows (*see* Figs. 2 and 3): (a) gravelly beach-xeric substrates with humic matter produced by grassy, herbaceous and heath growth and occurring in xeric and meso-xeric places of the upper parts of the beaches; (b) coastal detritus, as basal peat, composed mainly of wood, marine algae, shells, seeds, and parts of plants that grow at the shoreline, the whole mixed with sand in which occurs roots preserved in growth position and which represents the first terrestrial deposit that accumulated on the barren beaches slightly above a shoreline; (c) driftwood horizon, partly deposited on basal peat and partly on inorganic substrates and covered by rhizome peat; (d) several variants of sedge peat such as rhizome peat (mainly rhizomes), sedge peat sensu stricto (rhizomes and other parts of plants), humified sedge peat (often twiggy) with considerable amounts of grassy, herbaceous and branch remains; (e) various kinds of surficial deposits produced by recent plant formations such as heath, grassland, meadows, moss and sedge bogs, and clumps of low shrubs (*Alnus, Betula, Myrica*); (f) a complex of alluvial deposits. Their stratigraphy and horizontal distribution are shown in Figures 1 to 4.

Paleoenvironmental Results

Between the Norse houses and the shoreline of A.D. 1000 the following major landforms are recognized (Fig. 4): - (a) raised beaches; (b) the "driftwood bay"; (c) rock outcrops between Black Duck Brook and the sea, and (d) a former bay, now occupied by the valley of Black Duck Brook.

Sods for the construction of the walls of the Norse houses were taken from the gravelly xeric habitats covered by grassy, herbaceous, and heath vegetation which grew on the upper beach. Inland from this beach there were areas of dense sedge bogs and also lichen-moss and tundra-like growth of adjacent rock habitats, strongly disturbed by permafrost.

The middle beach on its lower seaward side was partly barren and partly covered by shore detritus, whereas its higher reaches were overgrown by primitive vegetation which produced thin layers of decomposed

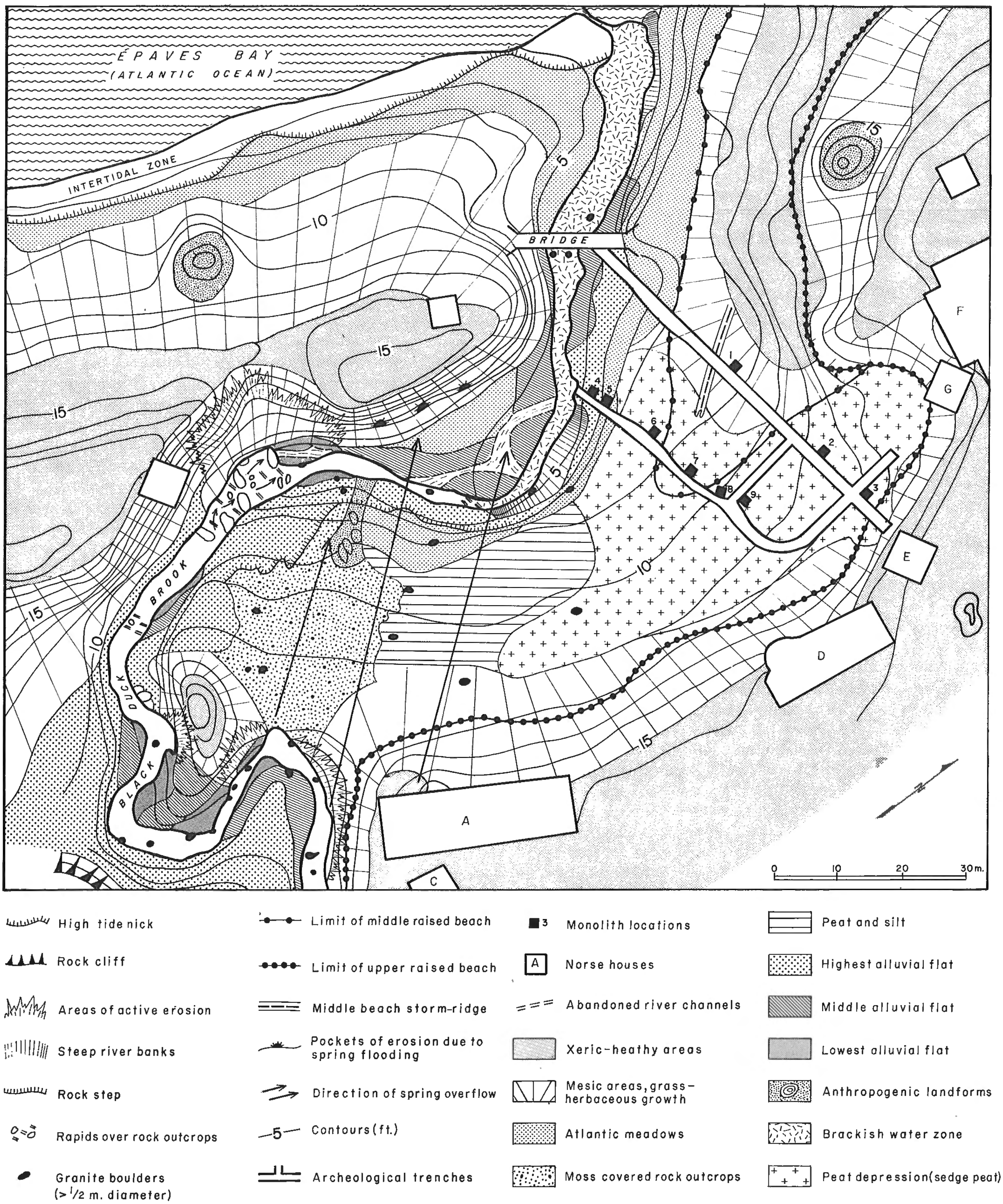

Figure 1. Environmental map of the historic site.

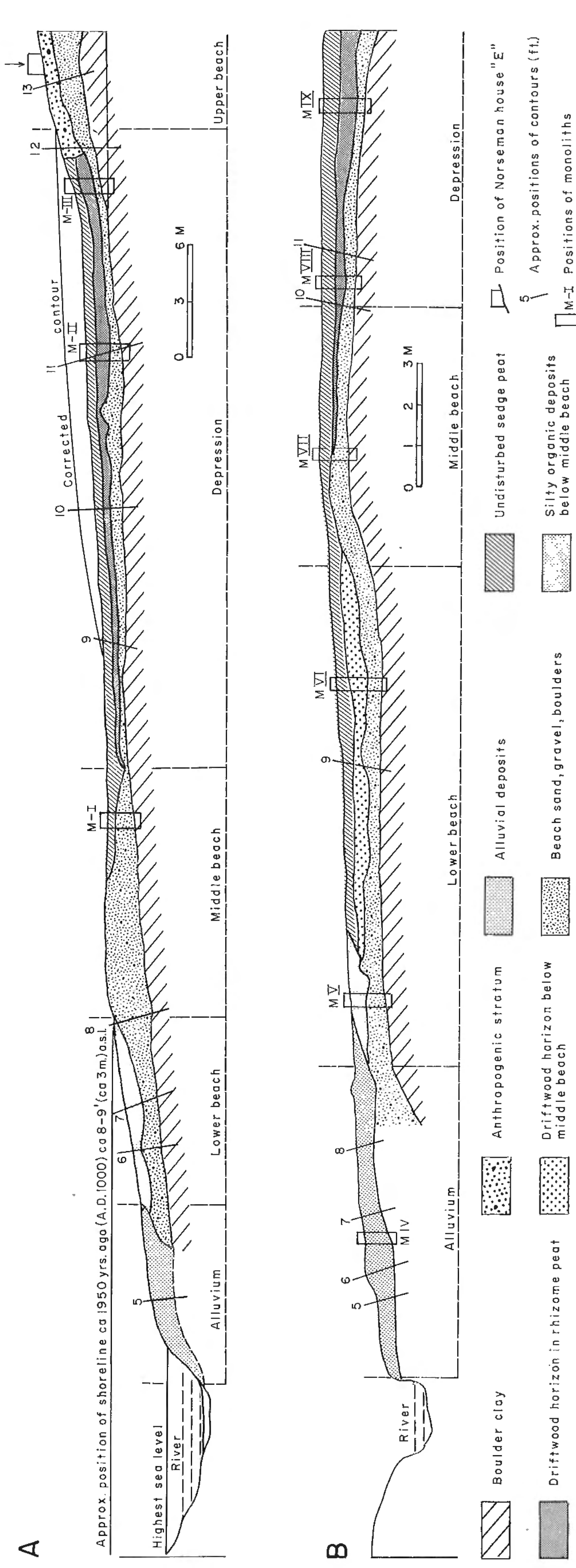

Figure 2. Biostratigraphy of layers exposed in archeological trenches between the Norse houses and the coast: A - trench no. 1; B - trench no. 2 (vertical dimensions slightly exaggerated).

humus and left roots in the underlying beach sand. These places were washed by the sea ca. 1,800 years ago.

The "driftwood bay" lies between the upper beach, the middle beach, and the area of rock outcrops. Some 1,800 years ago the inland part of this bay was covered by shore detritus on which accumulated "old" driftwood ranging in age from ca. 2,500 to 650 years. The borders of the bay were occupied by quite extensive sedge growth extending into its central part. Above this "old" wood horizon, undisturbed organic strata accumulated during the last millenium.

The wide area of rock outcrop between the smithy and house "A" formed low rock steps, and higher smooth elliptic sandstone outcrops divided the flow of Black Duck Brook into many trickles. Throughout this area people could walk easily.

The former bay, now occupied by the valley of Black Duck Brook, was narrow, recurved, shallow (maximum a few feet deep) and most probably was entirely within the intertidal zone. Inland it was terminated by a low rock step at the end of the bay, and towards the houses it nearly covered the flat area which is now the lower beach.

Vegetation changes during the last millenium

The general geobotanical character, vegetation zones, and plant communities of the area apparently have not changed appreciably during the last millenium. This is indicated by the paleoenvironmental studies (cf. also Nydal *et al.*, 1970, 1972) and Mott's palynological results (*see* this publication, report 125). Halophilous growth, atlantic meadows, heath, sedge and moss bogs, and dwarf forest invaded barren areas of the middle beach. Inland from these there was an extensive development of *Sphagnum* and sedge bogs, while tundra-like communities on rock outcrops were distinctly invaded by heath, herbaceous, shrubby and semi-forest growth.

Biostratigraphic significance of some radiocarbon data

The dates of 950 ± 90 years (T-530) from House "A" and 950 ± 50 years (T-531) from House "F" - both determinations on the humic bioproduct of mesic-type grassy herbaceous heath termed "turf" by archeologists (A.S. Ingstad, 1970; Nydal *et al.*, 1970) — are credible dates for the Norse houses provided that the materials dated were duff, seeds, stems or roots, which died shortly before or after the extraction of the sods. This bioproduct, however, includes considerable amounts of "old" decomposed humus.

Radiocarbon dates on charcoal found in houses "A-C, D, F-IV" in the kiln and in cooking pits I and II are 1,100 to 1,300 years old (T-306, 309, 310, 324, 326, 365, 367, 368). This suggests that the Norsemen used driftwood (A.S. Ingstad, 1970; Nydal *et al.*, 1970). Probably the driftwood was collected only from the shoreline of A.D. 1000 but not from the bottom of the "driftwood bay" where older logs are present i.e., (2,500 ± 60 years (GSC-1987), 2,200 ± 50 years (GSC-2076), and ca. 1,700 years (GSC-2069)). These logs

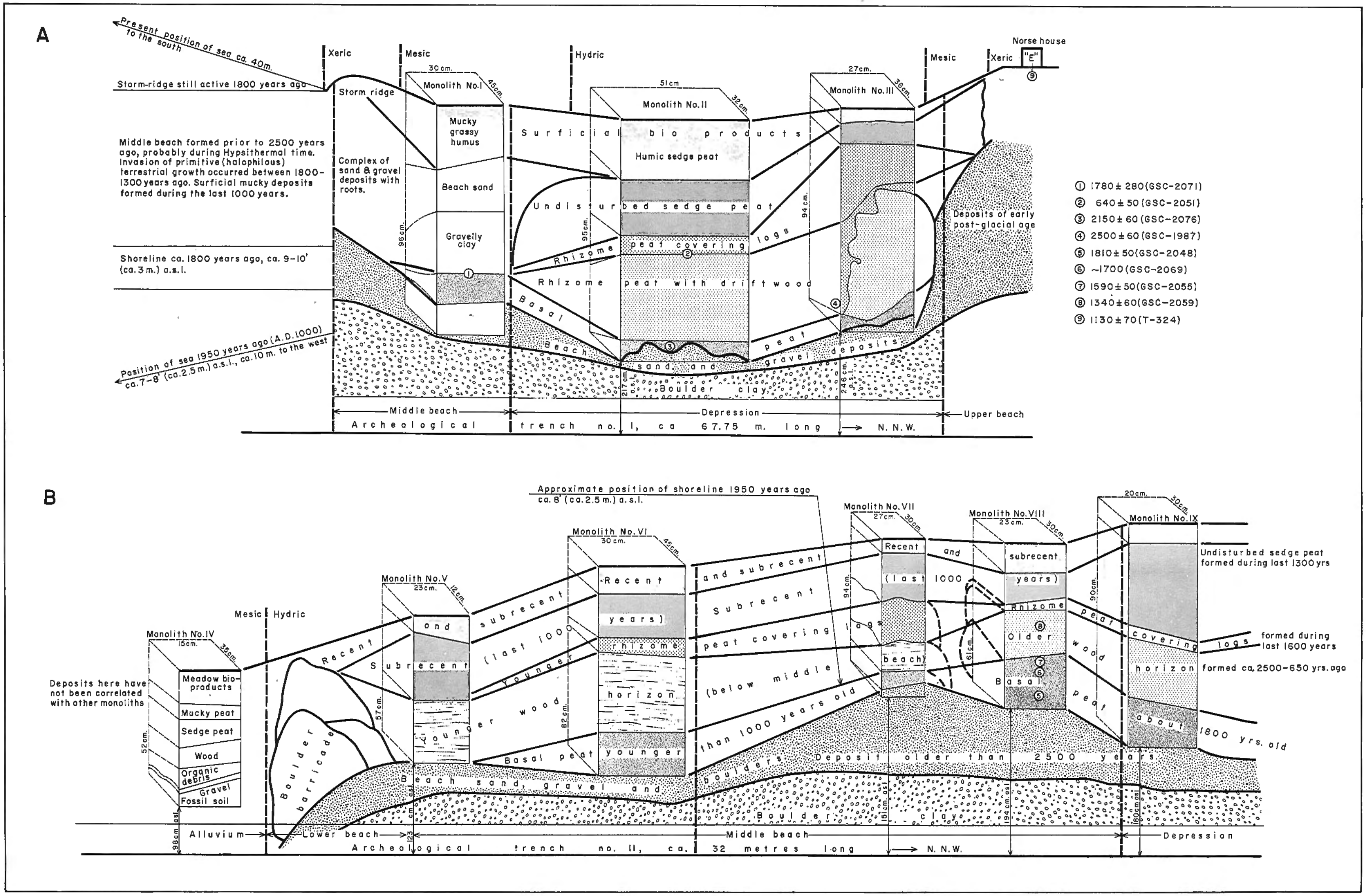

Figure 3. Diagrammatic correlation of major landforms, stratigraphy of organic deposits and the history of events: A. - trench no. 1, and B. - trench no. 2.

Figure 4. The A. D. 1000 reconstruction of the vicinity of the Norse settlement.

were covered by sedge peat by 1,340 ± 60 years B.P. (GSC-2059).

Basal peat deposited on the bottom of the "driftwood bay" is 1,810 ± 50 years old (GSC-2048) and basal peat on the inland slope of the middle beach near the storm-ridge is 1,780 ± 280 (GSC-2071) years old. This indicates that the deposit over the entire area of the "driftwood bay" accumulated in a short time, and that the middle beach storm-ridge is more than 2,000 years old.

Acknowledgments

I am grateful to Dr. J.S. Scott, for encouragement during the course of this study; to Dr. H. Ingstad (Oslo) for information about the highest tide levels; and to Mr. C. Lindsay (Ottawa) for his collaboration in the field.

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125. PALYNOLOGICAL STUDIES OF PEAT MONOLITHS FROM L'ANSE AUX MEADOWS NORSE SITE, NEWFOUNDLAND

Project 690064

R.J. Mott
Terrain Sciences Division

In 1960 a Norse settlement site was discovered at L'Anse aux Meadows, Newfoundland by an expedition led by Helge Ingstad of Norway. Archeological work was carried out between 1960 and 1968, and many radiocarbon dates were obtained from the site itself and from organic deposits in the area (Nydal *et al.*, 1970, 1972). Subsequently, investigations at the site were taken over by the National Historic Parks and Sites Branch, Dept. of Indian and Northern Affairs, and new work on the site has been undertaken.

During the summer of 1973 several peat monoliths were collected by M. Kuc (*see* this publication, report 124) for biostratigraphic study, radiocarbon dating, and pollen analyses. The monoliths were taken from the walls of two separate trenches. One of these trenches extended from the Norse house remains to the bank of Black Duck Brook, and the second extended from about the centre of the sedge peat area below the houses to the brook (Fig. 1). Both trenches were excavated in the organic sediment and bottomed in the underlying beach gravel deposits. Details of the site and stratigraphy have been described by Kuc. Two monoliths from the sedge peat area were chosen for preliminary pollen analyses and the results of this study form the basis for this account.

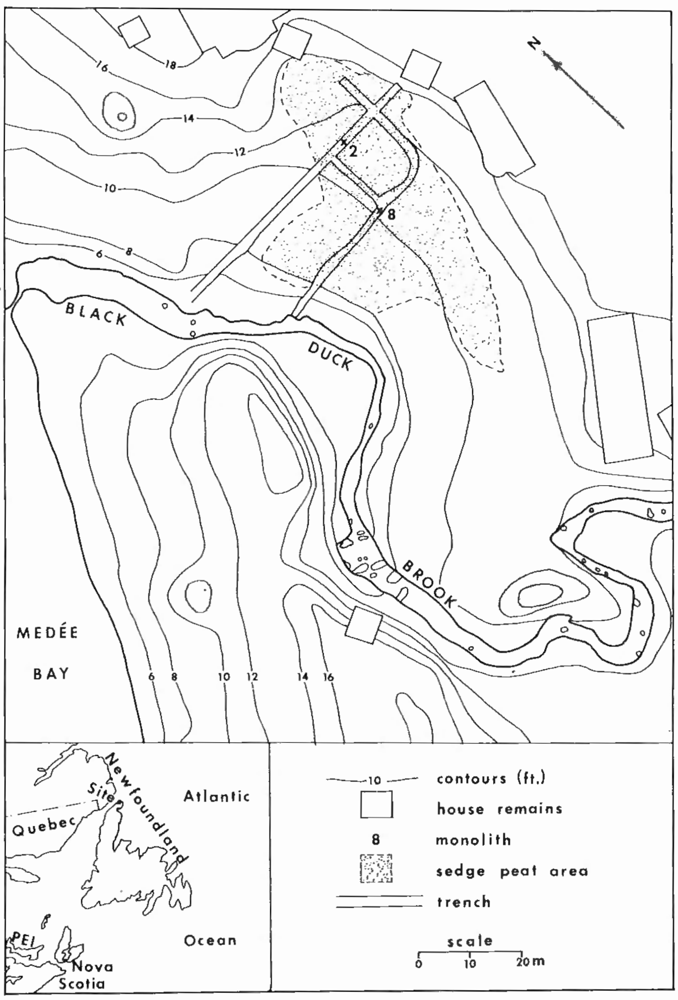

Figure 1. L'Anse aux Meadows Norse site showing location of peat monoliths.

The northern tip of the Northern Peninsula of Newfoundland, which includes the L'Anse aux Meadows site, is within the transitional zone between subarctic forest and tundra, the Forest-Tundra Zone of Rowe (1972). Stunted patches of forest occur among the tundra areas with the main species being black spruce (*Picea mariana*) and white spruce (*Picea glauca*) with minor balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*). Alder (*Alnus* sp.), willow (*Salix* sp.), and birch (*Betula glandulosa*, *B. nana*) occur in abundance as shrubs. The stunted trees denote a climate that is cold and wet with strong winds which limit upward growth by abrasion, especially in the coastal areas. The numerous open areas support abundant herbaceous plants, many with tundra affinities. Sedges (Cyperaceae) and grasses (Gramineae) are abundant in fens and sedge meadows.

Numerous wood samples from various monoliths were identified (L.D. Wilson, G.S.C. Wood Identification Report Nos. 74-28 and 74-36), and they are listed in Table 1. Some of these samples were used for radiocarbon dating as indicated. Much of the wood is driftwood that has been incorporated into the beach and peat deposits, but a few of the identified pieces obviously grew locally. Although much of the wood has drifted in from some more or less distant source, the taxa identified are all indigenous to the area. However, many of the logs are much larger than the trees growing locally.

The results of pollen analyses of monoliths 2 and 8 are shown in Figure 2 along with the generalized stratigraphy and radiocarbon dates obtained. Pollen percentages are based on total pollen, excluding Cyperaceae, aquatics and *Sphagnum*, equalling 100. Among the tree pollen types only spruce (*Picea*), fir (*Abies*), and birch (*Betula*) are present in significant amounts, and much of the birch pollen was derived from the dwarf or shrub species. The remainder of the tree pollen types occurs in minor amounts, and the presence can be best explained by long-distance transport. Pollen of alder, willow, *Myrica*, and various heath plants (Ericacea) are the most abundant shrubby representative, with alder being the most consistently abundant. Willow and *Myrica* are highly variable and heath plant pollen are present in very

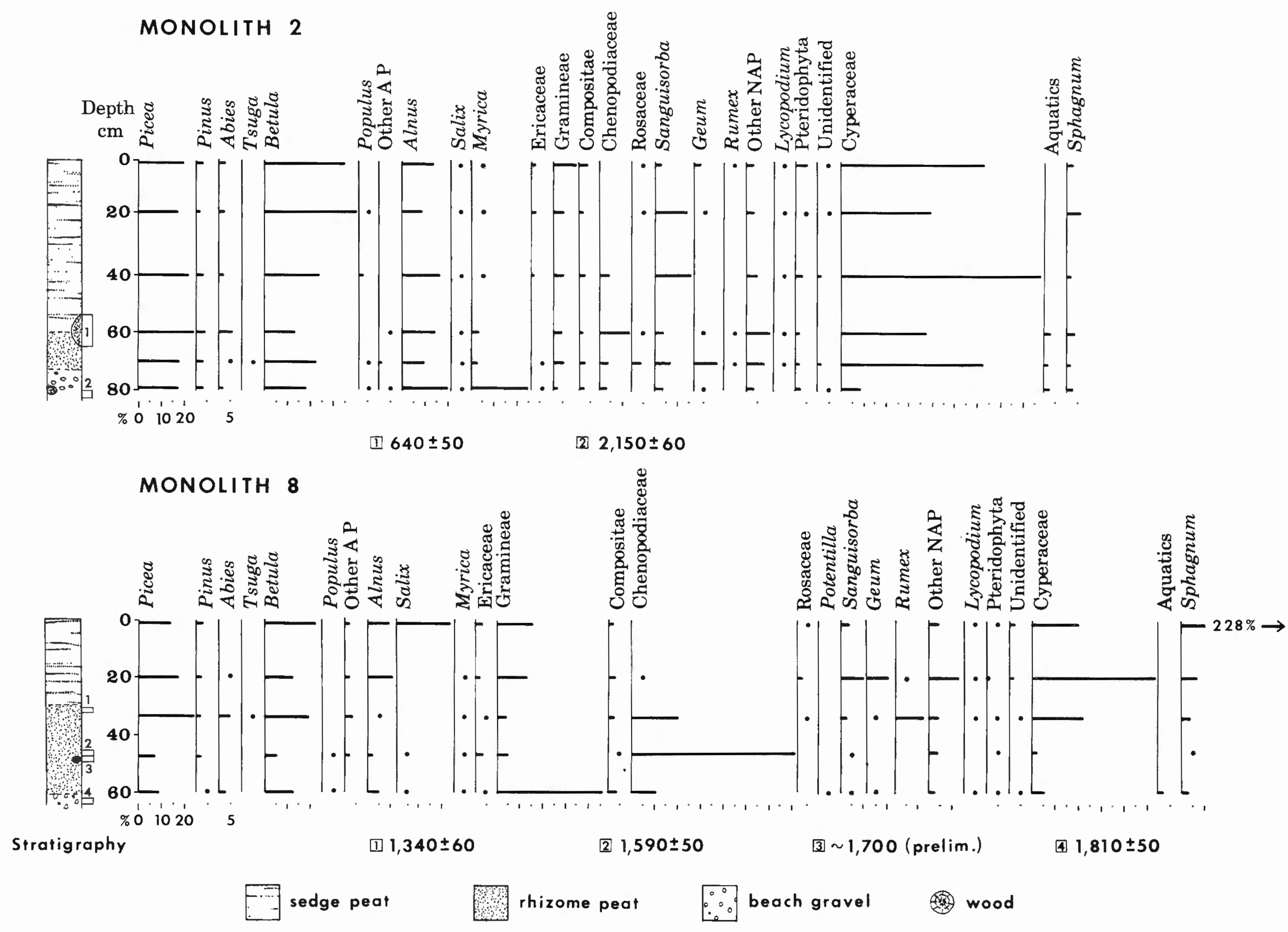

Figure 2. Pollen diagrams for peat monoliths 2 and 8.

Table 1*

Mono. No.	Depth	Identification		Laboratory Number	Age (uncorrected conventional ^{14}C years before 1950)
1	60 cm	Alder	*Alnus* sp.		
1	45 cm	Tamarack	*Larix laricina*		
1	37 cm	Balsam fir	*Abies balsamea*		
2	60 cm	Tamarack	*Larix laricina*	GSC-2051	640 ± 50
2	80 cm	Balsam fir	*Abies balsamea*	GSC-2076	2,150 ± 60
3	17 cm	Willow	*Salix* sp.		
3	40 cm	Spruce	*Picea* sp.		
3	50 cm	Spruce	*Picea* sp.		
3	76 cm	Balsam fir	*Abies balsamea*		
3**	85 cm	Balsam fir	*Abies balsamea*	GSC-1987	2,500 ± 60
4	30 cm	Spruce	*Picea* sp.		
5	40 cm	Spruce	*Picea* sp.		
8	51 cm	Tamarack	*Larix laricina*	GSC-2069	~1,700 (prelim.)
8	33 cm	Spruce	*Picea* sp.		
9	59 cm	Balsam fir	*Abies balsamea*		
Stump	Surface	Spruce	*Picea* sp.		
Stump	Surface	Spruce	*Picea* sp.		

*Wood samples identified by L.D. Wilson.

**This wood sample is from about 20 cm west of monolite 3 (pers. comm. from C.S. Lindsay to W. Blake, Jr., July 1974).

low percentages. Pollen of other non-arboreal pollen taxa form a significant part of both profiles. Grass (Gramineae) pollen is particularly abundant at the base of monolith 8 within the beach gravel unit. A change in habitat through increased organic accumulation causes it to be replaced, at least locally, by other species, but it remains fairly abundant throughout the profile. Chenopod (Chenopodiaceae) pollen is abundant in the rhizome peat unit and disappears within the sedge peat. Burnet (*Sanguisorba canadensis*) pollen is present in both profiles and is relatively abundant in the top half of both. As would be expected, sedge (Cyperaceae) pollen is very plentiful in the rhizome and sedge peat units. Sphagnum moss (*Sphagnum* sp.) spores are present in small numbers in both profiles and are extremely abundant at the top of monolith 8. Many other non-arboreal pollen taxa are represented by small numbers of grains, as can be seen from the pollen diagrams.

The main conclusion that can be drawn from the pollen diagrams is that over the time span involved, that is over the last 1,800 to 2,000 years, there have been no drastic changes in the vegetation of the area. The observation that the vegetation of 1,000 years ago was similar to the present was made previously by Henningsmoen (Nydal *et al.*, 1970).

If the assemblages at the top of each profile represent the vegetation of the area described briefly above, then throughout the past two millenia a stunted growth of spruce, some balsam fir, and white birch prevailed. The slight increase in birch pollen towards the top of the profiles may indicate an increase in white birch or the shrub birches in relatively recent times. The prominent changes among the non-arboreal pollen taxa indicate local changes in habitats that occurred due to peat accumulation, shifts in the stream channel, stabilization of beach ridges, and retreat of the coastline away from the site because of uplift.

The origin of the driftwood is intriguing. Driftwood is not accumulating on the present-day beaches (D.R. Grant, pers. comm., 1974), and since the vegetation was no different than today the driftwood must have been transported from some distance away by coastal currents. Either these currents are not functioning in the same manner today or the source of driftwood has changed.

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126.

UPLIFT STUDIES, SOUTHEASTERN HUDSON BAY

R.I. Walcott[1] and B.G. Craig
Terrain Sciences Division

Marine shell samples from raised beaches on Castle Island, one of the Manitounuk Islands some 47 km (30 miles) north of the settlement of Great Whale River, were collected in early August so as to define the rate of emergence of the land there during the last few thousand years. The rate can be determined from dated organic materials related in a recognizable way with past sea levels. Marine shells commonly indicate a sea level of their age at, or above, their present elevation, but in a few special circumstances the relationship to past sea levels can be determined more precisely. In the case of the Castle Island series, most of the shell samples are believed to have been emplaced in the beach from which they were collected when it was at highest water level. The radiocarbon age of the shells and the elevation difference between present highest water level and the beach, therefore, permit the rate of emergence for the region to be determined. There are, however, several corrections to be made because of known or suspected biases, particularly with regard to the age determination.

The elevation measurement is comparatively straightforward. Although it had been intended to use optical levelling equipment and levelling rods, the equipment did not arrive in the field in time; thus the elevations of the samples were determined using a single aneroid barometer. All samples were within 20 walking minutes of the highest water level at the shore and over the course of three days, each location was visited at least 5 times (and several sites more than 10 times) on a barometer traverse with closure from shore to shore within one hour. The temperature was stable over the three days (about 55° to 60°F) and humidity was generally about 60 to 80%. The standard deviation of the

Figure 1. Typical occurrence of *Mytilus edulis* in shingle cobble beach.

[1]Earth Physics Branch.

corrected elevations was less than 0.6 m (2 feet) with a range of 1.5 m (5 feet). The assigned error to the elevation with respect to the highest water level is taken to be ±1 metre.

Raised beaches were found on both the western shore and the leeward eastern shore of the island. Cobble and boulder beaches (derived largely from the local quartzite bedrock) have developed in most places, but coarse sand beaches were present in the bays. On the modern sandy beaches, shells, predominantly *Mytilus edulis,* are found at high-tide line and also on the surface of the sand, distributed over a zone several tens of feet wide on either side of the highest water level. This level is marked by a line of debris, largely wood, and by the lowest level of vegetation. The shells evidently were blown inland from the beach over the sand surface. In some restricted areas, surface shells also have been winnowed from the sand in which they were buried. Judging by the modern shore, shells are blown inland from the shore and mixed with earlier buried shells. Samples from raised sandy beaches therefore can be expected to contain shells of a wide range of age. On the raised cobble beaches shells are sparse and are not found on the surface. They can be found by turning over the larger surface stones and in one case in twenty, whole, often paired but separated valves (all but one being *Mytilus edulis)* are found nestled in the dry gravel underneath (Fig. 1). The shells are fragile and readily fractured by shifting stones. They manifestly could not have been emplaced in an active beach where the stones were being moved by wave action. They are believed to have been blown into crevices between the surface stones when the beach was at or near the highest water level. Because of the occurrence of paired whole shells they are unlikely to have been emplaced very much higher than that, as wind transport on cobble beaches is unlikely to be as effective as on sand beaches.

Eleven samples, at more or less regular intervals, were collected between sea level and an elevation of 63 m. The co-ordinates, elevations, and radiocarbon ages of the two samples so far measured are given in Table 1.

The emergence of the area near Great Whale River is of interest because it is near the centre of the dome-like uplift of the land presumably related to the glacio-isostatic rebound caused, in turn, by the melting of the Laurentide Ice Sheet. It is in this region that the greatest emergence and most rapid movements of the last 6,000 years have occurred. Samples of 6,700 to 6,000 years in age were obtained previously in the Richmond Gulf area, and to the east of James Bay. The closest collection of samples that was sufficiently numerous to obtain a sea level emergence curve came from Cape Henrietta Maria, about 350 km to the west. The two dates so far obtained show emergence is closely similar to that of Cape Henrietta Maria. The two radiocarbon ages show that between 3,420 to 3,300 years ago and 1,840 to 1,740 years B.P. the land emerged close to 36 metres, i.e. at a rate of 21 to 25 mm per year. The present-day emergence cannot be estimated reliably until the zero age bias (the radiocarbon age of modern, pre-bomb, shells) is measured. Work is proceeding on this.

The significance of the emergence in the centre of rebound lies in the relationship between uplift and rate of uplift and the lateral dimensions (the wavelength) of the disturbance, on the one hand, with the model for internal rheology of the earth, on the other. The Laurentide Uplift is about twice the linear dimensions of the Fennoscandian Uplift, and the present rate of rebound in the centre of the latter region is well determined at 9 mm per year. If the rate of rebound in the centre of the Laurentide Uplift is about the same or less, then present models of rheology indicate that the mantle viscosity at a depth comparable to the linear dimensions (1,000 to 2,000 km) is about 10^{22}P, in so far as the rheology can be described in terms of Newtonian fluid. If the rate of rebound were twice that (i.e., around 18 mm per year), the mantle viscosity would have to be considerably higher.

Table 1

Co-ordinates	Elevation m (ft.)	Laboratory dating no.	Age (uncorrected conventional ^{14}C years before 1950)
55°34'53"N 77°19'00"W	58(191)	GSC-2070	3360 ± 60
55°34'33"N 77°18'29"W	22(72)	GSC-2074	1790 ± 50

127. RECONNAISSANCE STUDIES OF SURFACE PROCESSES, BANKS ISLAND, DISTRICT OF FRANKLIN

Project 740065

Terry J. Day
Terrain Sciences Division

This project is concerned with the collection of basic reconnaissance data on the intensity and distribution of fluvial coastal, and slope processes on Banks Island, and is designed to provide an extensive array of basic geomorphic and hydraulic data relevant to possible future developments, as well as to provide a firm base for further studies.

The study was initiated during a three-week period extending from late July to mid-August. Fluvial processes were the primary focus during this initial period, with the intention of establishing the criteria and procedures for a sampling design which would provide relevant information on flood hydrology, channel instability, and sediment supply and characteristics. Two primary aspects of the river research were: (1) to develop a system for classifying rivers and their local physiography, according to their geomorphic and hydraulic characteristics; and (2) to identify, and in some cases, initiate studies into those aspects of the river systems that require more intensive study. Field work was begun in the Bernard River system where five hydromorphic sites were studied. These sites will serve as the base of a more extensive basin-wide network. Fluvial sediment studies also were undertaken along the Kellett and Masik rivers near Sachs Harbour, on the southern coast of the island.

Aerial surveys were conducted along sections of the northern (M'Clure Strait) and eastern (Prince of Wales Strait) coasts, as well as in the vicinity of Sachs Harbour. These surveys, coupled with aerial photo data, indicated that the western and southwestern (between Sachs Harbour and the Masik River) coasts are the more active.

Slope studies were restricted to those in the immediate vicinity of coasts and rivers; other aspects of slope development are being investigated by J-S. Vincent (*see* this publication, report 121). Preliminary surveys show that thermokarst features are extensive along the northern and southeastern coasts. Similarly, nivation has been indicated to be a major slope process affecting river channel stability and sediment supply.

PINGO INVESTIGATIONS AND TERRAIN DISTURBANCE STUDIES, BANKS ISLAND, DISTRICT OF FRANKLIN

Project 640004

H.M. French[1]
Terrain Sciences Division

Field work centred around (1) the study of ground-ice conditions and terrain disturbance in the vicinity of Sachs Harbour village, and (2) the investigation of pingo-like mounds which occur in the lowlands of many of the major river valleys of the island. The former is a continuation of previous studies undertaken in 1972 (French, 1973) and 1973 (French, 1974). The pingo investigations are being undertaken in co-operation with Dr. A. Pissart of the University of Liege (*see* this publication, report 134).

1. Pingo Investigations

(a) Thomsen River

Two weeks were spent with A. Pissart at latitude 73°42', longitude 119°56', where a group of eight pingos were examined (*see* Fig. 1). The largest pingo was over 14 m in height (Fig. 2). All the pingos occur on low terraces of the Thomsen River just to the north of the junction with Able Creek. Nearly all are elongate, complex in form, and show varying stages of collapse. Sections cut through two pingos revealed massive ice bodies in the centres of the features, with uptilted, fluvially bedded sediments on either side. In one pingo, the ice core possessed near vertical banding and is probably of a segregational origin. In the other, a number of irregularly oriented shear zones and fractures may indicate injection as well as segregation of the ice.

The age of these pingos is not yet known; however, it is hypothesized that they grew when a closed talik came into existence and subsequently froze following the abandonment of an old channel of the Thomsen River.

(b) Sachs River Lowlands

Several days were spent identifying and mapping pingos in the coastal lowlands that are currently drained by the Sachs River southeast of Sachs Harbour (Fig. 3). The pingos are of varying sizes and shapes and occur either singly or in groups. The majority occur within the bottom of abandoned meltwater channels or on the low and extensive terraces and flood plains of the Sachs River. They range from shallow, completely collapsed craters (Fig. 4) to striking, well developed mounds. In plan, most are approximately circular or elongate with no more than a 2:1 ratio of long axis to short axis. A few, however, are extremely elongate in form and possess a central linear depression bounded on both sides by a shallow cuesta-like ridge. One such feature can be traced for over 400 m. An explanation similar to that proposed above for the Thomsen River pingos is thought to be the most appropriate.

In addition, a few isolated pingos occur within the centres of recently drained thermokarst lakes and are, therefore, very similar to those which occur in the Mackenzie Delta (Mackay, 1973). These pingos are not very large, none being greater than 5 m in height. The draining of the lakes appears to be the result of either coastal retreat or the lateral migration and capture by adjacent thermokarst lakes.

The largest pingos in the Sachs River valley occur at the south end of Raddi Lake, where a group of five large pingos can be identified. The largest is over 15 m high and shows a tension crack depression at its summit. Another has been half truncated and eroded by a small stream entering the lake, and the ice core has melted completely leaving an open-ended, semicircular crater. This group of pingos occurs in a flat area adjacent to the lake and is bounded by an old lake strandline 2 to 4 m above the present level of Raddi Lake. The pingos probably grew as the lake bottom emerged in response to dropping lake levels, and when freezing of part of the sub-lake talik took place.

The age of the Sachs River pingos is not known. With the exception of the small pingos developed in the recently drained thermokarst lakes, however, it is likely that all developed immediately subsequent to the period when the Sachs River lowlands acted as a proglacial meltwater outlet for late Wisconsinan ice which impinged upon the southwest coast of Banks Island (*see* Fig. 3 and Prest *et al.*, 1968).

(c) Other Areas

Based upon casual observations made during previous field work in 1971, 1972, and 1973, and upon several air traverses made across the central and western lowlands in late July 1974, various other closed system pingos or pingo-like remnants tentatively were identified.

At least 30 to 40 isolated mounds, interpreted as pingos, occur in the sandy outwash plains and meltwater channels of east-central Banks Island. Significant concentrations exist in the upper reaches of the Thomsen River between latitudes 72°45' and 72°55' (e.g. at latitude 72°50', longitude 119°50'; *see* air photograph A 17379-10), and in the interior lowlands currently drained by the Bernard and Big rivers between latitudes 71°50' and 72°30', and longitudes 120°15' and 122°00' (*see* Fig. 1). In the latter area many of these can be identified from air photographs at a scale of 1:15,000 (e.g. A 16287 18-20, 161, 168-71).

[1] Department of Geography, University of Ottawa, Ottawa.

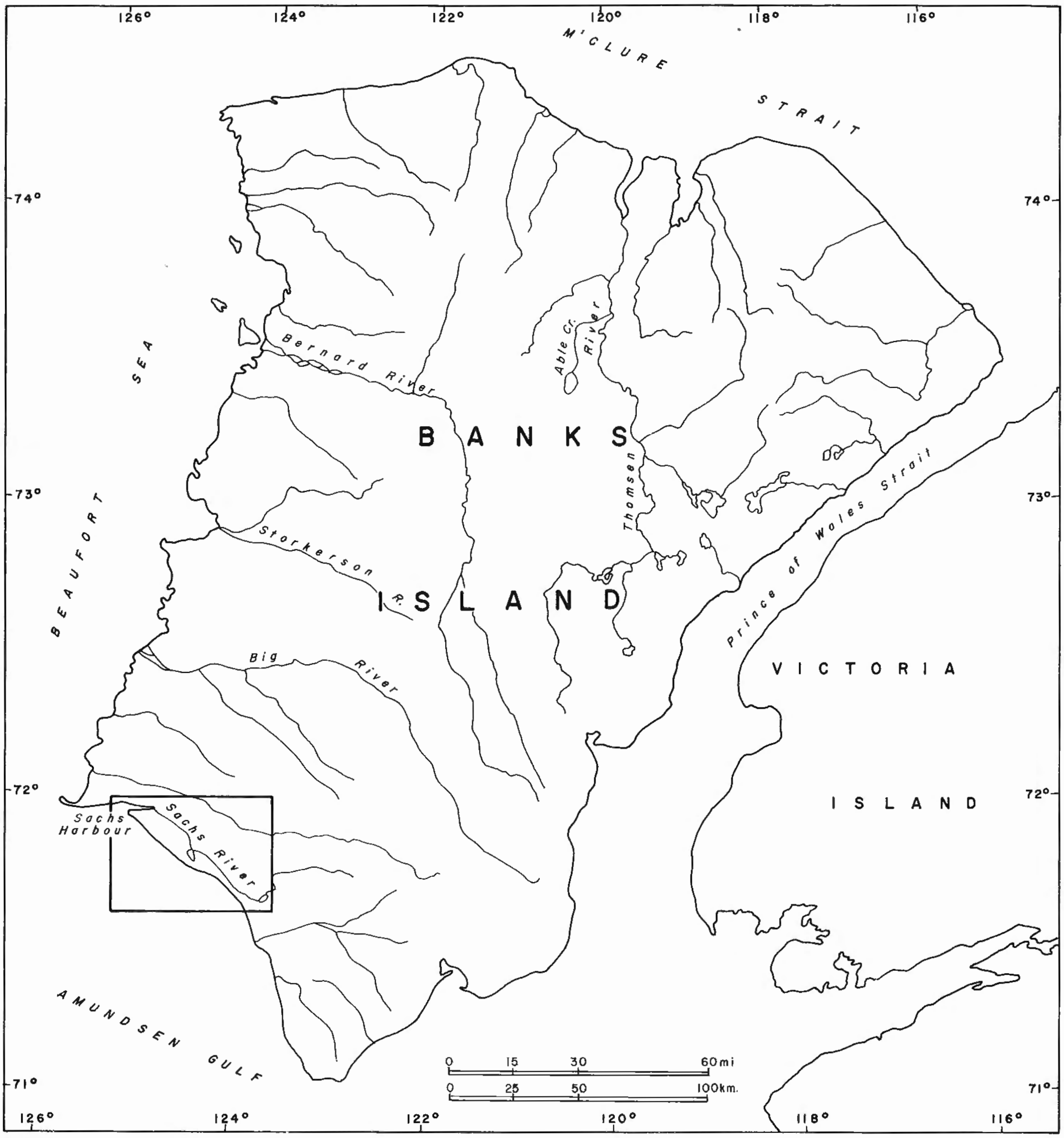

Figure 1. Location map of Banks Island showing localities mentioned in text. Area outlined by solid line is shown in Figure 3.

The possibility that some might be kames or naledi cannot be excluded without more detailed investigations.

In several areas of central and western Banks Island, collapsed pingos and puzzling pingo-like remnants were observed on low fluviatile terraces. For example, west of the elbow of Bernard River at latitude 73°23', longitude 123°15', distinct remnants of a group of elongate and circular pingos exist (e.g. *see* air photograph A 17564-48). In other areas, peculiar terrain resembling relict pingo fields has been observed. The topography is one of shallow depressions and subdued ridges or ramparts. The depressions may be 20 to 30 m in diameter and the ridges 1 to 2 m high. At first sight, the terrain is not unlike areas of low-centred ice-wedge polygons but closer inspection reveals a confused spacing and alignment of the ridges and depressions. Areas of such terrain have been observed (1) in the lower Bernard River (latitude 73°27', longitude 122°50'), (2) in the Sachs River lowlands (Fig. 3), (3) to the north of Raddi Lake (Fig. 3), and (4) in the western coastal lowlands between the Storkerson and Bernard rivers.

The interpretation of this terrain is difficult. Somewhat similar features, however, have been described from Walton Common, Norfolk, England, by Sparks *et al.* (1972). They interpret an irregular complex of depressions and ramparts as the result of the repeated growth of subsurface ice at a spring line site under

Figure 2

Two large pingos of the Thomsen River valley, north of the junction with Able Creek (latitude 73°47' longitude 119°57').
Man gives scale to the features.

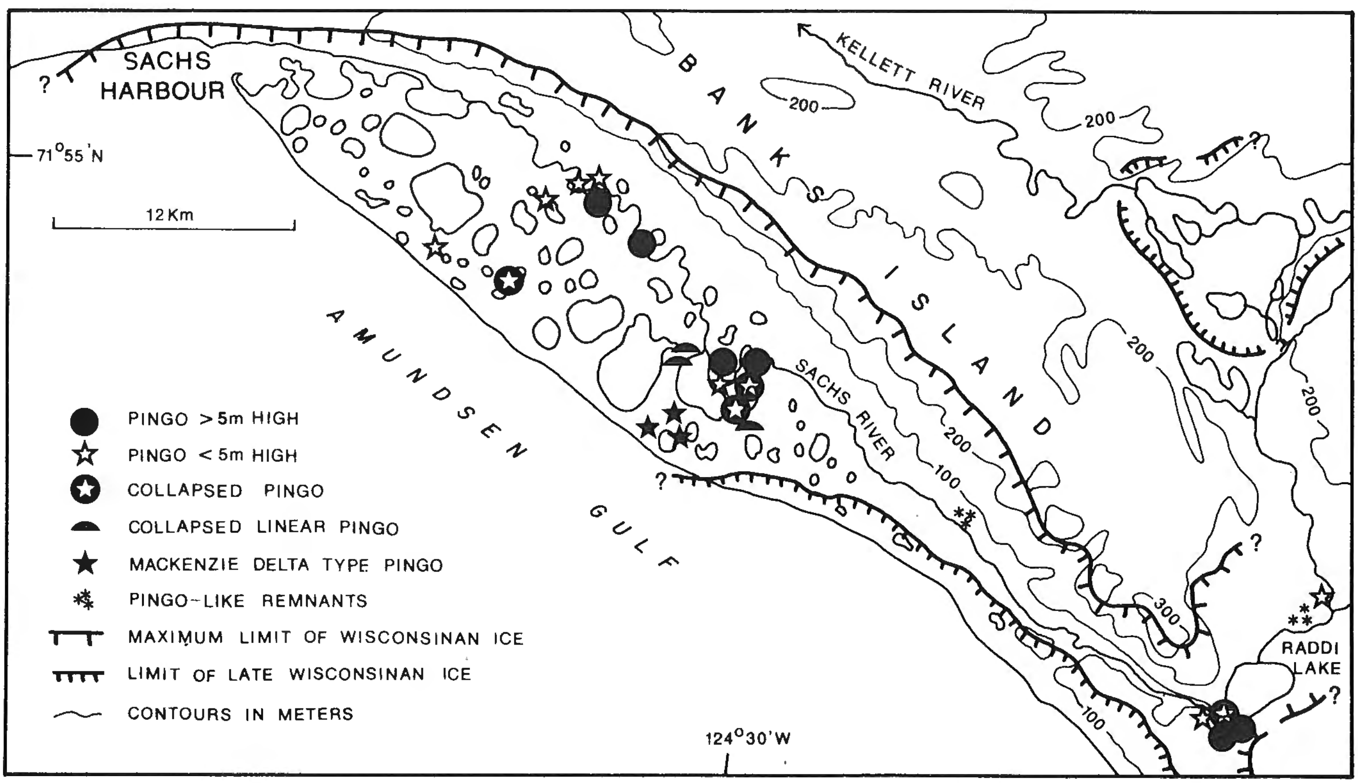

Figure 3. Map of the Sachs River lowlands showing pingo distribution and glacial limits.

Figure 4

Large collapsed pingo, Sachs River lowlands (latitude 71°50', longitude 124°25'). Ramparts are 4 to 5 m high. Dimensions of the pingo are suggested by the adjacent ice-wedge polygons, each of which is 20 to 30 m in diameter.

Figure 5

Gully that has developed along vehicle track depression on a 3 degree colluvium slope, approximately 100 m north of the Sachs Harbour townsite. Air photographs taken of this area in August 1972 indicate no gullying at that time. Present gully extends 80 m upslope. Photo taken July 27, 1974.

Figure 6

Example of active gullying within Sachs Harbour townsite, July 22, 1974.

Figure 7

Area of gully development along ice-wedge pattern, approximately 100 m north of present settlements. Standing water body in gully indicates permafrost and ice-wedge thawing. In early June 1974, this gully was over 3 m deep. All the gullying shown in this photograph developed since August 1972. Photo taken July 27, 1974.

conditions of shallow and local permafrost. On Banks Island, where permafrost is continuous and thick, such an explanation is inappropriate. On the other hand, since the features occur on low terraces, they may be associated with the freezing of small taliks which existed at one time beneath a braided stream. Under such a hypothesis, the migration of the stream and the freezing of the channel floors cause the growth of localized ice bodies and updoming of the surface. The ramparts then form through the sloughing-off of material from the summit, which also initiates thawing of the ice core and the formation of the depression.

2. Terrain Disturbance Studies Sachs Harbour Townsite

Attention was focused upon the nature and magnitude of gullying which has occurred within the Sachs Harbour townsite in recent years during the spring and early summer. Prior to 1970, the townsite did not experience significant gullying and terrain disturbance was not a severe problem. In 1972, however, a sizable gully developed, and in 1973 there were three gullies. In June 1974, at least five distinct gully systems were active, the largest of which began in 1973 and is now over 50 m long (Fig. 5). Although no buildings have yet been affected, some homes will be threatened in the near future (Fig. 6). For the past two years the gullying has necessitated an additional amount of road maintenance and in several areas, culverts were installed to prevent future washouts.

The development of these gullies is the result of the increasing degree of terrain disturbance caused by off-road vehicle track movement, which has destroyed a near-continuous mat of meadow tundra vegetation, combined with the presence of ice wedges in the underlying sediments. The lack of aggregate for gravel roads and the rapid expansion of the community in recent years are additional factors. Moreover, the general topography of the village site is conducive for the development of large snowbanks upslope from the village at the foot of the ridge upon which the airstrip is located. Observations made in 1973 and 1974 indicate the gullying process to progress through a number of stages. First, water percolating downslope from the snowbanks in early spring becomes channelled along vehicle ruts and causes direct erosion of a small gully. Second, ice wedges become exposed in the bottom of the channel and begin to melt. This results in the rapid expansion of the gully system (Fig. 7). The gully assumes an irregular plan, reflecting the pattern of the underlying ice wedges. In cross-profile, the gully is narrow at the surface but widens at depth to form an inverted 'T' shape. Third, by midsummer, snowmelt is complete and the gully begins to widen through the collapse of the sides and the burial of the ice wedges. Standing bodies of water may accumulate in the bottom of the channel behind fallen masses of soil and slumped material. Unless infilling or other remedial action is taken (e.g. culverts installed to divert meltwaters), the gully becomes the natural site for further activity the following spring.

Studies initiated in 1974 with respect to gully erosion include (a) the mapping of gullies at a scale of 1:1,200 and the examination of air photographs taken in 1968 and 1972, (b) the study of ice-wedge patterns in an attempt to predict future growth directions of gullies once they initiate, (c) the study of sediments and ground-ice conditions in a number of ice cellars within the village to assess thermokarst subsidence potential, and (d) the measurement of thermal differences between undisturbed and disturbed terrain within the townsite to assess the effect of the tundra vegetation upon the thermal regime of the active layer.

In order to compare the gully erosion process, observations were made of active gullying occurring at a coastal section 2 km west of the townsite. There, substantial ice wedges are exposed within 3 m of ice-rich (60 to 70 per cent 'excess ice') silty clays and overlain by 0.5 m of peaty sediments. Preferential retreat of the bluff along ice wedges already has resulted in the drainage of a small thermokarst lake and a second gully will cause drainage of another lake with one or two more years of continued headward retreat. Observations on gully retreat, the microtopography of thawing ice wedges, and ice-wedge patterns are being undertaken together with the determination of ground-ice conditions. The presence of organic sediments within the silty clays may give a maximum age for the formation of the ice wedges and the thermokarst lakes and, therefore, be of some relevance to the general interpretation of the topography of the Sachs River lowlands.

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TENSION-CRACK ICE, ICING-MOUND ICE, TUKTOYAKTUK COAST, DISTRICT OF MACKENZIE (107 C)

A. Gell[1]
Terrain Sciences Division

Introduction

Several types of ground ice have been studied in natural exposures and core samples from the coast near Tuktoyaktuk, N.W.T. (Gell, 1974a, 1974b). The purpose of this note is to discuss (a) tension-crack ice which forms in cracks produced by the mechanical rupture of the overburden, when pingos grow, and (b) icing-mound ice, formed by the injection of water from depth into the base of the active layer.

Tension-Crack Ice

Site Description

Radial tension cracks occur on a pingo (Mackay, 1973, Fig. 15, Pingo No. 9) which has grown up in a lake that drained shortly before 1950. The mean annual growth of the tension-crack ice at the top of the pingo for June 1973 to June 1974 was 10 cm (Mackay, pers. comm.). Samples of 1973-74 tension-crack ice were collected early in July 1974. Although the maximum age of the ice is known, neither the precise time of cracking nor the growth rate within the year are known.

Field Characteristics

The cracks are approximately planar and oriented vertically. The lateral contacts between ice and the adjacent soil in the active layer are sharp and locally irregular. A prominent banding occurs in the ice, determined by bubble content. These bands are parallel to one another and the plane of the crack, but do not show irregularities as strong as those of the ice-soil contact. The crack was closed for most of its length but displayed local open zones which could be probed to 1 m.

Bubble Pattern

Immediately adjacent to the ice-soil contacts occurred 1 to 2 cm-wide, bubble-free zones. Fragments of soil were included in the ice close to the contact. The change from bubble-free to bubble-rich ice is abrupt, essentially planar, and continuous laterally and vertically, except where slightly offset at large sediment inclusions. These characteristics indicate a singly major event. As water froze outwards from the soil contact, dissolved gases were rejected from the ice lattice and thus concentrated in the water near the interface. Eventually bubbles nucleated and grew. The small size (<0.1 mm) indicates that the water froze rapidly, not allowing time for further growth of bubbles, but the large number of bubbles indicates high gas content.

Several bands of varying gas content occur. Thus there is a major difference from wedge ice in which only one narrow crack can occur in a given year.

Crystal Characteristics

Crystal size varied with position in compositional bands. Adjacent to the soil occurred a zone of very small crystals, less than 0.1 mm^2, from which grew a zone of larger crystals elongated orthogonal to the banding. Several reached 0.5 cm and extended into the first bubbly zone while many smaller crystals terminated at the band contact. This pattern was repeated in association with alternating bubble content. The multiple crystal bands in one season's growth again contrast strongly with wedge ice.

The ice showed alternating bands of small and elongated crystals. The bands of small crystals adjacent to the soil represented zones of competitive growth containing anhedral and subhedral crystals. Straight grain boundaries represented compromise boundaries. Larger crystals tended to be elongated orthogonal to the banding. Grain boundaries show simple curvature. Crystal shape characteristics differ from those of wedge ice.

Optic axis orientations showed girdle preferred orientations in planes parallel to the banding. Thus basal planes are orthogonal to banding. Small crystals adjacent to the soil produced diffuse girdles; elongate crystals showed stronger concentrations tending toward a horizontal maximum.

Summary

Petrologic characteristics of one season's growth of pingo tension-crack ice have been enumerated to aid in recognition of ice type from limited core samples or from poor exposure. Distinctions from ice-wedge ice are emphasized.

Icing-Mound Ice

Field Characteristics

A small mound (3 m high) grew over the winter 1973-74 on the side of a pingo (Mackay, 1973, Fig. 18, Pingo No. 13) 20 km east of Tuktoyaktuk, N.W.T. Water was injected at the base of the active layer, having moved up a tension crack from depth.

Bubble Pattern

Bubbles were the only inclusion type, occurring in distinct bands parallel to the mound surface. Bub-

[1]Department of Geography, University of British Columbia, Vancouver, B.C. V6T 1W5.

ble sizes and shapes were consistent in a given band but varied from band to band. Characteristically, bubbles were elongate orthogonal to the banding. In many cases bubbles widened from filament-like at the top to bulbous at the base; the inverse was never seen. Many bubbles were associated with crystal boundaries, suggesting higher gas supersaturation and ready bubble nucleation. Once the bubbles nucleated, gas moved down the concentration gradient and developed the bulbous shape.

Crystal Characteristics

Crystal size varied with position in the sample. At the top, a zone of small crystals indicated nucleation adjacent to the cold active layer material. From this zone grew very elongated crystals, some over 20 cm long, widening from 0.2 cm at the top to 2 cm at a depth of 40 cm. This is characteristic of crystal growth into free water, rather than water supply through a porous medium, as in pingo growth.

Crystal shapes were typically anhedral with few complex boundaries. Locally, slight serrations occurred adjacent to the upper bubble bands. A strong dimensional orientation developed orthogonal to the bubble banding. Slight differences in extinction position in a given crystal occurred mainly in the upper part of the sample, associated with updoming.

A strong lattice preferred orientation was found in the majority of the ice body. A c-axis girdle pattern parallel to the bubble banding indicated basal planes parallel to the growth direction, as occurs in ice growth in bulk water.

Other Features

The above pattern was disturbed by a fracture which opened to allow later ice growth. This ice showed markedly different bubble pattern, crystal size, shape, and substructure. Bubbles showed no regular banding, and varied in shape. Some crystal growth occurred in lattice continuity with earlier crystals, but generally new crystals grew in varying shapes and sizes trending into the fracture. Several crystals had a cellular substructure reminiscent of saline ice. This suggested the later water to be of higher chemical content. Such features have not been observed in massive ice (Gell, 1974a) or pingo ice. In contrast to the lattice orientations in the majority of the ice, this ice gave a much more diffuse pattern, due to freezing in from several directions.

Summary

A description has been given of the petrologic characteristics of injection ice which grew in 1973-74. This injection ice is different from ice of segregation origin in massive ice bodies.

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FRASER DELTA SEDIMENTATION, VANCOUVER, BRITISH COLUMBIA

Project 740062

John L. Luternauer
Terrain Sciences Division, Vancouver

The natural patterns of sedimentation at the active, western delta front of the Fraser River, the area currently under investigation (Fig. 1), have been altered by the succession of jetties and causeways that have been built across local tidal flats since 1914 (Pretious, 1972), by the dredging of major distributaries and by the damming of a smaller channel northwest of Sea Island, which, prior to 1961, discharged its sediment load across northern Sturgeon Bank (Fig. 1).

Sediment dispersal routes across the delta front will be disrupted further if future urban and industrial growth require: (a) the expansion of existing bulk loading and ferry terminals on southern Roberts Bank (Fig. 1), (b) the extension of runways onto the flats from the Vancouver International Airport on Sea Island, (c) the regulation of river flow, and/or (d) the dredging of the main arms of the Fraser River to an even greater extent than they are now.

This project was initiated to provide a geological/sedimentological knowledge base of the Fraser River Delta which would help predict environmental consequences of sediment budget disruptions. As such, this study should eventually attempt to determine what factors are governing local erosion-accretion rates, what tidal flat morphologic changes are a consequence of man-made structures, what is the residence time of sand on different parts of the tidal flats, what influence the salt-water wedge has on sediment dispersal, what volume of both mud and sand is discharged through each distributary, and what dispersal routes are followed by total sediment loads discharged from each distributary mouth.

However, during the first phase of the project initiated this past summer, all effort has been directed towards monitoring sedimentary and geomorphic responses to seasonal fluctuations of the local wave-current-river climate. This was planned to be accomplished first, by re-occupying sampling sites on the tidal flats during periods of lowest tide every month and, secondly, by sampling and bathymetrically surveying the delta slope both shortly after erosive winter storms had subsided and after the summer freshet had deposited its load across the delta front. The acquired record is expected to reveal the normal range of major seasonal fluctuations in the sediment distribution and geomorphology against which disruptions in prevailing patterns of sedimentation can be readily and reliably recognized. Although earlier studies have described both the broad sedimentary characteristics of the western delta front (Johnston, 1921a; Mathews and Shepard, 1962) and some specific local features (Johnston, 1921b; Garrison *et al.*, 1969), seasonal variations in patterns of sedimentation have been studied in only a very general fashion (Johnston, 1922; Luternauer and Murray, 1973).

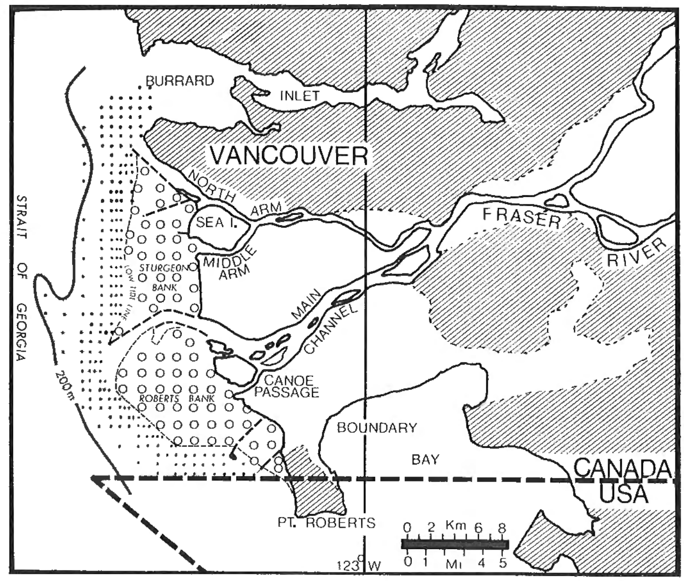

Figure 1. General geographic location and geology of the Fraser River Delta and sample locations for this project. Recent alluvium is blank whereas older deposits are crosshatched. The western delta front extends from the North Arm distributary to Point Roberts Peninsula. Open circles represent tidal flat sampling sites, solid dots represent slope sampling sites.

Sampling of the top centimetre of sediment from as many as 72 tidal flat stations (Fig. 1), over an area of approximately 170 km^2, was carried out from a radar-equipped Canadian Coast Guard Hovercraft on four occasions: Feb. (5, 6, 7), April (24, 25), May (23, 25), and June (20, 21, 22). This part of the sampling program was to be continued throughout the remainder of the year so that the full effects of the freshet discharge and subsequent increasing influence of the erosive winter storms could be observed. Unfortunately, this program had to be discontinued after June because a spare-engine breakdown prevented use of the Hovercraft for any operations other than search and rescue. No other vehicle available has the capability to cover the often deeply gullied, vast muddy expanses of the tidal flats during those few hours of any one month when spring tides expose most of the flats.

Two hundred and twenty Shipek grab samples were obtained from the delta slope (Fig. 1) from a Department of Transport launch (currently on loan to

Dr. Littlepage of the University of Victoria, but released to us for this project) on which a monitor for a Trisponder navigational system had been mounted. The sampled portion of the slope extends from the low tide line to the 200 m contour (except off the North Arm where it extends only to the 100 m contour) (Fig. 1) Sampling operations, which were first carried out between March 11 to 25, will be repeated during the latter half of October.

All samples obtained to date over both the tidal flats and slope (491) have been analyzed for silver, cadmium, cobalt, copper, iron, manganese, nickel, lead, and zinc (and, in selected cases, mercury) by Mr. Dave Grieve of the Department of Geological Sciences, University of British Columbia (under supervision of Dr. K. Fletcher) in the course of a Masters thesis project in which prevailing trace metal levels and dispersal routes from suspected discharge sites are being studied. Preliminary maps of the areal distribution of copper, lead, and zinc reveal these elements are more concentrated on the slope than on the tidal flats and tend to increase in concentration from south to north along the slope.

The pre and postfreshet bathymetric surveys run for this project by the Canadian Hydrographic Service during March to April and August to September, respectively, span the same segment of the delta slope which was sampled in detail (Fig. 1). Over most of the area a sounding density of approximately 45 soundings/km^2 was maintained. The rate of erosion-accretion across the slope can be estimated when this survey is compared to another less precise survey undertaken in 1968 (having approximately only 8 soundings/km^2). A comparison of the pre and post-freshet surveys may reveal sites of most significant freshet deposition.

Preliminary examination of track lines replicated during any one survey indicates that over the bulk of the surveyed area sounding reproducibility (which is dependent on the precision of both the sounder and navigational systems employed) is better than ±0.5 m. However, at the top of the slope off the main channel, where the sea floor is incied by steep-walled, narrow gullies, reproducibility is no better than ±3 m.

Although a precise and comprehensive comparison of the delta front bathymetric surveys can be done only once the compiled soundings are digitized, a preliminary contouring of field sheets produced from the 1974 surveys does reveal the presence of at least two previously undetected submarine canyons off the mouth of the main channel of the Fraser River which may be important conduits of coarser sediment to the Strait of Georgia sea floor.

During the latter part of the summer a total of 292 samples also were collected from a variety of British Columbia inlet and estuarine environments (other than the Fraser River Delta): Skeena River estuary and delta front (210 samples), Powell River shoreline (6), Toba Inlet-head delta (11), Bute Inlet-head delta (28), Quatse River tidal flats (near Port Hardy) (9), Cousins Inlet (9), and the Kitimat River Delta (19). When analyzed these samples can serve as a basis for future studies of the variation in sediment distribution and pollution dispersal within different wave-current-river/pollutant discharge climates. Operations were carried out from the *C.S.S. William J. Stewart* (June 17 to 23) during a Canadian Hydrographic Service survey of the Skeena River, *C.S.S. Laymore* (August 12 to 24) during a biological survey of various estuaries under the direction of Dr. Colin Levings (Pacific Environment Institute) and from the *C.F.A.V. Endeavour* (August 25 to 30).

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RELICT ICE WEDGES, PELLY ISLAND, N.W.T. (107 C/12)

Project 680047

J. Ross Mackay[1]
Terrain Sciences Division

Pelly Island is in the southern Beaufort Sea, about 150 km northwest of Inuvik, N.W.T. and it is in an area of continuous permafrost. The island is composed of Pleistocene (or older) sediments which have been extensively deformed by glacier ice. The northwest-facing coastal bluffs, which attain a maximum altitude of 20 m, are exposed to rapid wave erosion. In some years, large undercut blocks, at least 10 m wide, have become detached and have slumped seaward. Two tiers of ice wedges, separated by an unconformity, have been exposed for at least 10 years as the coastal bluffs have receded (Fig. 1). It is the purpose of this note to describe and discuss the lower tier of ice wedges. The lower tier of ice wedges (Figs. 1 and 2) are believed to be relict ice wedges that were truncated by thaw during the Hypsithermal Interval or in an earlier warm period. Relict ice wedges have been described in Alaska (e.g., Sellmann, 1967), but the writer is

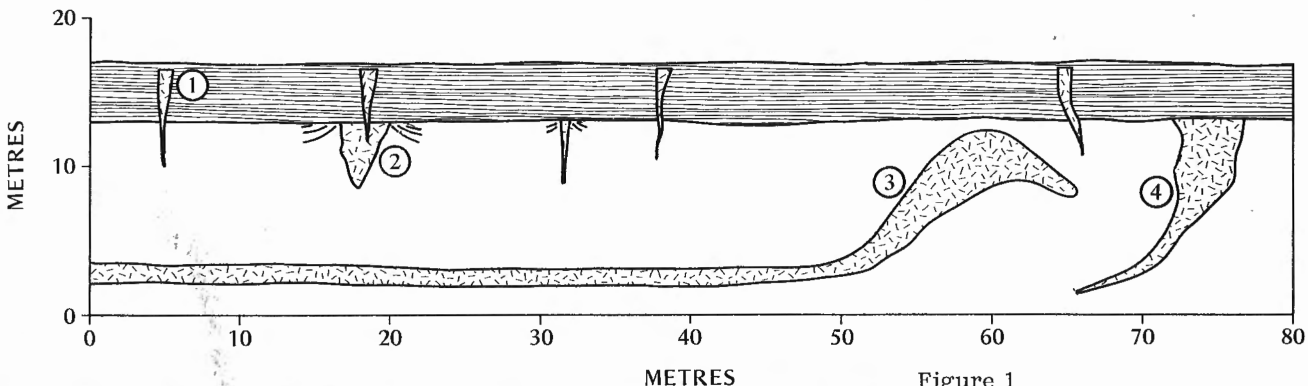

Figure 1

Northwest coast of Pelly Island, N.W.T., in August 1973. The area above the thaw unconformity is horizontally shaded. Number 1 is a modern ice wedge; number 2 is a relict ice wedge, in transverse section, with upturned beds on the side; numbers 3 and 4 are glacially deformed beds of pure ice, with number 4 being truncated at the thaw unconformity.

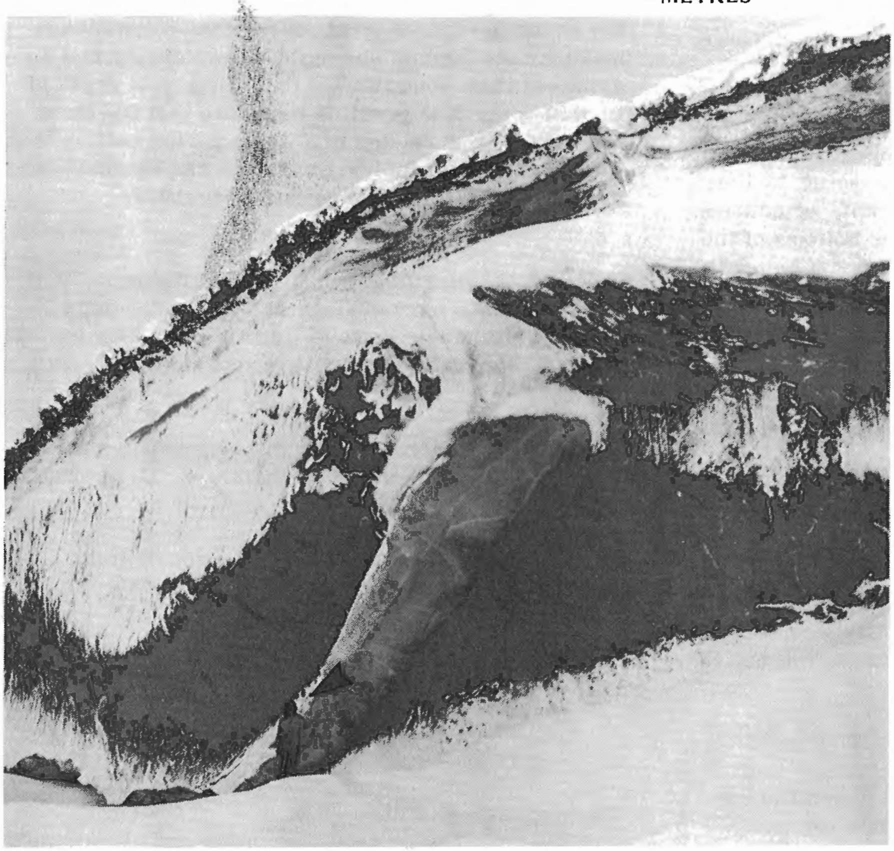

Figure 2

The section in Figure 1, as seen in March 1973. The glacially deformed bed of pure ice is that of number 3, Figure 1, with an arrow pointing to a man, for scale. Note the unconformity between the deformed beds and the material above.

[1]Department of Geography, University of British Columbia, Vancouver, B.C.

unaware of any previous discussion of relict ice wedges at depth in the Western Canadian Arctic.

Thaw Unconformity

A clearly defined unconformity lies from 3 to 4 m below the ground surface on the northwest bluffs of Pelly Island. On lower hill slopes, the unconformity may occur at a greater depth because of burial by downslope movement. A thaw origin, rather than an erosional or depositional origin, best explains the unconformity for the following reasons:

a) Although roots of living plants are necessarily restricted to the active layer, old roots penetrate downwards in abundance below the active layer to the unconformity where they abruptly cease. This indicates that the material between the unconformity and the present active layer was at one time seasonally thawed, whereas the material below the unconformity, with the truncated ice wedges, has obviously remained as permafrost ever since the ice wedges commenced growth.

b) The ground ice above the unconformity is typical of growth conditions that accompany an upward rise of the permafrost surface; the ground ice below the unconformity is largely segregated ice typical of downward freezing.

c) All organic matter attributable to burial by downslope movement lies above the unconformity.

d) The unconformity is continuous irrespective of topography and material. It can be traced from beneath hill tops to low sites where it underlies lake sediments.

Relict Ice Wedges

The lower tier of old ice wedges appears similar in size, vertical extent, and horizontal spacing to the upper tier of modern ice wedges, except, of course, for the missing truncated portions. The bottoms of the larger wedges of both tiers terminate 6 to 7 m below the ground surface. Consequently, the relict wedges, prior to truncation, were probably similar in size to the active surface wedges of today.

None of the relict wedges were reactivated during the cooling period which followed that of maximum thaw. Ice-wedge cracks originate either at the ground surface or just below the surface, but near to the top of the ice wedge. Inasmuch as the tops of the truncated wedges lay 3 to 4 m below the ground surface, only by chance would a crack of near-surface origin propagate downwards to intersect a relict ice wedge. Elsewhere in the Western Arctic, where thaw unconformities are only a metre or so below the ground surface, multi-tiered ice wedges have tended to grow as the active layer thinned.

Ice-Wedge Casts

No ice-wedge casts have been seen above the unconformity, although the faint trace of one ice-wedge cast has been seen, at one site, for about 1 m above the truncated wedge. As the material above and below the unconformity is primarily a stony clay, there is considerable excess ice below the unconformity and, therefore, presumably above the unconformity prior to thaw. As there has been extensive downslope movement above the unconformity, conditions have been poor for the preservation of ice-wedge casts.

Age

The most recent warm period of long duration was the Hypsithermal, which has been placed in the period 8,500-5,500 B.P. (Fyles *et al.*, 1972; Mackay and Terasmae, 1963; Ritchie and Hare, 1971). During this warmer interval, the boreal forest extended northward into the Richards Island and Tuktoyaktuk Peninsula area, not far distant from Pelly Island. However, it seems doubtful if thaw depths were as much as 3 to 4 m, because the present thaw depth at Inuvik, N.W.T., in a forested area, is barely one metre. A 3 to 4 m thaw depth, at present, only occurs far to the south in discontinuous permafrost.

Conclusions

Relict ice wedges at Pelly Island, N.W.T., lie beneath a thaw unconformity some 3 to 4 m below the present ground surface. Prior to thaw, the ice wedges were probably of the same size as present ice wedges in the same area. As a thaw unconformity, without the numerous relict ice wedges of Pelly Island, occurs at Garry Island, N.W.T., 10 km to the south (Mackay, 1974), both may be of the same age. The thaw depth is considerably greater than would be expected for the Hypsithermal Interval, even when allowance is made for ice lensing above the unconformity and an apparent thaw zone thicker than the actual depth of thawed soil. It is possible therefore that the thaw unconformity is related to a warm period earlier than the Hypsithermal Interval but until radiocarbon dates are available, this must remain speculative.

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FREEZING PROCESSES AT THE BOTTOM OF PERMAFROST, TUKTOYAKTUK PENINSULA AREA, DISTRICT OF MACKENZIE (107 C)

Project 680047

J. Ross Mackay[1]
Terrain Sciences Division

Tuktoyaktuk Peninsula, is in an area of continuous permafrost where permafrost depths, in general, exceed 300 m. In order better to understand the thermal and physical conditions that have produced the ground ice now found in permafrost, field work has been carried out where thin permafrost (e.g. <50 m) is now growing, for the first time. The sites to be discussed are the bottoms of recently drained lakes. The field studies of drained lake bottoms have involved, primarily: 1) the installation and precise levelling of about 100 "anti heave" bench marks, anchored well into permafrost; 2) the installation of temperature cables; 3) the collection and analysis of ice samples from permafrost and samples from subpermafrost water; 4) limited geophysical measurements of permafrost depths; and 5) the observation of surface features, such as the growth of ice wedges, icing mounds, and pingos. The objectives of this report are to summarize, comment upon, and interpret some inferred freezing processes at the bottom of permafrost.

Freezing Processes

Lake bottom sediments, prior to drainage, were saturated. Sands and silts with a veneer of reworked till (a stony clay) are the most common sediments. Freezing at the bottom of permafrost in a drained lake may involve one or more of the following processes (Fig. 1):

1) The pore water can be expelled downwards in advance of the lower permafrost surface, to an amount of about 10 per cent of the volume of the pore water that is frozen. If the expelled pore water moves to another site, negligible upward lake bottom heave (ΔH of Fig. 1) will result at the expulsion site. However, the downward growth of permafrost (ΔZ of Fig. 1) will be a maximum.

2) The pore water can freeze in place. The vertical lake bottom heave then will amount to about 10 per cent of the volume of the frozen pore water.

3) Subpermafrost water (whose source can be expelled pore water) can move to the basal permafrost surface to form ice lenses. The vertical heave (ΔH of Fig. 1) will be equal to the cumulative thickness of the ice lenses (ΔH' of Fig. 1).

4) Unfrozen pore water, in fine-grained sediments, either may freeze in place as the ground of permafrost progressively cools, or it may move under any one of a number of potential gradients to another site. The resulting heave is unpredictable.

5) Subpermafrost water - whose source can be expelled pore water - can be injected into either the permafrost or the active layer above it where the injected water subsequently freezes. The heave will reflect the size and shape of the ice mass. Heave from "injected" ice is not shown in Figure 1.

The vertical movement (ΔH of Fig. 1) of most bench marks can be measured, by precise levelling, to considerably better than 1 mm. Table 1 gives some typical ΔH values in centimetres rounded off to the nearest half millimetre, for the years 1971/72, 1972/73, and 1973/74 for two lakes referred to as A and B (Mackay, 1973, Fig. 2), 25 km apart, at the southern end of Richards Island. As the surveys were not carried out on the same date each year, the actual periods involved are sometimes slightly greater or less than a calendar year, but for the purposes of the following discussion, no 365-day adjustment has been made.

Negligible heave and water expulsion

In many lake basins with relatively thin permafrost, a "no heave" situation may persist for a year or more over part or all of a drained lake bottom, even though permafrost is aggrading. For example, Table 1 shows that the annual heave (ΔH) in the 1971 to 1974 period was 0.5 cm or less for four of the seven bench marks in the two drained lake bottoms. However, computations based upon the depth of permafrost, thermal regime, and soil type indicate that *in situ* freezing of pore water would produce about 1.0 cm of heave or more. In the year 1972/73, therefore,

Table 1

Lake bottom heave (ΔH) in centimetres

	1971/72 (cm)	1972/73 (cm)	1973/74 (cm)
Lake A			
Bench Mark 89	0.75	1.55	4.05
Bench Mark 90	0.80	0.05	4.95
Bench Mark 91	1.20	0.50	2.75
Bench Mark 92	2.80	0.50	5.20
Bench Mark 93	5.60	2.05	5.35
Lake B			
Bench Mark 86	1.00	2.25	6.35
Bench Mark 87	0.40	0.90	1.75

[1]Department of Geography, University of British Columbia, Vancouver, B.C.

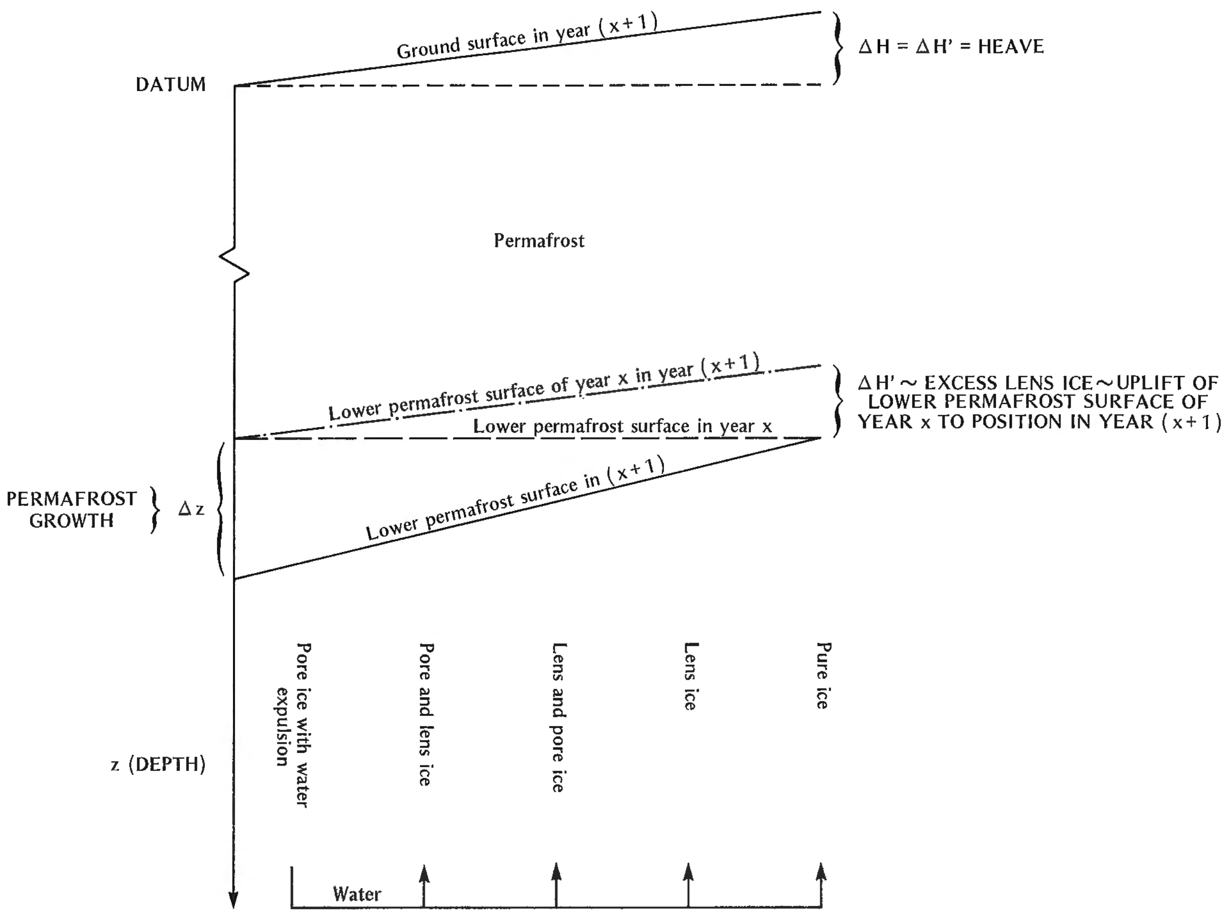

Figure 1. Schematic diagram to show the inferred relationships between ground surface heave (ΔH), permafrost growth (ΔZ), and the formation of excess ice (ΔH') under different freezing processes.

when Lake A bench marks 90, 91 and 92 heaved only 0.05, 0.50, and 0.50 cm respectively, some pore water expulsion probably occurred.

Rapid heave and ice segregation

A far greater uplift can be achieved, under a given heat loss, from the growth of ice lenses than from the freezing of pore water. If the amount of uplift considerably exceeds that which would result from the *in situ* freezing of pore water, ice segregation can be inferred. If only pure ice grows, then the thickness of the pure ice equals that of the vertical heave. At sites where there are temperature cables, a reasonable estimate can be made of the thickness of pure ice which can be frozen in one year, but otherwise, accurate estimates are impossible.

Most drained lake basins have areas where rapid heave (ice segregation) is more frequent and prolonged than elsewhere. In many basins, the central deeps heave more than the shallower peripheries, so that an inversion of relief results, with arcuate residual ponds surrounding a central domed area.

Climatic implications of the freezing processes

The climatic conditions that favour one freezing process over another are unknown, although it seems probable that a steep temperature gradient would be conducive to ice lensing. But other factors are involved, such as the soil properties at the freezing plane, subpermafrost water, overburden pressure, and the permeability of the sediments below the freezing plane. In addition, as temperature waves are lagged with depth, the correlations between freezing processes at the bottom of permafrost in one year and past surface climatic conditions are complex.

Although the heave records of the bench marks are not yet long enough to provide unequivocal evidence to correlate seasonal temperature changes with freezing processes, there is sufficient evidence to suggest that ice segregation has occurred in some years and not in others. For example, Table 1 shows that most of the bench marks in Lakes A and B heaved more in 1973/74 than in 1971/72 or 1972/73. For example, bench mark 90 of Lake A appears to have been located at a site where pore ice grew in 1971/72, pore ice with water expulsion in 1972/73, and considerable lens ice in 1973/74.

Figure 2

Icing mound which grew during the winter of 1973/74 adjacent to a pingo about 150 km northeast of Tuktoyaktuk, N.W.T. The overburden thickness in general is less than that of the active layer. In July 1974, a spring issued on the side of the mound. Permafrost is estimated to be about 20 m in thickness. The mound is about 3 m high. The hill to the left is a pingo.

Injection of Subpermafrost Water

In areas of discontinuous permafrost, supra permafrost flow of water through the active layer may be blocked on slopes, to produce icing mounds. However, the upward intrusion of subpermafrost groundwater in areas of continuous permafrost either into the permafrost above it or even farther into the active layer, to produce icing mounds, is very uncommon. Only three examples are known to the writer for the Western Arctic Coast, and each has involved an icing mound fed from subpermafrost water in a drained lake basin. In 1935, Porsild (1938) saw an icing mound, about 3 m high, in the middle of a drained lake. A large pingo now has grown at the site. In the summer of 1974, two icing mounds were found by the writer to have grown during the preceding winter at widely separated sites on Tuktoyaktuk Peninsula (Fig. 2). Each icing mound measured about 2.5 to 3 m in height, 10 to 20 m in width, and about 30 m in length. The icing mounds had grown adjacent to pingos and each mound had the following characteristics: the intrusion of water was at the base of the active layer; the water source was from subpermafrost groundwater, issuing from springs on the sides of the pingos; the springs were still flowing in the summer of 1974; the adjacent pingos had large radial tension cracks which extended onto the lake flats; and the adjacent pingos, in the past, have exhibited a pulsating "rise and fall" growth pattern (e.g., one of the pingo summits grew 25 cm in 1969/70, dropped 8 cm in 1970/71, grew 7 cm in 1971/72, dropped 3 cm in 1972/73 and a further 11 cm in 1973/74).

At the present time, five drained lake bottoms in which pingos are actively growing are under precise survey. At each of the sites, there is evidence of either icing mound growth, artesian flow, or both. The existence of the icing mounds, the pulsating pingos, and the artesian flow combine to suggest that thinner permafrost areas of some drained lake bottoms may be nearly "floating" on subpermafrost water which, when it escapes, causes subsidence. The source of the subpermafrost pore water is, with little doubt, expelled pore water (Fig. 1). Periods of pingo subsidence can be associated with the escape of subpermafrost groundwater in the form of springs.

The Lower Permafrost Surface

The amount of lake bottom heave is governed by the growth of excess ice, or the lack of it, during permafrost aggradation. The ratio between the maximum amount of soil which can be frozen per unit time as compared to the amount of ice that can form, is of the order of 2:1 (Brown, 1963; Mackay, 1966). Therefore, a "no heave" situation indicates maximum downward permafrost growth, and pure ice lenses the maximum amount of heave, but no downward penetration of the freezing plane, which must remain stationary. Consequently, the position of the lower permafrost surface of one year, such as year x, will rarely be the same as it is in the next year (x + 1), because it will be uplifted by growth of excess ice, as schematically shown in Figure 1.

Conclusion and Comments

The growth of permafrost in drained lake basins of the Tuktoyaktuk Peninsula area, shows that a variety of freezing processes are involved at the bottom of permafrost. For "thin" permafrost (e.g., 10 m), ice segregation occurs in an irregular fashion, varying from one year to the next, and may be climatically controlled. It seems quite possible that in the future, the alternating bands of soil and ice lenses, which are now growing and which can be seen in very old permafrost, may be used to derive data on past thermal and groundwater conditions.

Pore water expulsion beneath an advancing surface seems to be very widespread and the resultant effects most important for an understanding of permafrost growth. The expelled pore water provides an abundant water source for ice segregation; it raises the pore water pressure and may cause artesian flow if tapped; it may issue at the surface through cracks to create springs and icing mounds; and it may nearly "float" pingos and other areas of thinner permafrost. During periods of glaciation, the high pore water pressures, generated by water expulsion, may well have contributed to a loss of shear strength at the bottom of permafrost and thus facilitated glacier ice thrusting, which is common in some permafrost areas.

Lastly, although not discussed here, some bench marks located 20 to 50 m from the shores of former large and deep lakes have been observed to heave. Where permafrost depths are known, this heave permits an estimation of the subpermafrost profile prior to drainage, because bench marks cannot heave, unless permafrost is aggrading at depth, or else unfrozen pore water is freezing. Such indirect evidence suggests that the offshore subpermafrost profiles of large, deep lakes dip at angles of 45 degrees or more.

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UNDER-ICE DIVING OBSERVATIONS IN THE COASTAL ENVIRONMENTS OF SOUTHEAST MELVILLE AND WESTERN BYAM MARTIN ISLANDS

Project 730020

Patrick McLaren
Terrain Sciences Division

The 1974 field season completed a two-year coastal process study (McLaren, 1974a). In addition to re-examining formerly established profiles and zonals, the nearshore environments (to 100 feet depth) were extensively observed by the use of SCUBA[1] diving (McLaren, 1974b). A total of 93 dives, making up 50 underwater hours, were successfully completed. At 25 different locations (Fig. 1) the sea floor and/or sea ice were studied using underwater photography, augering, coring, slope measurements, and sample collection (Fig. 2). A full description of under-ice SCUBA and geological techniques for marine studies is given in a paper being prepared by P. McLaren and D. Frobel.

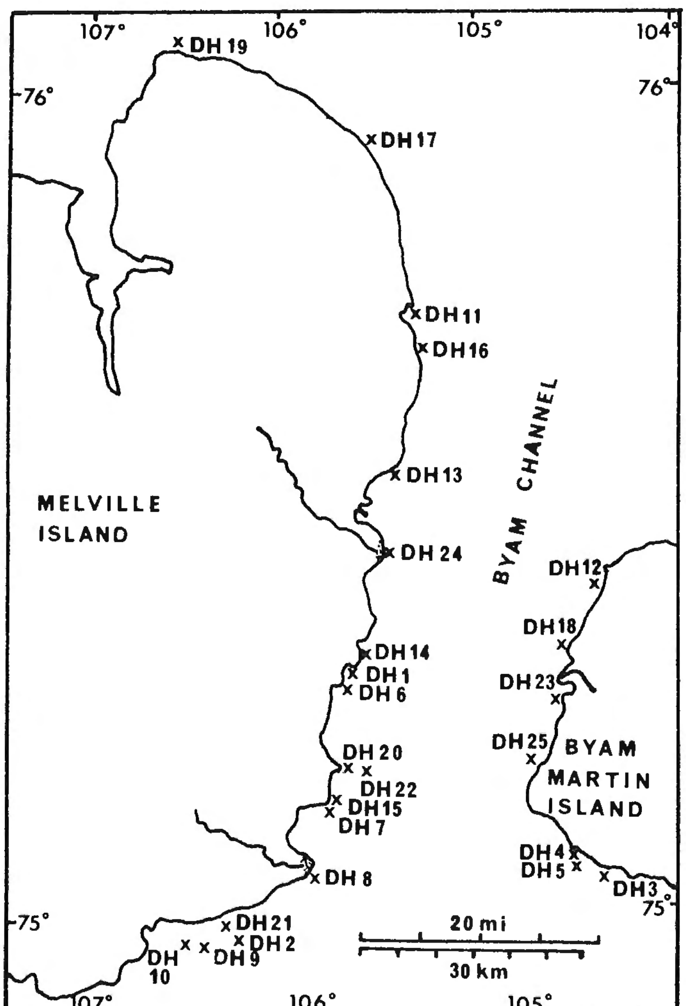

Figure 1. Melville and Byam Martin islands showing drive hole (DH) locations.

[1]SCUBA - Self Contained Underwater Breathing Apparatus

Four different bottom environments were recognized as follows.

Rocky Bottom

Bottoms consisting of pebbles, cobbles, and occasional boulders were consistently found adjacent to rocky headlands on the coast. They were observed at DH 8, 15, 17, 20, 21, and 22 (Fig. 1). Fine-grained sediment cover was too thin to take cores, suggesting that the pebbles and cobbles were a thin veneer over bedrock.

Sea-ice grounding affects a rock bottom by producing shallow (1 to 2 feet), wide (30 to 50 feet) scours that commonly are apparent because kelp, normally attached to a rocky bottom, has been removed. Displaced sediment and/or bedrock that has been gouged out of a scour by ice action forms linear ridges that parallel each side of a scour. Since their morphology resembles levees, they will be named "scour levees". Larger accumulations are pushed into mounds in front of a moving ice block and resemble a moraine in front of a glacier; they will be named "scour moraine". Scour levees and scour moraines show abundant rocks of the same bedrock lithology found on the adjacent coast (Fig. 3).

Poorly Sorted Sand-Silt Bottom

This type of bottom observed at DH 1, 2, 3, 5, 7, 9, 11, 12, and 19 was the most ubiquitous (Fig. 4) and commonly was found offshore from the 20-to 25-foot depth contour. It was present at the deepest dives of approximately 100 feet. Scattered pebbles and cobbles almost always were observed both on the surface of the bottom and in the cores. Ice scour was common and in many cases appeared to be an active and continuous process. It is suggested that an area of bottom would not be immune from scour for very many years at a time. Some bottoms appeared to be so churned by ice activity that an "undisturbed" bottom did not exist.

The source of the rocks throughout the sediment is not entirely clear. Ice rafting was the immediate explanation, but as the number of observations increased, this hypothesis became less tenable since grounded ice and undersurface of multi-year ice always were seen to be entirely free of sediment. Moreover, no sedimentation appeared to be taking place as evidenced by the lack of deposition on the rocks and on dead fauna and flora. It is suggested, therefore, that this facies is a till of which the top 5 to 10 feet continually is being disturbed by ice scour, and that present deposition, if it is occurring at all, becomes incorporated into the sediment.

Figure 2

Dive in progress through an offshore crack in the ice. Note the core tubes and soil auger in background.

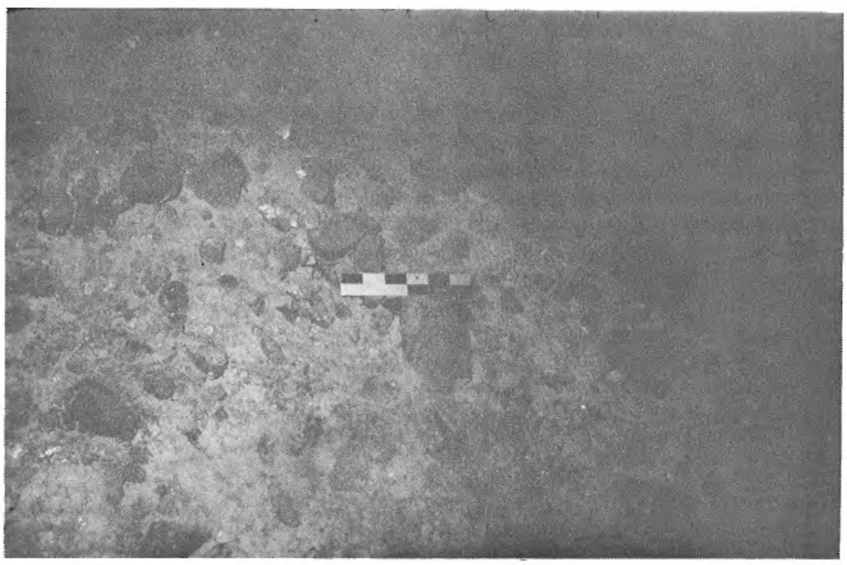

Figure 3

Rocky scour moraine produced in front of a dragging ice block. The scale is 30 cm. Water depth is approximately 50 feet.

Figure 4

A grounded ice block and its associated scour moraine. The sediment is mostly poorly sorted sand with silt. Pebbles are present throughout. The brittle stars are approximately 7 to 8 cm across (measuring from one leg tip to an opposite leg tip). Thus the scour moraine is approximately 80 cm high.

Shallow Sand Facies

A well sorted sand was found in most dives close to shore in 5 to 20 feet of water (DH 4, 14 and 16). No rocks or pebbles were present and it appears that the sand is the result of preferential sorting by wave action. Scour occurs in this sand facies but nearshore waves and currents quickly infill and obliterate the effects of ice.

Delta Front

The deltas of this region are of the Gilbert type (McLaren, 1974a) and dives on the delta fronts (DH 23 and 24) showed a steeply dipping (13 to 15 degree) foreslope. They consisted of well-sorted medium to fine sand.

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BANKS ISLAND, N.W.T.: PINGOS, WIND ACTION, PERIGLACIAL STRUCTURES

Project 640004

A. Pissart[1]
Terrain Sciences Division

During July and August 1974, periglacial research was carried out on Banks Island. The author observed numerous periglacial features, but will concentrate on three main subjects: a) pingos, b) wind action, and c) structures in relation with patterned ground.

Pingos

Pingos were observed on aerial photographs in several places on Banks Island. Three groups were studied in the field.

Figure 1. Pingos in the Thomsen valley.

Figure 2. Wind-blown sands in the Thomsen valley.

[1]Université de Liege, Belgium.
A. Pissart worked in Canada during summer 1974 as an award-holder of the Canada Council.

Figure 3. Pingos in the Able Creek valley.

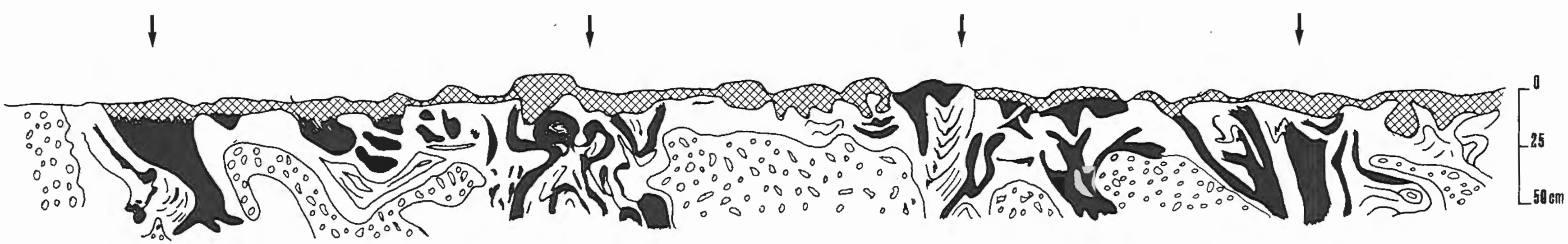

FIG 5 _ SECTION IN NON-SORTED STRIPES

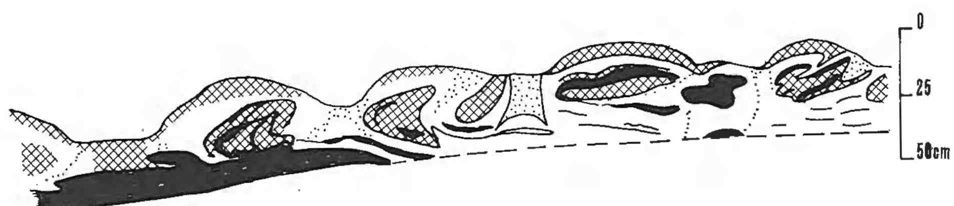

FIG 4 _ SECTION IN HUMMOCKS

0 25 50cm

STRIPE AT THE SURFACE

PEBBLES IN SILTY SANDS

HUMIFEROUS SANDS

YELLOW SANDS

The first group of pingos is located on terraces of Thomsen River (lat. 73°43'30", long. 119°56'; Fig. 1) and was studied in collaboration with H. French (*see* this publication, report 128). Seven mounds with heights ranging from 5 to 14 m and lengths ranging from 75 to 180 m were investigated. Cross-sections were made using a pump in two of these; they showed the ice core of the pingos and the fluviatile sediments upheaved by the growing of the ice. These pingos are elongated and are thought to follow old channels of the Thomsen River.

The second group is a dozen pingos on low terraces of Able Creek, 8 km southeast of the first (lat. 73°41' 20", long. 120°00'). The height of these mounds varies between 3 and 9 m. They are elongated with the largest one being 230 m long and 30 m broad (Fig. 3). At this location also, their shape is in relation to an old channel of the river. Sections in two of these mounds have shown ice and demonstrated that these features appeared in a lake. Several samples taken for ^{14}C dating will give the age of these features. It is probable that these pingos grew only in the bed of Able Creek after the lake drained because the upper frozen ground was thinner there due to the flowing water.

A third group of pingos was examined 70 km southwest of Johnson Point (lat. 72°28'50", long. 120°9'). In this location, it is difficult to make the distinction between pingos and kame deposits. However, several mounds are definitely pingos, not only because of their horizontal-circular shape and their morphology, but because ice was observed in a section that was cut in one. The glacial history of the region must be considered in order to explain these pingos.

Wind Action

Along the Thomsen River between lat. 73°40' and 73°50', the present wind action is obvious on aerial photographs. Large surfaces of wind-blown sands are free of vegetation; deflation and accumulation appear very active (Fig. 2).

The wind deposits were studied in collaboration with J.S. Vincent. It is clear that the wind is now reworking old wind-blown sand deposits which in some places are more than 7 metres in thickness. These sands probably were supplied by the Thomsen River, and for a part at least, are derived from the Isachsen Formation. It looks probable, however, that these thick wind deposits are related to a Quaternary local event, perhaps an ice-dam lake.

Plant remnants and, in places, peat are conserved in these deposits. R.J. Mott collected samples for palynological studies and also for ^{14}C dating. When the age of these deposits is known, it will be possible to say more about their formation.

Some well developed ventifacts, stones faceted and polished by wind, were observed on a terrace of Thomsen River, in relation with these deposits.

Structures in Relation with Small-Scale Patterned Ground

At the beginning of thawing, cracks that exist between small non-sorted polygons and hummocks are filled with ice (depth 40 to 60 cm; width 5 to 30 mm). The cracks are probably initially due to desiccation and are filled by congelation of water when the snow begins to melt. This ice plays an important role in the evolution of these periglacial patterns.

Structures seen in sections cut through small non-sorted polygons (hummocks) show the upheaval of the material below the hummocks and, where sands are wind blown, some infilling of cracks occurs by eolian material (Fig. 4).

Frost scars (sorted circles) are the surface expression of cryoturbations. These phenomena occur in the upper part of the soil far from the top of the permafrost. It is always the finer material which is upheaving in the coarser one. Under the large non-sorted stripes that were investigated, large cryoturbations were found showing that this kind of patterned ground is due to important movements in the soil (Fig. 5).

FURTHER OBSERVATIONS OF THE SCOURING PHENOMENA IN THE BEAUFORT SEA

Project 700092

Jim Shearer and Steve Blasco
Terrain Sciences Division

Introduction

Previous work by Pelletier and Shearer (1972) in the Canadian western Arctic, Reimnitz *et al.* (1971, 1973) off the Alaskan Shelf and Weeks *et al.* (1971) have established much of the baseline information on occurrence of sea bottom scours and the characteristics of the sea ice causing these scours.

The summer of 1974 was a poor year for seismic reflection, echo sounding, side scan surveying, and bottom coring because of the very heavy ice conditions. Generally the edge of the polar pack was not much more than 15 miles offshore, except in Mackenzie Bay where the indentation southwards off the Mackenzie River delta gave, on occasion, up to 40 miles of open water. For this reason and the fact that this open water area was the only one where reasonable water depths were encountered (up to 50 m) most of the summer's work was carried out here.

Despite the proximity of the polar pack, some detailed side scan sonar profiling of the sea bed was obtained; indeed, were it not for the polar pack, a number of significant observations concerning drift-ice phenomena would not have been made.

Observations

The two main types of floating ice bodies found in the Beaufort Sea area are ice islands (Figs. 1 and 2) and pressure ridge remnants (Figs. 3 and 4). The ice island fragment seen in Figures 1 and 2 was located approximatley 1 km east of the west coast of Mackenzie Bay roughly equidistant between Kay Point and King Point in about 15 m of water. The pressure ridge fragment on the other hand was located about 60 km north of Tuktoyaktuk in about 30 m of water. The location of these ice fragments is not particularly significant, other than it demonstrates that they are found in all areas of the Beaufort Sea. The ice island fragment shown in Figures 1 and 2 was photographed in early August 1971 and is believed to be the same one blown into Babbage Bight and grounded during the severe storm of mid-September 1970. Its position at the time of photography indicates that the ice island had refloated and moved 5 miles northward from its original wintering position. Although it is believed to have been aground at this time because of its lack of drift, side scan sonar profiling around this piece of ice shows no record of a scour terminating at that point (Fig. 5).

This year, a number of side scan passes were made very close to large pieces of ice that were thought to be aground with similar absence of correlative scours. This has precipitated the concept that any of these fragments of ice alone cause little, if any, scouring. Consider the analogy of a large oil tanker, which has lost its power and is drifting from wind and wave action into shallow waters; upon touching bottom, it will soon be fast aground, having done very little ploughing into the bottom. It is proposed that all scouring by ice on the bottom is done when the ice is frozen into the polar pack and its effective momentum is orders of magnitude greater than when drifting alone. Many of the scours observed are in fact a network of parallel scours caused by the movement of one or more pressure ridge and ice island keels frozen into the polar pack and thus all moving as part of a rigid system (Fig. 6). Some scours that run parallel for long distances have been observed to cross one another or vary their spacing between adjacent ones, which is believed to be a result of a rotation of the ice pan into which the various ice fragments are frozen. This idea implied that bottom scouring takes place primarily in the winter months when wind-driven pack ice exists in large enough pans to effectively cause scouring of the bottom. It also implies that scouring takes place seaward of the edge of the shore-fast ice zone. This perhaps explains some of the observed paucity of bottom scours inside the 10-m depth contour.

It must be mentioned that, as well as most areas with water depths less than 10 m, many other areas offshore show little evidence of scouring. These areas are principally bathymetric lows protected from the scouring of pressure ridge and ice island keels by the existence of shallow sills (i.e., Herschel Basin, etc.). Another example of this basin and sill phenomenon preventing local scouring occurs in the moat areas of most offshore pingos found in the Beaufort Sea and in the submerged Wisconsin (?) river channels running northwards across the continental shelf from the East channel of the Mackenzie River and from Hutchison and McKinley bays which are protected from all directions other than a direct southerly flow of ice. (*see* Natural Resource Charts No. 23092, 23096, 26508, 26602 and 26606 for the detailed bathymetry). Offshore pingos located directly to the north of Hutchison and McKinley bays may have the effect of causing the polar pack to "run aground", as it were, on these bottom aberrations, offshore of its predicted zone of bottom contact.

Echo sounding profiles with a 200 kh_z sounder have shown that the properties of the bottom scours in profile seem to vary considerably from shallow to deep water and from area to area. Figure 7a to 7c shows differences in the nature of the bottom for three depths in central Mackenzie Bay. In all three areas, maximum amplitudes for scours (relief) is around 10 feet but the width (wave length) varies considerably from shallow to deep water. The bottom scours in shal-

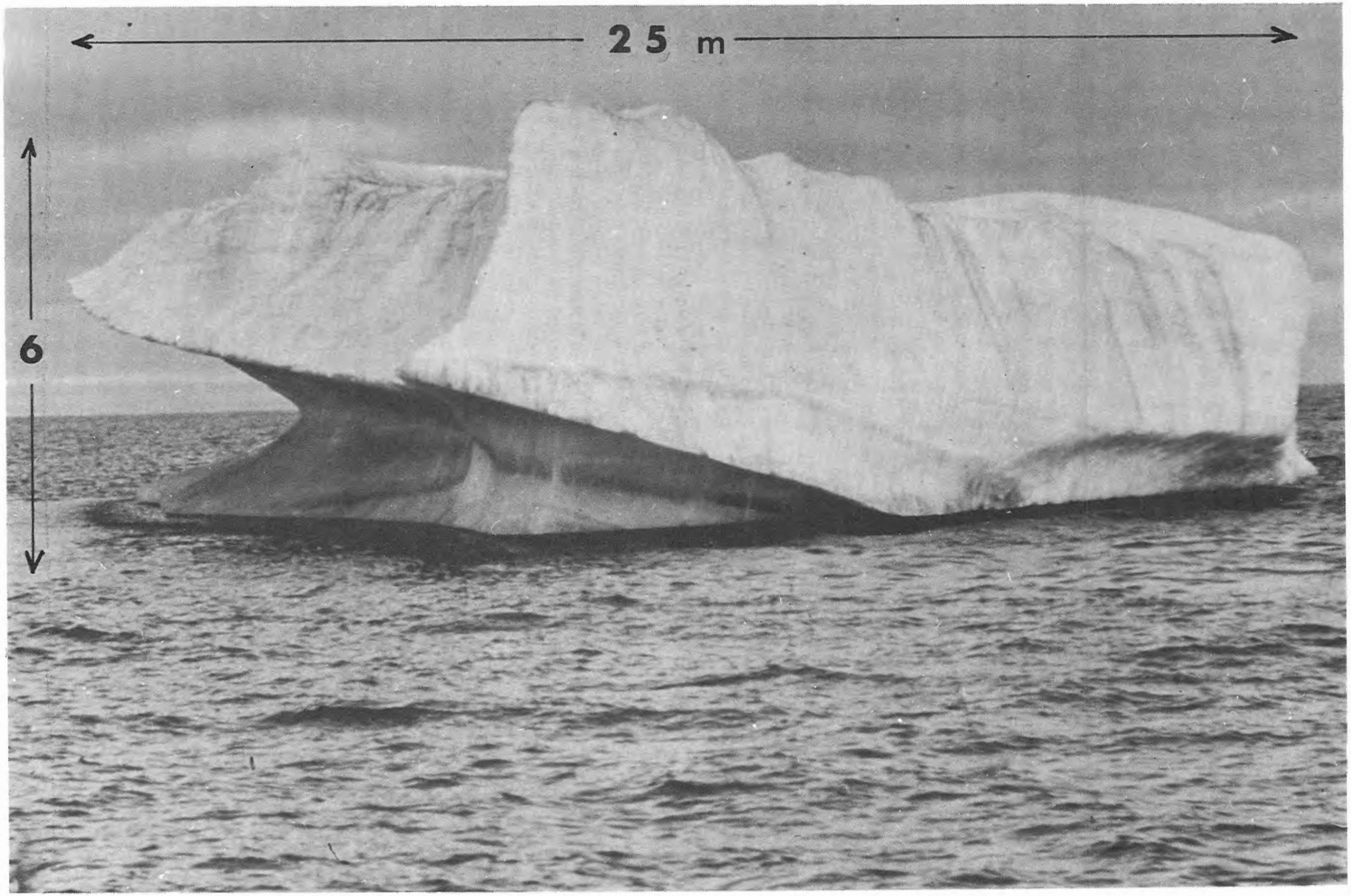

Figure 1. View facing north of ice island found in west Mackenzie Bay. Note parallel laminations and tilted wave-cut terrace on left side. Measurements made by estimating distances and height in relation to the boat.

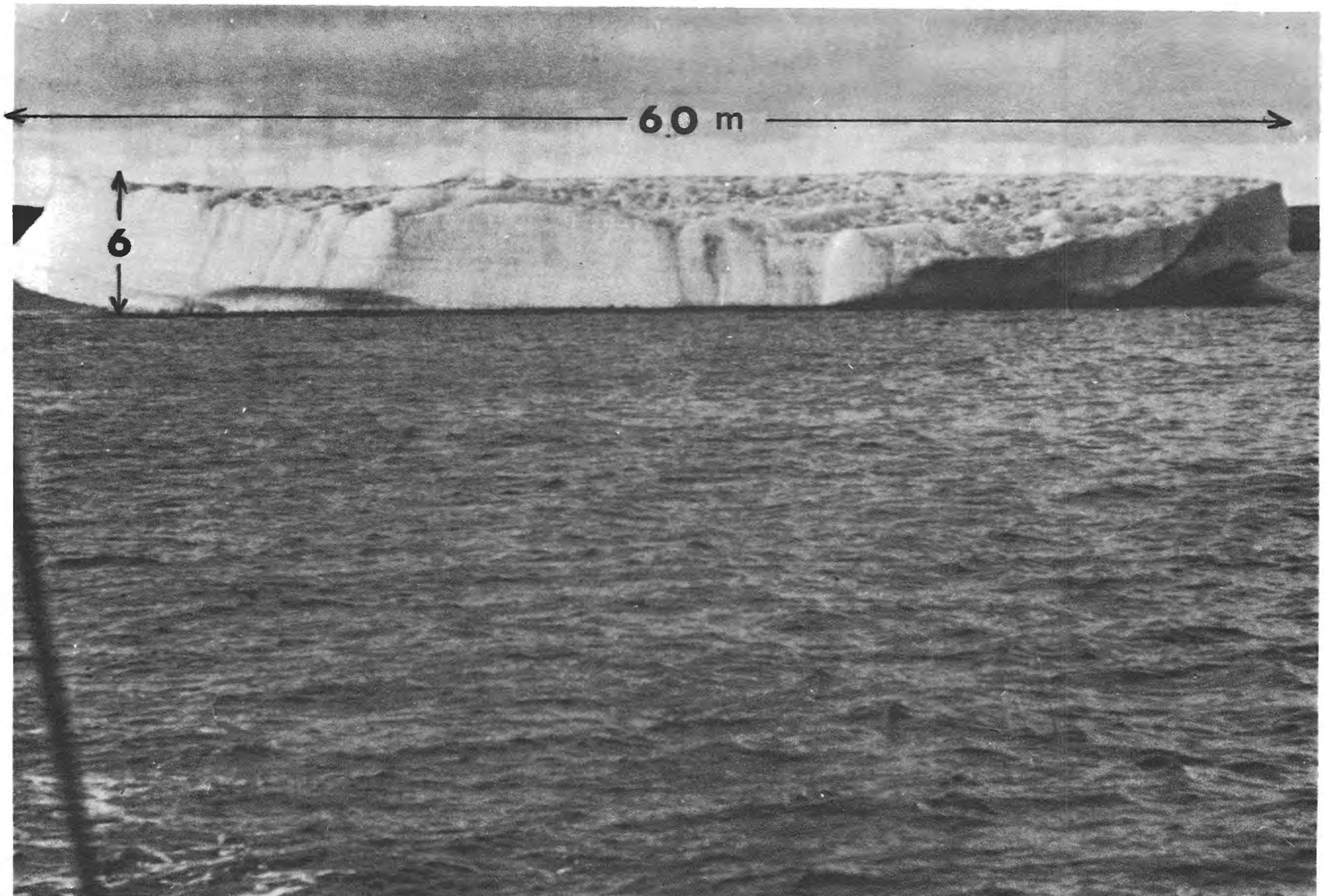

Figure 2. Same ice island as in Figure 1. View looking west, showing total length of fragment.

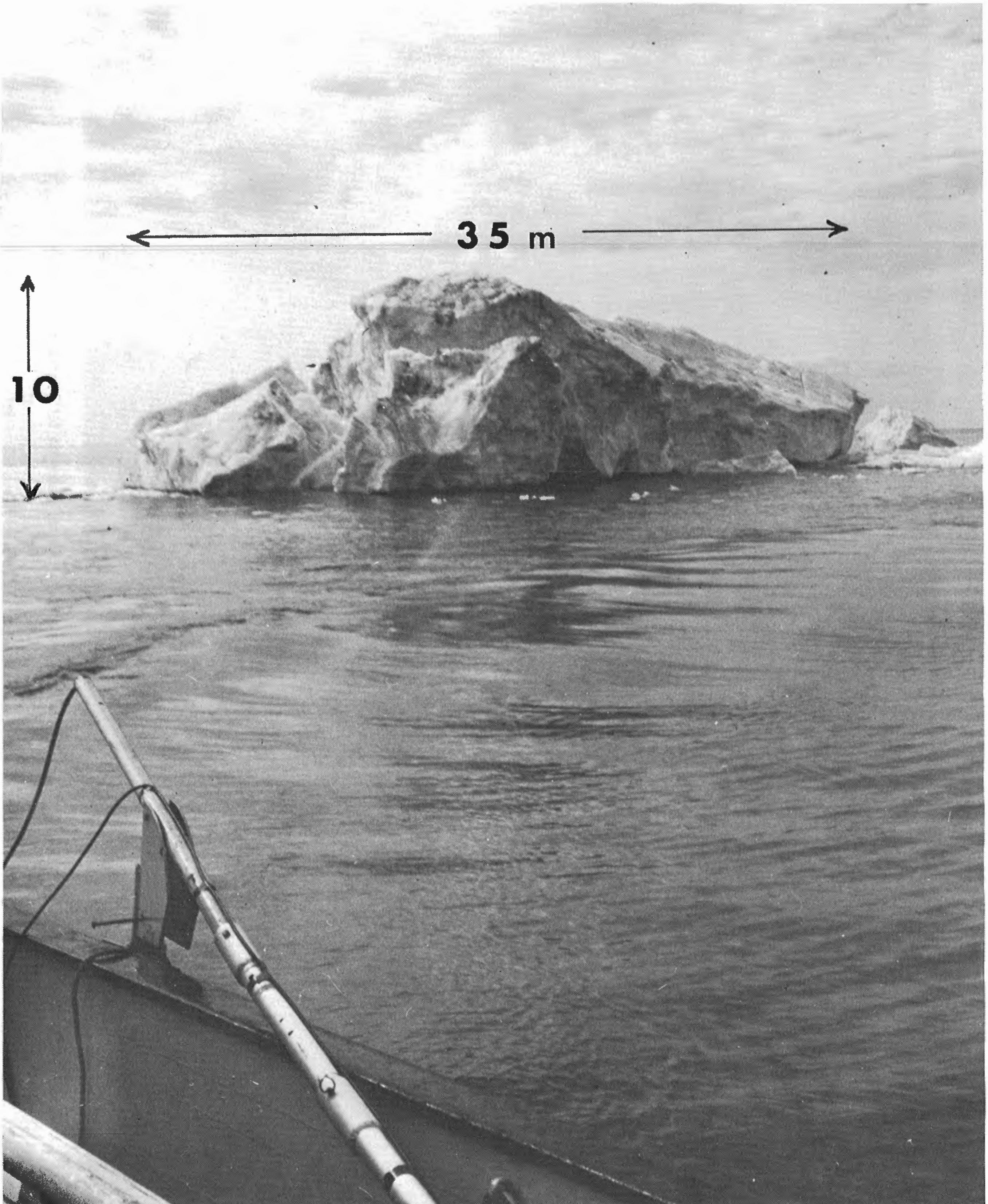

Figure 3. Pressure ridge fragment, looking at short side. Note small disorientated blocks making up total mass. Also note wake on left side formed by water currents transporting eroded pieces away from grounded main body.

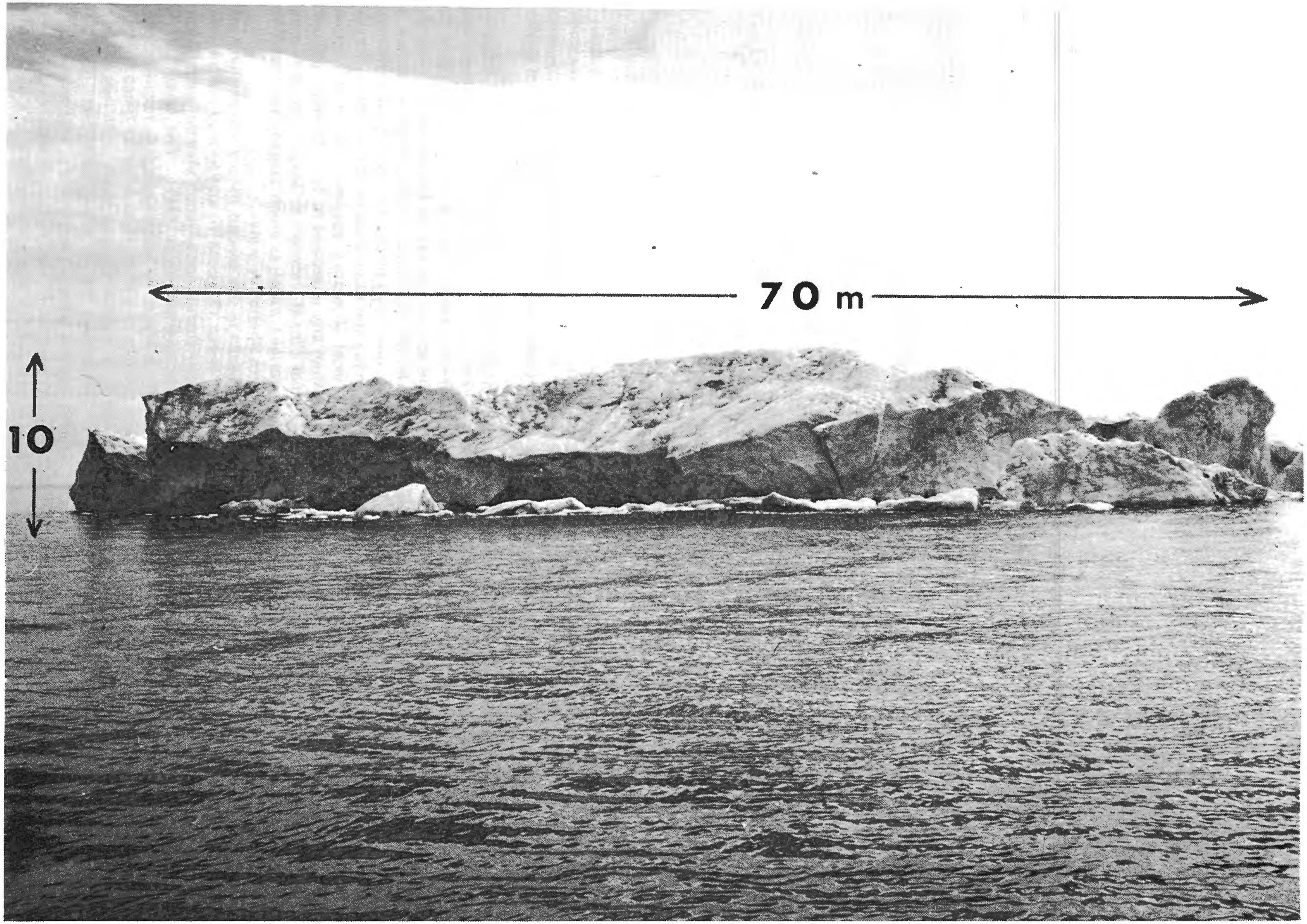

Figure 4. Same fragment as in Figure 3 showing total length.

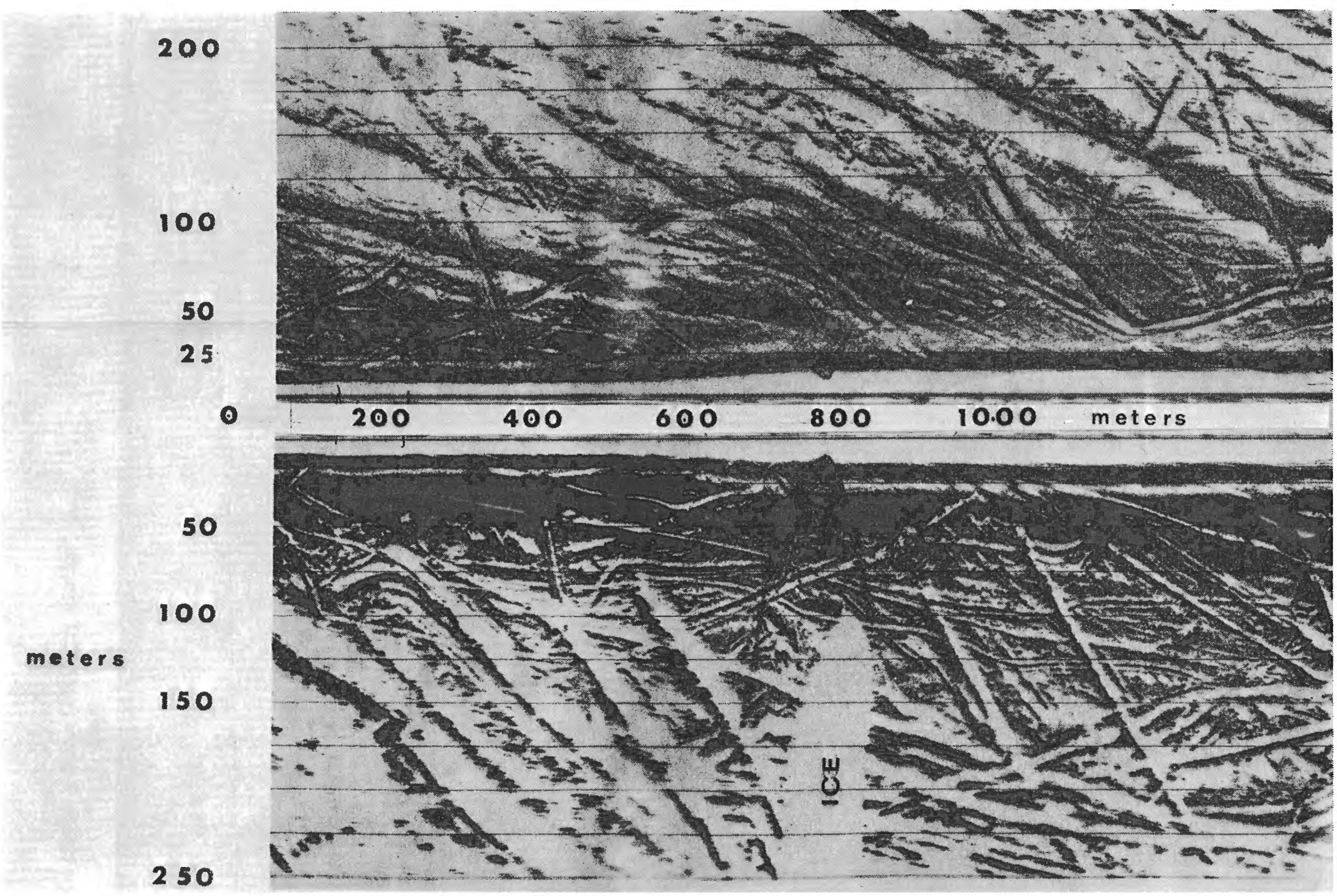

Figure 5. Side scan sonar record from very close alongside the grounded(?) ice island. Shadow (blank patch) indicates a lack of signal return from this area becasue of interruption by ice mass. The shadow does not mean for certain that the ice is on bottom, nevertheless it is an indication that the fragment possesses considerable depth. Note reflection from ice on the surface (dark hyperbolic reflector at 800-m mark).

low water seem to be much narrower and more peaked (i. e., radius of curvature of base of scour is very small) than those in deeper water. All three profiles were taken on the same line with very little alteration in heading. It is assumed here that the scour azimuths are somewhat similar throughout the line. Therefore the different in scour width is real and not just due to a change in the angle of incidence of the survey line to the scours. If scour orientation changed significantly with depth, one would expect to traverse at least one scour at a high angle of incidence which should exhibit a pronounced peakedness if that scour type is present. Nevertheless, no instance of shore wave length (narrow), high amplitude scours were found in water deeper than 100 feet.

Two theories regarding the relationships between age and shape of scours are presented, each of which partially may account for the observed data.

Many of the very steep-sided (narrow) scours (Fig. 7a) are thought to be younger than those with greater width (Fig. 7b). In East Mackenzie Bay, Figures 7 and 8 show a fresh scour that has cut older infilled scours. In this case, where the rates of sedimentation are high (Mackenzie Bay), older scours seem to be more infilled and possess flatter troughs than do fresher ones (Figs. 8 and 11). In Figure 7b most of the scours seem to be infilled to the same degree and hence may have formed at the same time (i. e. keels from one large pressure ridge gouged into the bottom during the same pass over that area). Nevertheless, most of scours observed in 7b are larger (wider) than any observed in 7a. Whether infilled (7b) or not (7c) the scours in deep water have a shape (cross-section) which is much larger than that found in scours in shallower water.

This leads to the second theory where the scour in deeper water (Figures 7c and 9) may not necessarily be any older than those of much shorter wave length (width) in shallow water (7a). The amount of ice needed for a fragment large enough to touch bottom, in say 150 feet of water, is roughly 27 times that volume needed for a similar-shaped piece in 50 feet of water. As an example, a sphere of radius 30 feet, if scouring 10 feet into the bottom (amplitude), will cause a disturbance roughly 45 feet wide. In contrast, a sphere with a radius of 80 feet and scouring to a similar depth

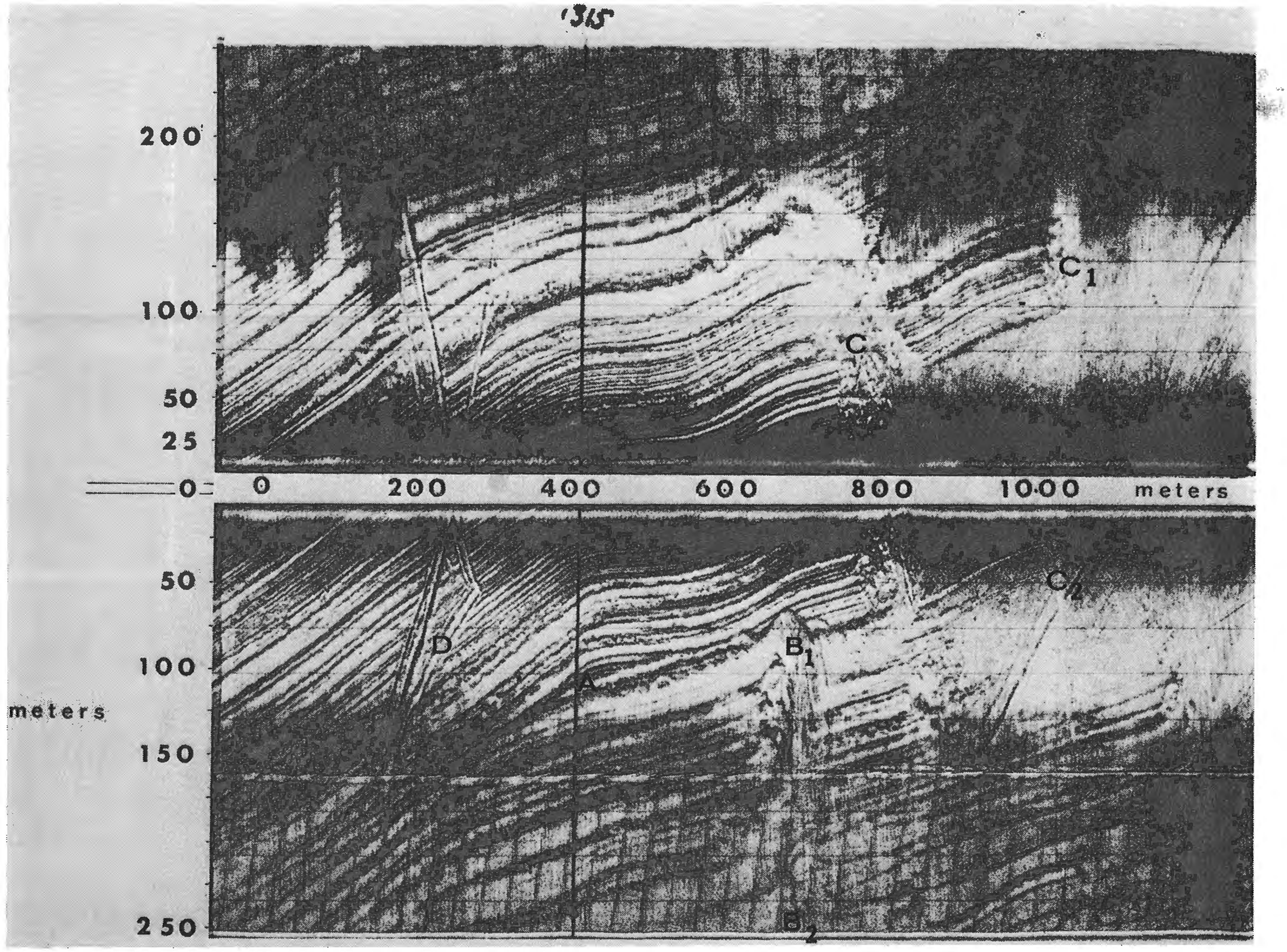

Figure 6. Side scan sonar record of a multitude of subparallel scours all formed during one pass of a large fragment of ice thought to be frozen into the polar pack. Note the angular unconformity between scours at point A. It is thought that the mass of ice responsible for scouring the swath as far as push ridge B_1-B_2 was some hundreds of metres behind the mass scouring to the line C_1-C_2. Both masses were moving towards the upper right sector of the record (shallower water) with the lowermost one (B_1-B_2) following behind and twisting less than the mass in front, as it moved from its pivot point A to C_1-C_2. Also note scour at point D, which effectively has cut across the older network of scours. Sea floor image was recorded with an EG and G side scan sonar unit in 10 m of water about 10 miles north of Pullen Island.

of 10 feet will have a scour width of about 80 feet. In other words, the size of a piece of ice scouring the bottom in shallower water is smaller, with accompanying smaller radii of curvature of the block as a whole, compared to a block of ice in deeper water. One would expect then, never to have a small fragment of ice scouring in deep water. Within the Arctic polar pack, one can expect a certain amount of horizontal compression compensating for and overriding the natural isostatic equilibrium obtained during free flotation. Nevertheless, this force is not thought to be enough to render thin slabs of ice to significant depths. At the same time one would expect very few large scours in shallow water, although with a fortuitous distribution of multiyear ice, it is at least possible. In general, scouring in shallow and deep water is thought to be made by small and larger fragments which cause narrow and wide scours respectively.

In conclusion, it appears that the age of scour in general cannot be related to width or peakedness alone, but that relative ages can be assigned to scours whatever the size, depending upon the amount of infilling. The flatness and horizontality of the base of the scour are directly associated with the amount of infilling and are parameters that can be measured on high frequency echo sounding records. In order to distinguish scour and interscour areas so that these parameters can be measured properly, a side scan sonar record should be taken simultaneously with the echogram. The best method of positively identifying fresh scour is to run repeated side scan surveys in the same location at regular time intervals (i.e. every summer). In this way new scours can be recognized and their parameters

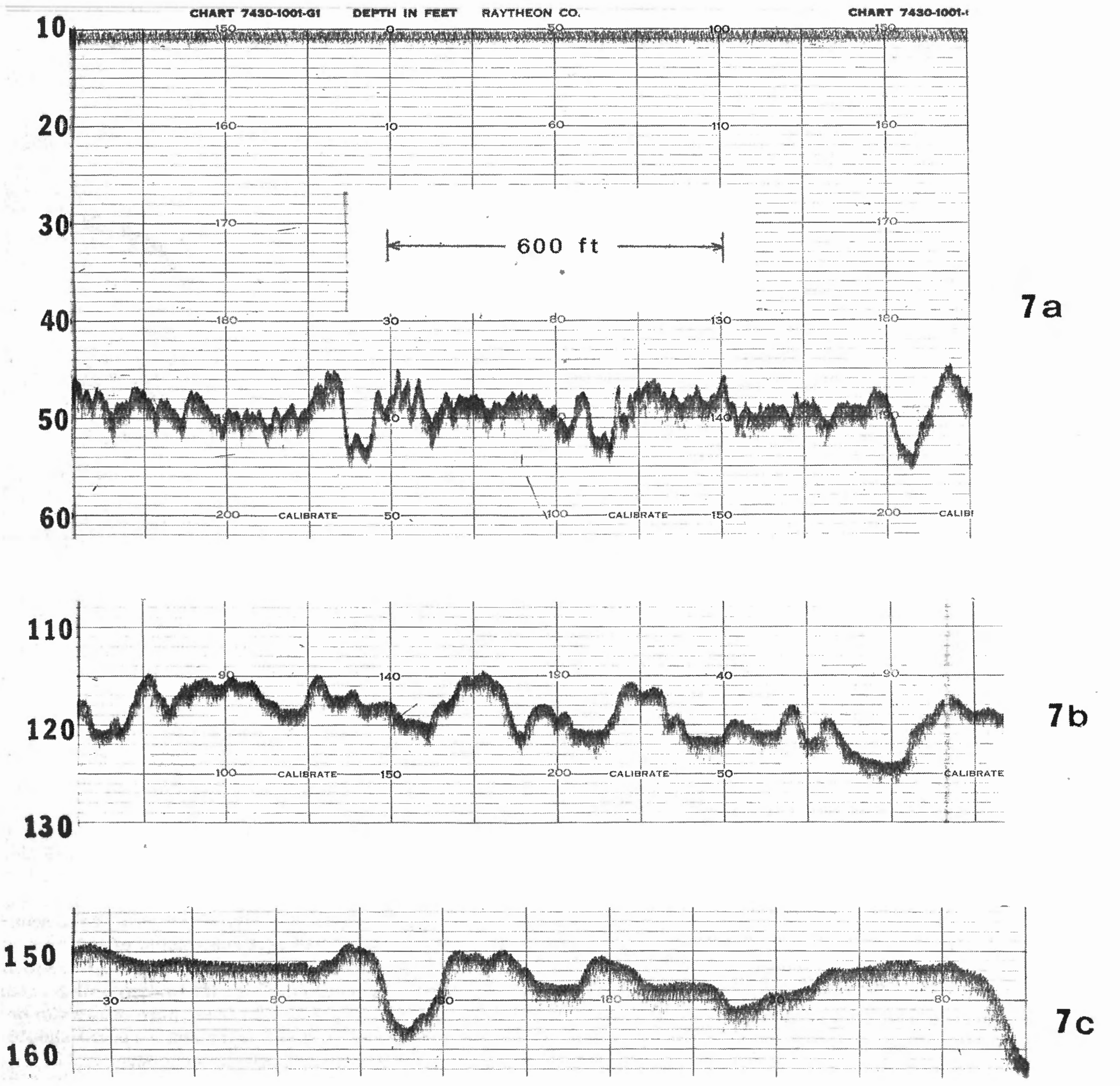

Figure 7. Three echo sounding profiles with the same horizontal and vertical scales, covering different depth ranges.

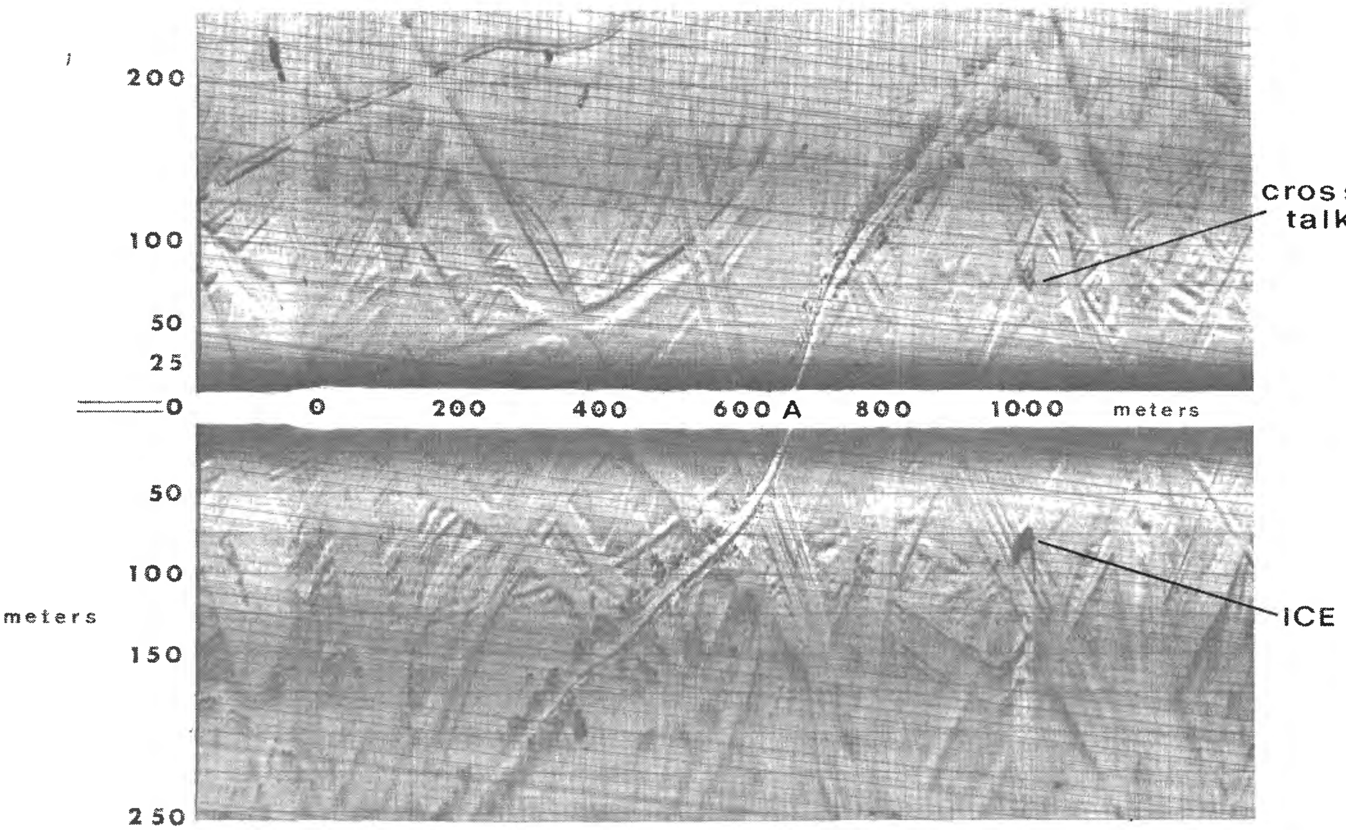

Figure 8. Scour at A possesses very steep slopes, giving a better contrast than do other scours. Dark patches on either side of fresh scour (A) are thought to be mounds of sediment pushed aside by a "snow-plough" effect. Note the reflection of surface ice on the lower channel and its false image on upper channel.

catalogued, and with time a file of the characteristics of fresh scours can be built up. It should be noted that the specific geomorphic characteristics identifying fresh scours probably will vary for different depths of water and for different areas. Where the rates of sedimentation are small (i.e., east of the Mackenzie River delta and north of Atkinson Point) older scours may have very little infilled material and thus look like fresh scours found in Mackenzie Bay (Fig. 10).

During the summer of 1974 a Pisces IV submersible was available in the Beaufort Sea for diving, to observe and sample scoured areas of the bottom. At least eight dives were made with very little success at sampling in the desired localities because of limited bottom visibility. By making the submersible negatively buoyant, it was possible to feel the scours, with the inclination from the horizontal being 26 degrees at one point.

In general the surface water (fresh Mackenzie River water) was very muddy with zero visibility. At every dive site the visibility improved rapidly, between 5 and 10 m below the surface, to a maximum of about 3 m (with 2 x 100 watt strobe lights). In general, a sharp temperature decline accompanied this visibility improvement (i.e., surface temperatures of $45+^{o}F$ compared to about $32^{o}F$ or even $30.5^{o}F$). The water column retained its midwater visibility right to the bottom where the water depth exceeded 60 m. In lesser water depths the lowermost 3 to 5 m of water was clouded and bottom visibility decreased to less than 1 m at around 30 m water depth.

The suspended sediment in bottom water was at first thought to be due to the effect of orbital velocities from surface wave action which, though very small, might be enough to remobilize the saturated unconsolidated sediments on the bottom. This hypothesis was favoured in lieu of bottom currents, because there is a direct correlation between bottom visibility and water depth. Nevertheless, the abrupt improvement in visibility at 60 m of depth would seem to favour, in part at least, another mechanism. Becasue the polar pack was present this summer, it is possible that bottom currents were accelerated above normal values due to the constricted passages between the base of the sea ice and the sea bed where ice keels approximated the water depth. Thus in shallower water, with grounded and floating ice fragments, the accelerated currents may have remobilized and resuspended the bottom sediment. Once in suspension, the particles take a long time to settle out and thereby create the observed poor bottom-water visibility.

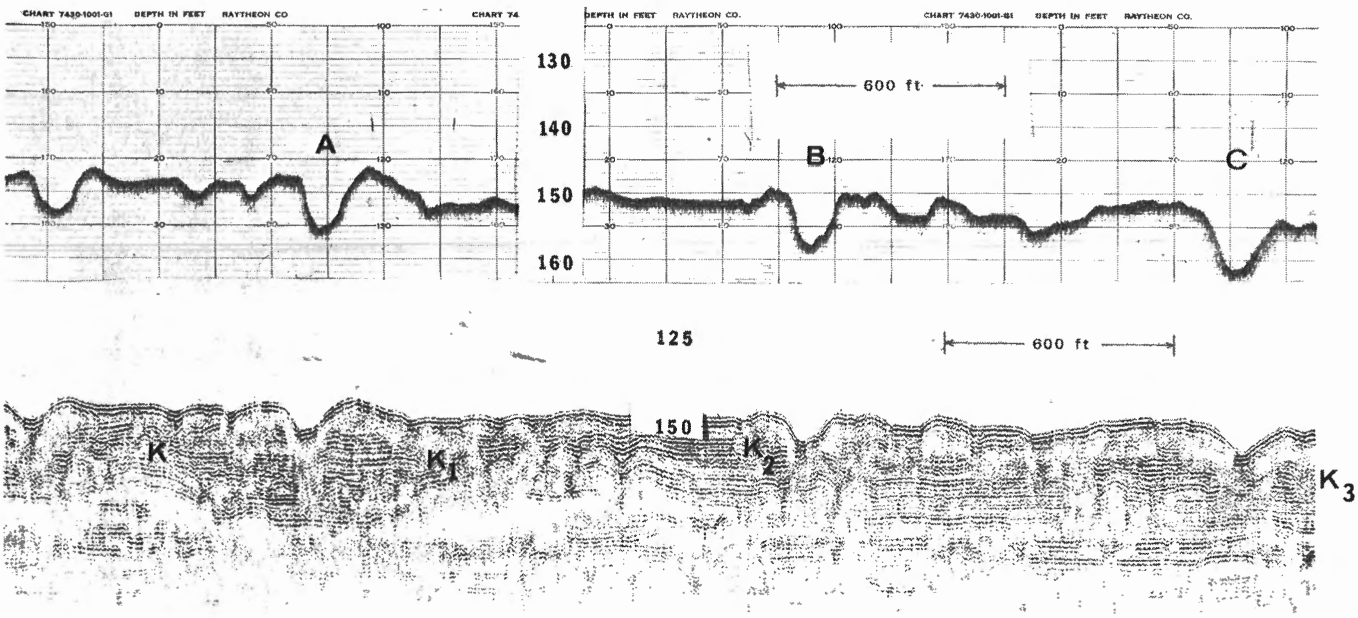

Figure 9. Two hundred khz and 2 khz reflection records of the same area in central Mackenzie Bay. Note scours A, B, and C, the mounds of which are in the uppermost layer of sediment, indicating a time of scouring which at least postdates the underlying horizon (K to K_3). If one assumes that the top 30 m of sediment overlying the thick sequence of outwash was deposited during the last 6, 000 years since sea level stabilization, one arrives at a rough rate of sedimentation of 0. 5 cm per year. The uppermost layer, approximately 10 feet thick, indicates that the scours A, B, and C are less than 600 years old.

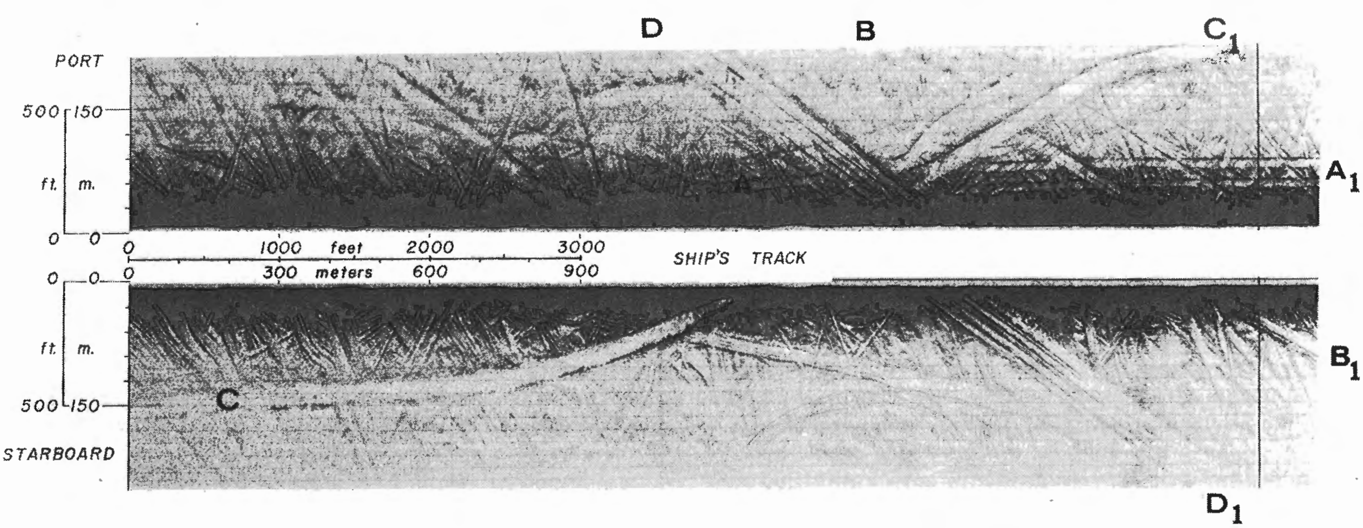

Figure 10. Side scan sonar record from north of Atkinson Point in the Beaufort Sea in about 30 m of water containing fresh-looking scours with presumed ages of a few years to several thousand. Note the four distinct generations which overlap one another; oldest A-A_1 to the youngest D-D_1.

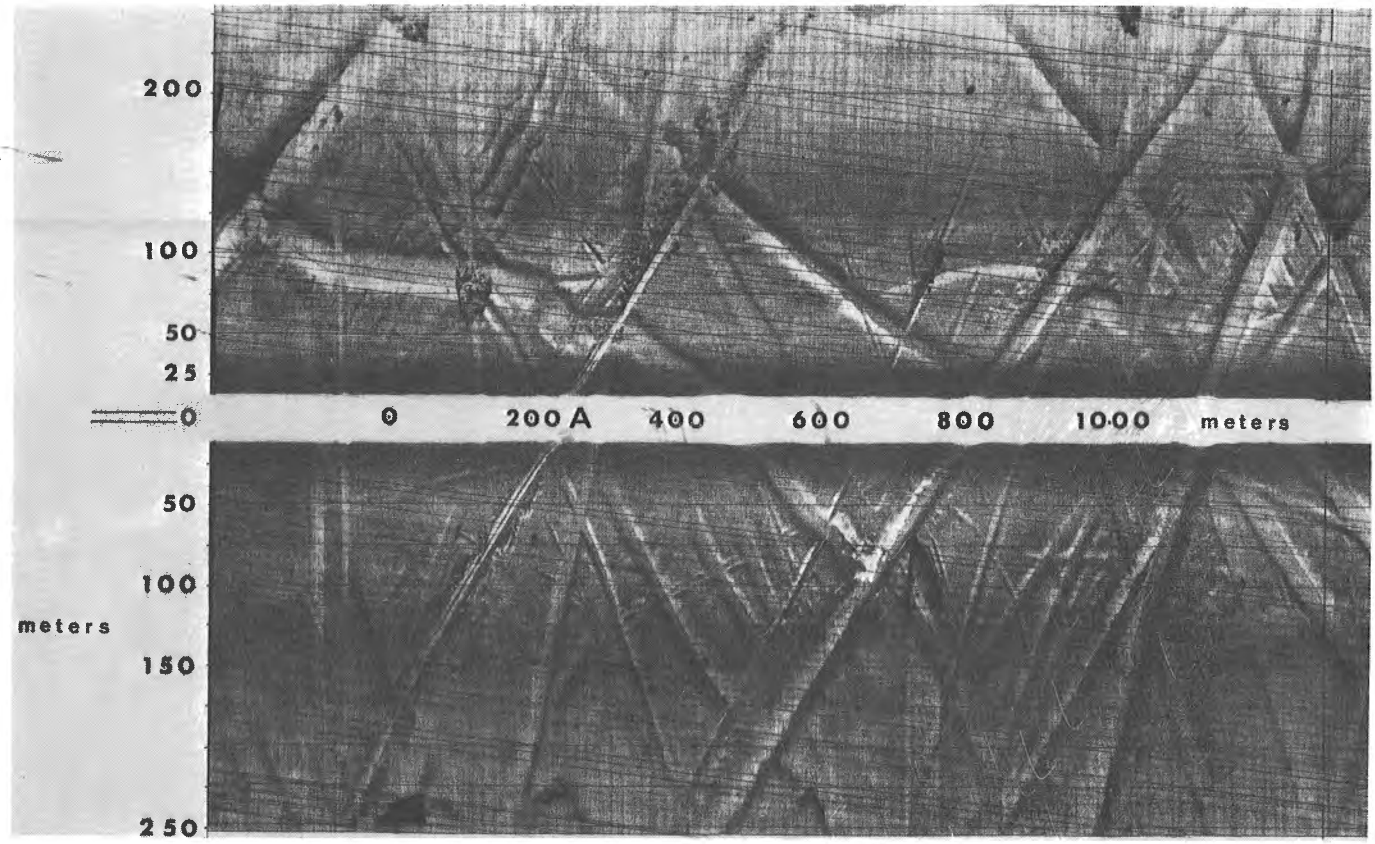

Figure 11. Fresh scour (A) at about 30 m depth, has very similar characteristics to the fresh scour observed in Figure 8. Note other scours, which seem to exhibit less contrast, and possess flatter troughs. Note also as in Figure 8, surface ice reflections with their corresponding false image (cross-talk) on upper channel only.

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DISPERSAL OF CLASTS AND TRACE ELEMENTS IN THE WINDSOR ESKER, SOUTHERN QUEBEC

Project 690095

W.W. Shilts and B.C. McDonald
Terrain Sciences Division

The Windsor esker, lying in the St. Francis River valley north of Sherbrooke, Quebec, has been the subject of recent detailed sedimentological study (McDonald, 1971; Banerjee and McDonald, in press). Numerous borrow pits along the 14-km length of the esker provide good exposure. The esker begins just south of a mass of serpentinized peridotite, and similar ultrabasic rocks outcrop a few kilometres southwest of the esker (Fig. 1). The location of the esker affords a good opportunity to compare ultrabasic dispersal patterns in glaciofluvial sediment to those for till derived from similar ultrabasic rocks in the Thetford Mines area (Shilts, 1973), 80 km northeast. In 1970 a study was made of the variation along the esker of lithologic composition of pebbles. This study has been complemented in 1974 by a study of the distribution of chromium, nickel, cobalt, copper, lead, zinc, and magnetic minerals in different size and mineralogical fractions and in different facies along the esker.

Geology

The Windsor Esker was deposited in contact with the Lennoxville glacier (McDonald and Shilts, 1971), the front of which retreated northward down the St. Francis River valley while standing in a deep (100 m ±) proglacial lake. The earliest ice flow recorded here was toward the west. In late Wisconsin time, ice flow near the glacier margin in the St. Francis Valley was generally towards 115 to 150 degrees (Fig. 1). Late-glacial perturbations are described by Lortie (*see* this publication, report 114) and Lamarche (1974).

The esker lies on or near bedrock throughout its length. Bedrock consists of quartzite, trachyte, and black slate (Cooke, 1950) except near the northern end of the esker where serpentinized peridotite outcrops.

Morphology and Sedimentology

Windsor Esker consists of three different morphologic types: a) between sites 0 and 10 there are 20 beads, and samples 0 to 15 are located mostly in beads that are 10 to 20 m high and about 285 m apart; b) samples 16 to 22 and 27 to 28 are located in a continuous steep-sided ridge, 10 to 20 m high; c) samples 23 to 26 are from a complex double ridge. Most exposures reveal a 1- to 2-m-thick capping of fine sand and silt that is interpreted as a zone of lacustrine or eolian reworking.

Sedimentology of the Windsor esker is discussed in detail by Banerjee and McDonald (in press). A wide variety of facies are present. Although the predominant grain size is sand, grain sizes of individual units vary from silt to coarse cobble gravel. Sedimentary structures vary from parallel lamination and parallel bedding to cross-lamination and large-scale crossbedding. Hundreds of paleocurrent measurements clearly indicate southeasterly flow of meltwater during all phases of esker deposition. The beads have been interpreted as subaqueous fans deposited during yearly stillstands of the ice front; the ridges are interpreted as having been deposited in subglacial tunnels.

Sampling and Analysis

Sand

Channel samples were collected from 34 sites in the crossbedded or ripple-laminated sand facies, each from fresh gravel pit exposures. In about half of the pits, additional samples were collected for comparison from other exposures of the same facies or from other facies. On Figure 1, each result is related to one of four facies types.

Samples were sieved to -64μ (-250 mesh). Magnetic grains in the fine and very fine sand fraction (64μ to 250μ) were separated by hand magnet from the methylene iodide heavy mineral fraction (SG > 3.3). Weight percentages for the magnetic fractions were calculated as a per cent of the total methylene iodide separate. The -64μ and the magnetic fractions were then digested in perchloric acid and analyzed for Cu, Pb, An, Cr, Ni, and Co by atomic absorption techniques.

Pebbles

Samples of 100 pebbles each were collected from 25 sites along the esker. At several sites additional samples were collected to study 'within-site variation' in pebble composition. Pebbles sampled varied from 2 to 5 cm intermediate diameter. Samples were taken from particular facies, and the pebbles were identified in the field.

Discussion

Figure 1 summarizes the concentrations noted for the most important ultrabasic components. Where more than one sample has been collected from a pit, the data show considerable variation. In pits 18, 21, and 25, for example, Ni is almost as variable among the various facies in the pit as it is from one end of the esker to the other. The magnetic fraction shows similar variation in pit 4. Chromium and nickel values for the magnetic fraction are extremely variable in some pits (21) but very close together in others (4). Compared to similar analyses of many hundreds of till samples from the Thetford Mines area, the esker analyses are quite variable and give little hint of a dispersal pattern. This variability is presently attributed to primary depositional factors in the esker (such as the differing hydraulic behaviour of mineral grains of highly variable specific

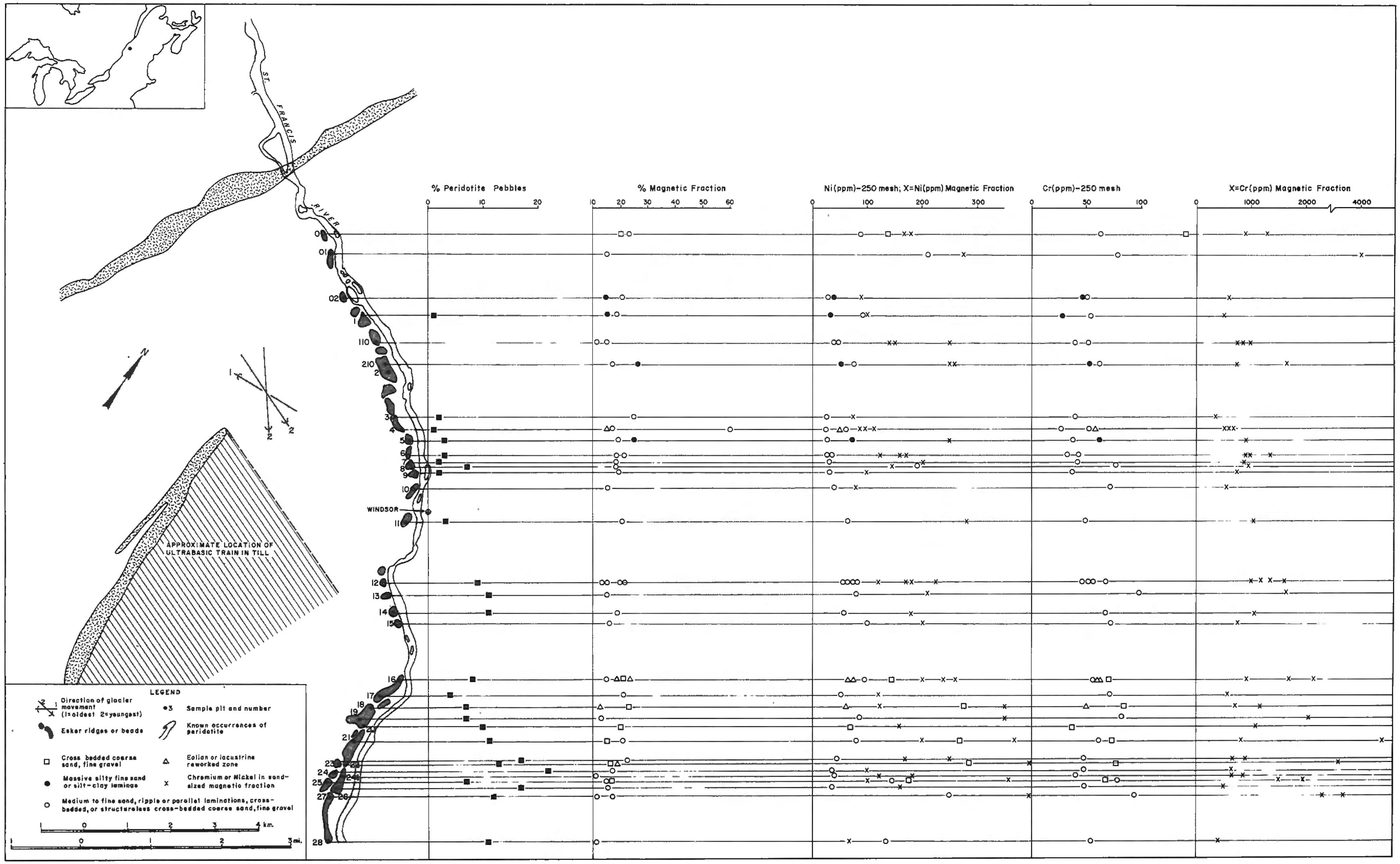

Figure 1. Windsor esker, showing distribution of ultrabasic pebbles, magnetite, Ni, and Cr. Meltwater flow in the esker stream was southeastward.

Table 1

Trace element concentrations (ppm) in -64μ (-250 mesh) portions of esker samples

Locality Number	Cu	Pb	Zn	Ni	Co	Cr	Facies
210	100	78	174	78	42	62	fine, ripple-laminated sand
8	190	117	240	191	62	76	coarse, pebbly sand
18	281	184	230	277	84	84	coarse, pebbly sand
21	190	115	169	269	48	73	coarse, pebbly sand
22	190	139	128	284	79	76	coarse, pebbly sand
25 (A)	94	79	100	174	34	67	coarse, pebbly sand
25 (B)	104	74	135	146	42	78	fine, ripple-laminated sand
Mean value for esker (exclusive of samples above) N = 44	22	37	65	69	26	57	
Range for esker (exclusive of samples above) N = 44	6-72	27-70	40-112	24-250	16-46	26-156	

gravities) and not to sampling, processing, or analytical errors. Vertical variations may also be related to changing sediment sources during deposition at any one site.

In pits 0, 01, 8, and 19 to 27 ultrabasic pebbles and other ultrabasic components appear to be high. The ultrabasic components at pits 0 and 01 probably are derived from glacial or glaciofluvial erosion of the main ultrabasic mass at the north end of the esker. There, fluvial transport does not seem to have been more than a few kilometres. The origin of the sporadic but relatively high values at pit 8 is unknown. High values in pits 19 to 27 probably are related to glacial transport southeastward from the second ultrabasic outcrop west of the esker (Fig. 1). A train of ultrabasic debris, similar to that outlined in the Thetford Mines area (Shilts, 1973), probably existed in the basal and englacial load of the Lennoxville glacier at the time of formation of the esker and was intercepted by the esker stream. The esker probably derived much of its sediment from debris in the basal portion of the glacier or from underlying till.

High values of Cu, Pb, Zn and Co, accompanying some of the high nickel values in pits 210, 8, 18, 21, 22, and 25, suggest that some anomalously high nickel values may not be related solely to silicate nickel from ultrabasic sources but to base metal sulphide mineralization in the trachyte or black slate as well (Table 1).

Variations in pebble composition of a number of rock types along the esker are shown on Figure 2. Within-site variation of pebble composition is considerable. McDonald (1971) reported that for sample sizes of only 100 pebbles, (a) frequencies less than 3 per cent are unreliable, (b) variations within one exposure could be as much as half the frequency indicated by a single 100-pebble sample, (c) variation at one locality is unpredictable both vertically and laterally, and (d) considerable variation is possible laterally within the same bed over as little a distance as 2 metres.

In order to use compositional variations in esker sediments as an indication of bedrock composition in areas where bedrock outcrops are sparse, it would be of interest to know the distance back from the terminus of an active glacier that the escaping meltwater was localized in basal tunnels. The length and time-transgressive character of most eskers indicates that subglacial tunnels extend themselves headward as the ice-front recedes, so the length of the esker per se is no guide to this problem. The combination of known bedrock distribution near the Windsor esker and compositional variations within the esker (Fig. 2) can be used to obtain a crude answer to this problem, and this might assist in understanding the problem elsewhere. The following simplifying assumptions could be made:

(a) All esker sediment is derived from erosion of underlying material, and the concentration of a particular material in the esker is directly proportional to the length of esker stream located over the source of that material;

(b) Deposition of esker sediments takes place primarily at the ice front (this must be verified first by field study; in the case of the Windsor esker, beads give this indication); and

(c) The esker stream extends headward at the rate of ice-front retreat, i. e. the length of the esker stream remains constant.

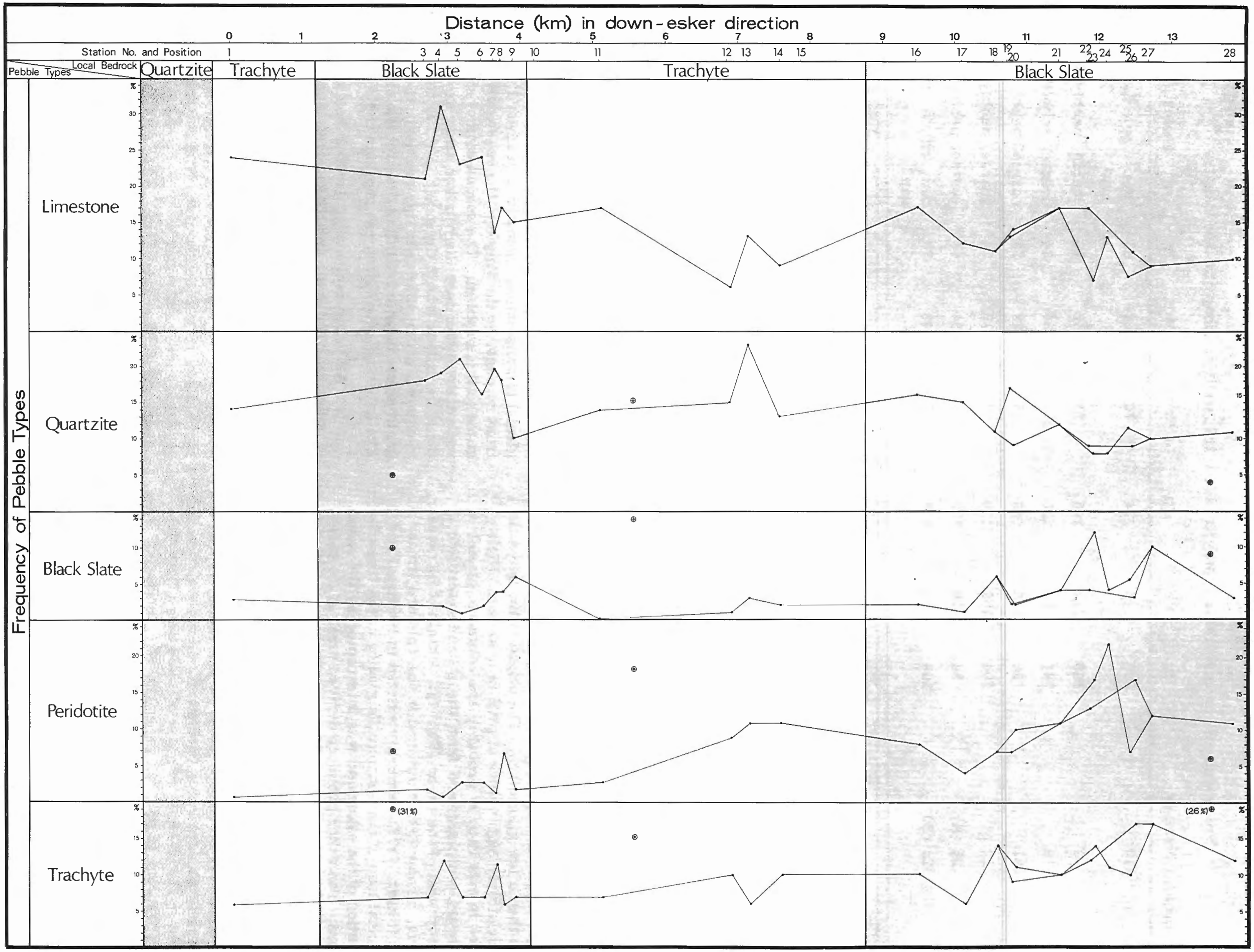

Figure 2. Distribution of pebble lithologies relative to bedrock outcrop along Windsor esker. (Circles with dots at three locations show pebble compositions in till adjacent to the esker.)

The question of the nature of the underlying source material is an important one; if glacial sediments are thin, then this material is probably bedrock; if glacial sediments are thick, then the underlying material could be till and a compositional peak in the esker could reflect the existence of a glacial train in this till. Thus the nature of this source, or "target", will have to be determined. The portion of the Windsor esker that best satisfies assumption (b), while traversing an area of thin drift, is that part of the esker upstream (northwest) of locality 15.

It follows from the above assumptions that the shape of the concentration curve in the esker is a function of the length of the esker stream relative to the width of the outcrop. Three cases are possible:

(a) Esker stream longer than outcrop width: This generates a broad peak that reaches a maximum at the downstream edge of the outcrop belt and maintains that maximum for some distance downstream from the outcrop belt;

(b) Esker stream same length as outcrop width: This generates a relatively sharp peak at the downstream end of the outcrop belt; and

(c) Esker stream shorter than outcrop width: This leads to a broad peak over the downstream portion of the outcrop belt.

Turning to Figure 2, it is possible to examine the distribution of trachyte and black slate upstream from locality 15 in terms of this admittedly crude model, as the esker stream completely traversed relatively well known outcrop widths of these rocks. In the case of black slate, the esker stream crossed an outcrop width of 3 km between localities 1 and 10. A sharp peak is visible at locality 9, near the downstream edge of the outcrop belt. This would appear to fit case (b), above, and leads to a suggested length of 2.5 to 3.5 km for the esker stream. In the case of trachyte, the esker stream crossed an outcrop width of 1.5 km near locality 1. A broad, multiple peak may be present, the downstream edge of which is at locality 7. This configuration appears to fit case (a), above, where the distance from the upstream limit of the trachyte outcrop to the downstream edge of the peak is 3.5 to 5 km. On the basis of these two cases it can be suggested that the esker stream was 3 to 4 km in length. These suggestions must be regarded as extremely tenuous in view of within-site variation, the spacing between sample sites, and the apparent inability of the model to explain the peak in peridotite pebbles at locality 8.

Conclusions

1. Hydraulic sorting and considerable lateral and vertical variation of depositional environments greatly complicate the study of dispersal of trace elements and clasts in an esker.

2. In the Windsor esker, downstream fluvial transport apparently is restricted to between 3 and 4 km.

3. Some relatively high concentrations of ultrabasic components probably are related to erosion, by the esker stream, of a glacial train derived in turn from ultrabasic outcrops occurring some distance laterally from the esker.

4. Some high nickel values may be related to base-metal mineralization in slates or trachytes rather than to silicate nickel typical of the ultrabasic rocks.

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COASTAL INVESTIGATIONS OF NORTHERN SOMERSET ISLAND AND BARROW STRAIT, DISTRICT OF FRANKLIN

Project 730021

R. B. Taylor
Terrain Sciences Division

Field studies in 1974 were concentrated along the northern shore of Somerset Island between Aston Bay and Garnier Bay, with special emphasis on Cunningham Inlet. An examination of coastal features and processes also was completed on Lowther Island, in central Barrow Strait, and on southeast Bathurst Island (Fig. 1).

Somerset Island

A series of 41 beach profiles were established along the coast within previously selected characteristic coastal environments. These environments vary from well developed raised beach terraces, intermittently broken by high cliffed shores, to tundra pond-barrier island environments and wide sand beaches (Fig. 2a, b, c). The beach profiles were continually resurveyed between June 27 and September 14 as the shore-fast ice melted, and whenever the beaches were subjected to storm waves. In 1973 a resurveying of the ten beach profiles established in 1972 (Taylor, 1973a, b) indicated very little change other than minor ice-push features on the lower beach (Fig. 3). In 1974, however, Barrow Strait became free of ice much earlier than usual which resulted in the generation of several sets of storm waves from the northwest and northeast. Consequently the beaches along northern Somerset Island underwent large changes as nearshore ice was moved tens of metres inland and the beaches suffered from considerable wave overwash.

Echo sounding from small pneumatic boats provided extensions to the established beach profiles and invaluable information on the nearshore bathymetry. Further information collected at each of the profiles took the form of sediment samples, and the determination of the frost table depth using hand augers. The latter information was supported by ground temperatures collected from a 100-cm thermistor probe containing thermistor beads at 10-cm intervals. The probe was located at mean high tide level in Cunningham Inlet.

Coinciding with the research on the active beach was a collection of geomorphic information and organic samples from the raised beaches for radiocarbon age determination. Two wood samples collected at 17. 3 m and 20. 3 m a. s. l. on the northwest side of Cunningham Inlet have been analyzed and found to be 4, 930± 70 years B. P. (GSC - 2081) and 5, 300±70 years B. P. (GSC - 2080) respectively.

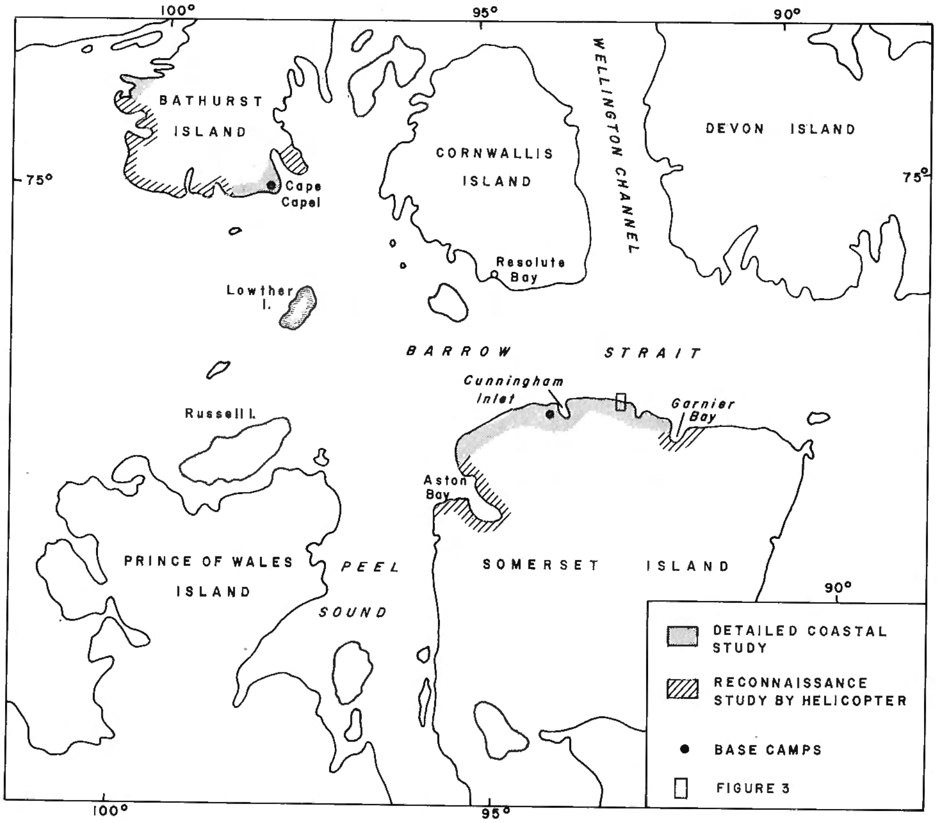

Figure 1. Location of coastal investigations in Barrow Strait and vicinity.

Cunningham Inlet

Throughout the 1974 field season an estuarine study was conducted in Cunningham Inlet. The study also included the collection of discharge, suspended sediment and water chemistry measurements at three of the streams entering the west side of Cunningham Inlet.

Salinity and temperature measurements collected in late June indicated the fresh snow meltwaters only modified the water column to a depth of 2. 0 m. Water temperatures varied from 0°C at the surface to -1. 8°C on the inlet floor. As the spring melt progressed and the streams flowing into the inlet reached flood stage, July 6 to 9, the larger freshwater input modified the sea water to depth of up to 7. 0 m. Sea water temperatures varied from +1. 0°C at the surface to -1. 5°C at the sea bed. By July 30 the surface sea water temperatures averaged +6°C and the bottom water temperatures ranged from +2° to +4°C. The final set of

Figure 2a

The raised beach coastline west of Cunningham Inlet, Somerset Island.

Figure 2b

The tundra pond environment, north-western Somerset Island.

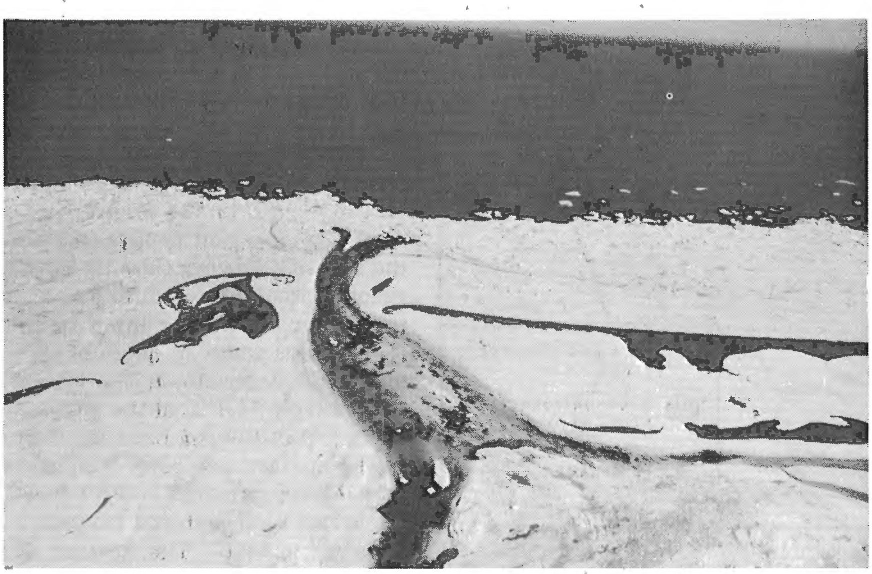

Figure 2c

Barrier Islands and main tidal inlet, west of Garnier Bay, Somerset Island.

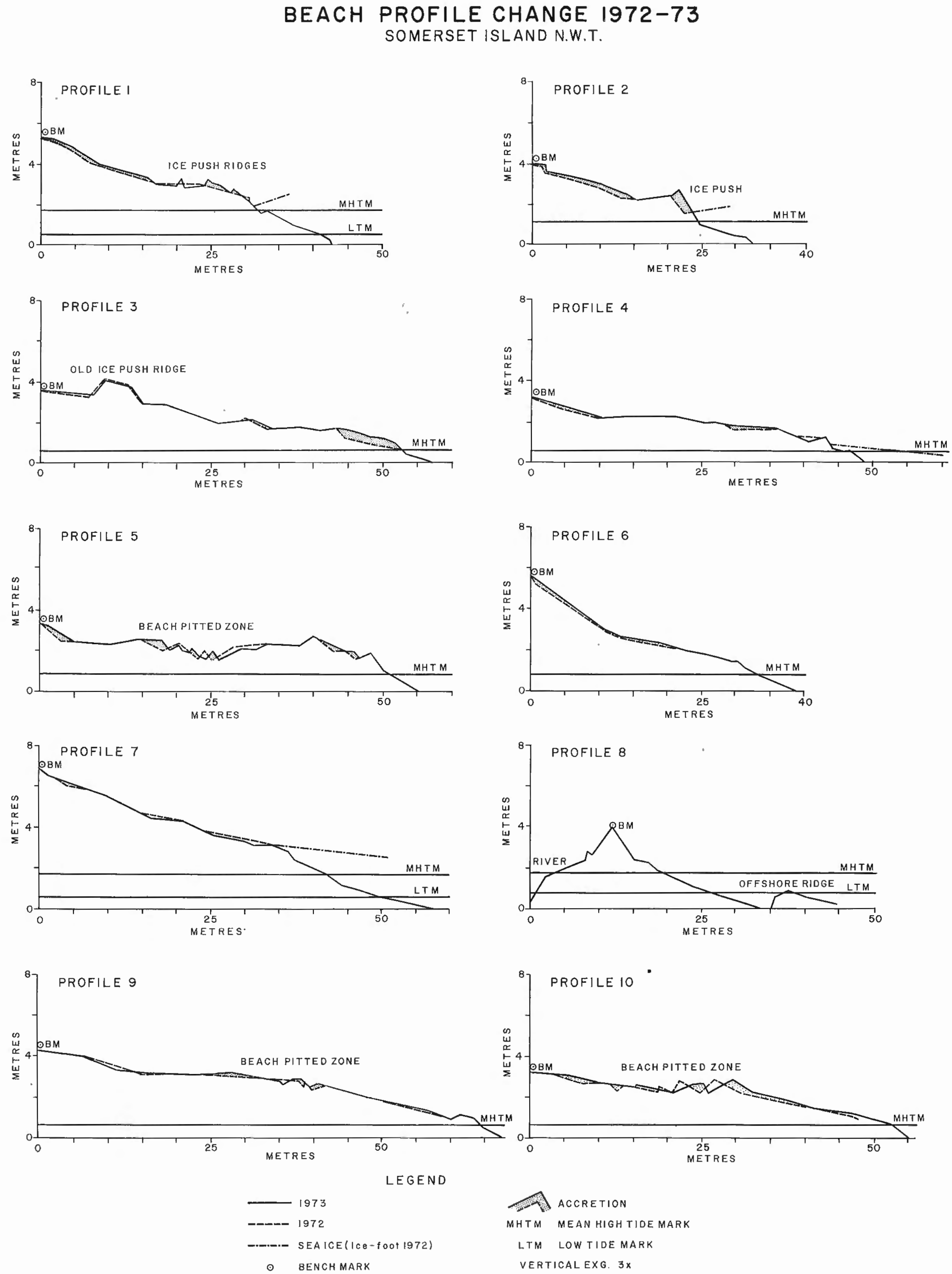

Figure 3. Change in beach profile between July 1972 and August 1973 at one area along the north Somerset coast.

salinity and temperature readings obtained on September 13 showed constant salinity values of 23 to 25 $^{o}/oo$ with depth. Water temperatures had decreased to $0^{o}C$ which reflected the cold air temperatures experienced in early September and the greater influx of sea ice into the inlet at that time.

Also included in the estuarine study were tidal current measurements which were collected using drogues with vanes set to various water depths.

Geological and hydrographic research both within Cunningham Inlet and the waters immediately offshore was completed in support of this project with the use of the barge from the *C.S.S. Hudson*. This research was conducted by C.F.M. Lewis (Project 730031 *see* this publication, report 138) and J. Hunter.

Bathurst Island and Lowther Island

Similar research to that conducted on Somerset Island was initiated on Bathurst and Lowther islands in early August. An aerial reconnaissance was made by helicopter of the entire south coast of Bathurst Island and the smaller offshore islands. In addition, profiles established in 1972 by the author at Hooker Bay, west Bathurst (Taylor, 1973a) were reprofiled to obtain the rate in beach profile change over the two-year period. New beach profiles were established along the southeast coast of Bathurst particularly around Cape Capel, where nearshore bathymetry was also obtained.

The author acknowledges with thanks the invaluable assistance given to him during the 1974 field season by D. Fisher, R. Wahlgren, R. Featherstone and B. Cooper.

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138.

NEARSHORE MARINE GEOLOGICAL RECONNAISSANCE AT CUNNINGHAM INLET, SOMERSET ISLAND, N.W.T.

Projects 730031 and 730021

R. B. Taylor and C. F. M. Lewis
Terrain Sciences Division

A geological reconnaissance of the sea bed at the mouth of Cunningham Inlet (Fig. 1) was carried out from August 16 to 27 using the 'Hudson Barge' which had been transported to Cunningham Inlet by the *C. S. S. Hudson*. The barge is a 31-foot land craft, constructed of aluminum and weighing 8 tons. It had been specially refitted and equipped just prior to the *C. S. S. Hudson's* 1974 Arctic Cruise for marine research in coastal waters by the Bedford Institute of Oceanography and Atlantic Geoscience Centre. Sediment grab samples, gravity cores, echo sounding, and side scan sonar records were collected in support of the beach and nearshore studies (Project 730021) which also were being carried out along the north shore of Somerset Island. The survey vessel also carried a 300 joule sparker reflection seismic system, which unfortunately suffered recorder malfunction during the period of work in Cunningham Inlet. Shallow seismic refraction profiles were run by J. A Hunter of Resource Geophysics and Geochemistry Division to provide estimates of thickness of unconsolidated marine deposits and to test for the presence of frozen ground. A 19-foot pneumatic boat provided an effective auxiliary platform for many of the data collection operations. Horizontal control for the offshore work was provided by a trisponder system, rented from ComDev Marine Ltd., which consisted of a master read-out unit on board the barge providing distances from two remote units (Fig. 1) located at known positions on shore.

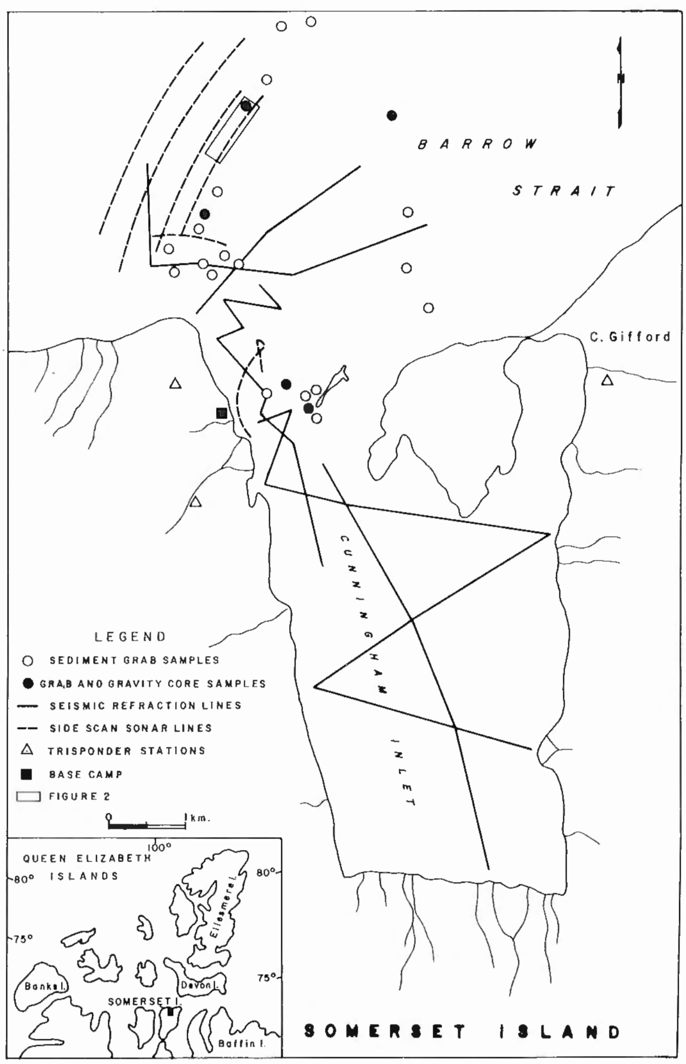

Figure 1. Location and types of marine research at Cunningham Inlet, Somerset Island.

Bathymetric information at the mouth of Cunningham Inlet is very sparse. Boat transects in this area indicated shallow waters of 2 to 3 m depth extend to 1.0 km offshore whereupon the sea bed drops steeply to depths of over 35.0 m. The seaward edge of this nearshore platform commonly was outlined by grounded sea ice. A well developed estuarine channel was absent between the tombolo and the small island at the entrance to the Inlet, but between the latter and the western shore of Cunningham Inlet a major, partially divided channel of 6.0 to 7.0 m depth was observed. A large shoal was found to extend 1.4 km offshore of the western headland of the inlet. The sea bed slope was gradual on the western side of the shoal but much steeper on the northern and eastern sides.

Using a Shipek grab sampler and an Alpine gravity cover it was observed that the nearshore bottom was primarily bedrock covered by a thin veneer of beach gravels with scattered pockets of cobbles and boulders. In the estuarine channel, particularly adjacent to the western shore of the small island, a very putrid-smelling, dark grey mud of fine sand and silt was sampled. The latter sediment grab samples substantiated the seismic refraction results which had indicated the presence of a low velocity sediment body in the estuarine channel. A thick layer of mobile beach gravels together with pockets of a hard compacted grey silt covered the large shoal, while further offshore below depths of 50.0 m one observed an undisturbed cobble sea bed with only traces of sand and shell fragments.

Visual observations of the sea bed to 10 m depth plus the collection of side scan sonar records have led to the conclusion that although well developed ice-scoured grooves are present on and to the west of the above mentioned shoal (Fig. 2) much of the scour observed from the air is merely the removal of kelp from the hard sea bed by sea-ice movement. A dense

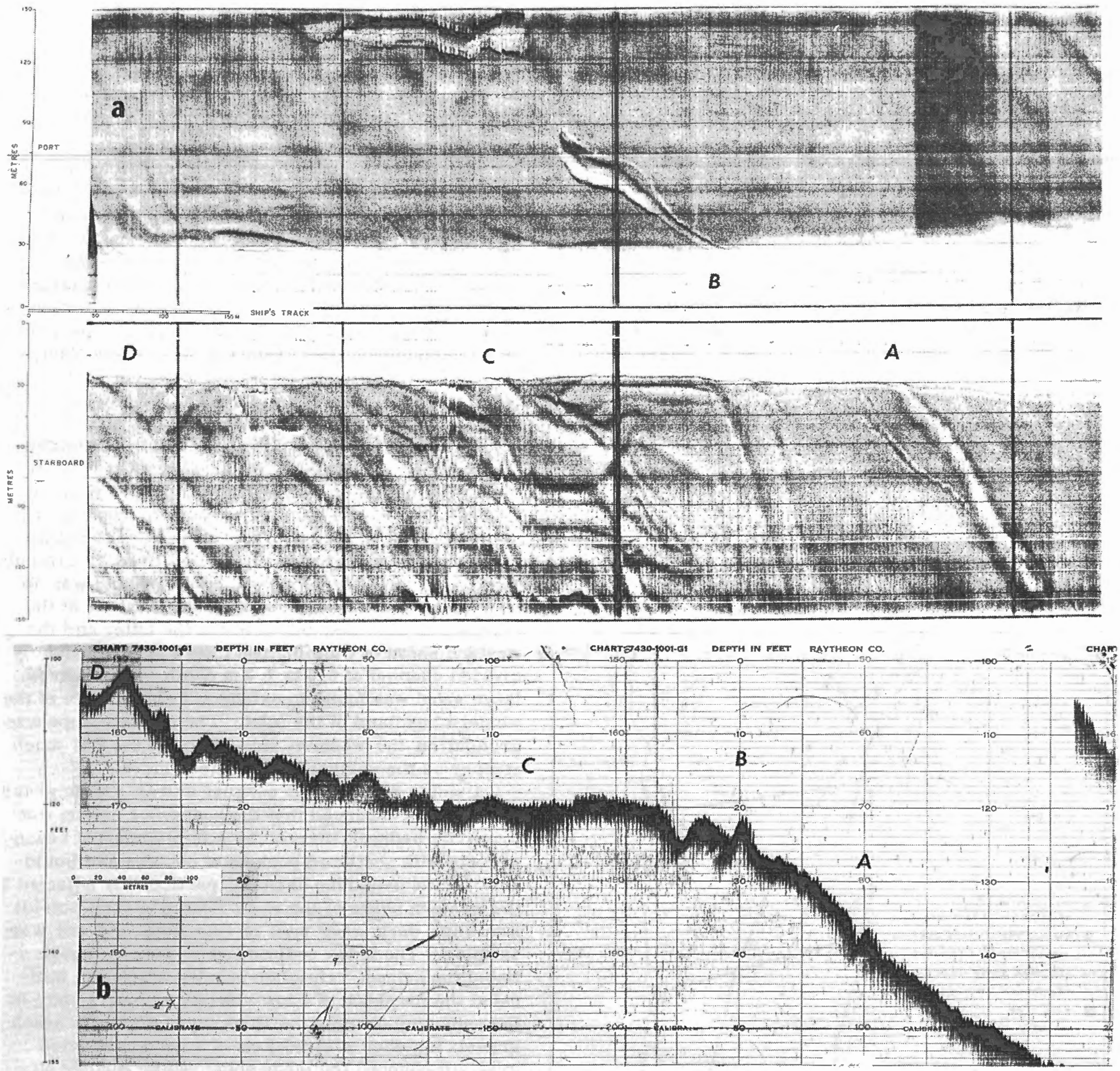

Figure 2. Corresponding side scan sonar record (a) and echogram (b) of the sea bed in 100 to 150 feet (30 to 45 m) of water near the entrance to Cunningham Inlet (*see* Fig. 1). Ice scours at A and B have penetrated the sea bed to depths of about 4 and 3 feet (1.2 and 0.9 m) respectively. Between C and D the starboard channel of side scan sonar record and the echogram illustrate an irregular bottom, possibly controlled by bedrock outcrop. A Klein side scan sonar produced record (a); echogram (b) was obtained from a Raytheon DE719B fathometer.

cover of kelp streamers within the entrance channel to Cunningham Inlet also produced a distinct, discontinuous, streak-like pattern on the side scan records, a phenomenon which without visual observations would have been most puzzling.

The effects of grounded drift-ice were clearly visible off Cunningham Inlet headland where the sea bottom could be observed visually in water depths up to 10 m. In order of increasing severity, grounding ice may simply remove bottom-fast plant growth with little or no disturbance of bottom materials or it may contact the bottom with greater force and pressure where it rolls cobbles and boulders over the sea bottom floor and presses them into the substrate to produce a cobble 'pavement'. With greater grounding pressures the moving sea ice actually displaces the cobble veneer and scours into the grey silt sub-bottom material.

Acknowledgments

The authors gratefully acknowledge the support of the Atlantic Geoscience Centre (A. G. C.) and Bedford Institute of Oceanography in providing and servicing the landing craft 'Hudson Barge'. Much of the equipment including trisponder, sparker seismic system, and side scan sonar was kindly made available by Atlantic Geoscience Centre. We are indebted to P. Dort and R. Taylor of *C. S. S. Hudson* for handling the survey vessel and to J. A. Nielsen of Atlantic Geoscience Centre for expert assistance in technical and nautical matters.

139. MACKENZIE HIGHWAY EVALUATION

Project 740055

J.A. Heginbottom
Terrain Sciences Division

In the autumn of 1972 Terrain Sciences Division undertook to assist in assessing the impact of construction of the Mackenzie Highway on the environment of northern Canada. The assessment is being co-ordinated by a working group (the Environmental Working Group) of the interdepartmental Mackenzie Highway Committee. The guiding principle of the Mackenzie Highway Project is "that the highway can be developed in accordance with good engineering practice and with a minimum of environmental damage." Thus the Geological Survey project has as its goal, in contributing to the assessment, the task of ensuring that all geotechnical matters which affect the routing, design, construction, maintenance, and stability of the highway are fully considered.

The Mackenzie Highway (Fig. 1) is being designed by the Department of Public Works for the Department of Indian Affairs and Northern Development. The design passes through some five phases before finally being approved. These comprise route selection, route revision, preliminary design, final design, and preparation of tender documents. At each stage the documents are made available to the Environmental Working Group for review and comment. Separate submissions are made for the locations of bridges across the larger rivers and for the bridge designs. Also made available to the reviewers are copies of all the consultants' reports commissioned by the Department of Public Works as a basis for their design. These include extensive reports on the nature and distribution of surficial geologic materials along the proposed alignment, of permafrost and ground ice conditions, of hydrological and hydraulic data, of the present environmental conditions, and of the possible impacts of highway construction.

The evaluation procedure by the Environmental Working Group is as follows: each design submission with pertinent background documents is made available to the Geological Survey in Ottawa and Calgary, and to other government agencies in Ottawa, Winnipeg, Calgary, Edmonton, and Yellowknife. Within the Geological Survey the actual assessment is done largely on the basis of the knowledge and experience gained during field operations in the Mackenzie Valley. It is supported by documentary information when necessary. Specific recommendations are made for the solution of all problems or concerns identified.

The reports of the individual staff members are forwarded to co-ordinators in each Department (Energy, Mines and Resources; Environment; and Indian Affairs and Northern Development). The co-ordinators meet and prepare a consolidation of the individual assessment reports for presentation to the Environmental Working Group.

Following acceptance by the Environmental Working Group, the report with the final recommendations

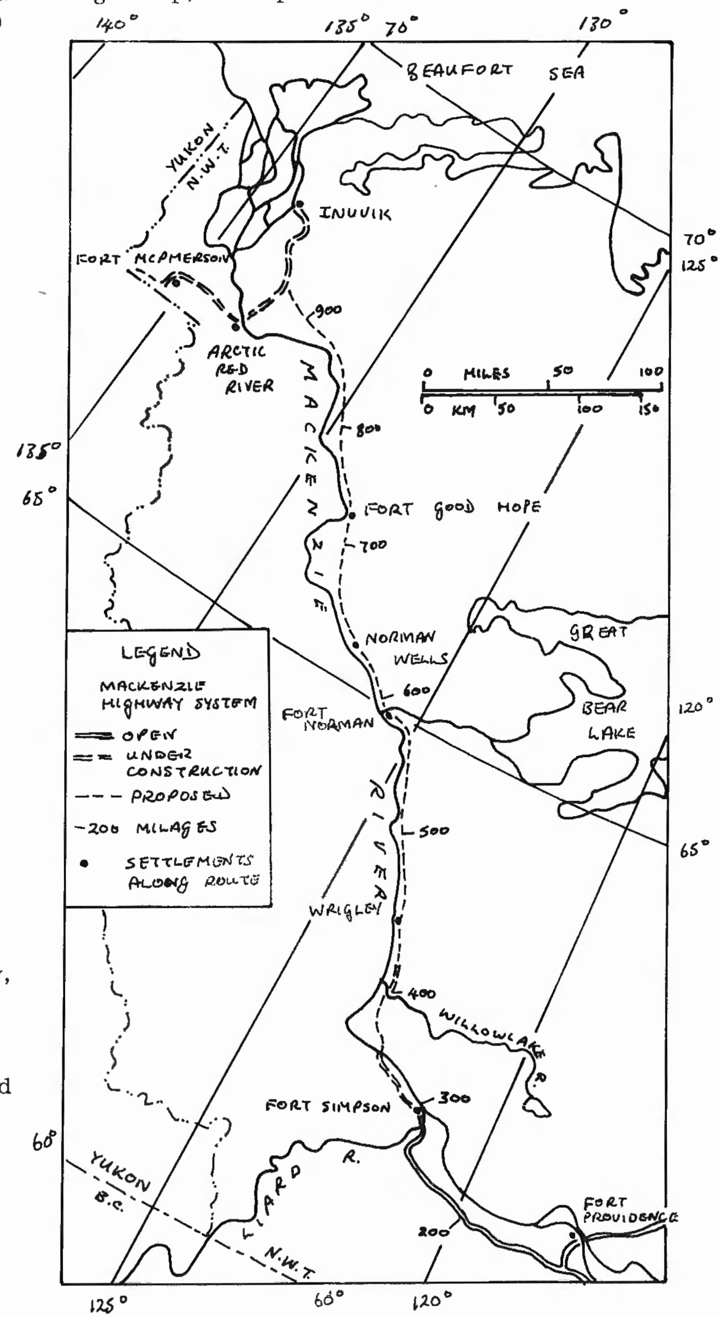

Figure 1. The Mackenzie Highway Route.

for changes and improvements is forwarded to the Mackenzie Highway Project Manager for implementation. The co-ordinators also have the responsibility for checking the completeness of the documentation submitted for review in terms of a set of standards agreed on by the Environmental Working Group, the Department of Public Works, and the Project Manager, and for reviewing the acceptability of responses to comments made on early phases of the design.

To date about 20 preliminary design packages, 10 final design packages, and 14 bridge designs have been submitted for review. As well as this, preliminary and revised alignments have been submitted for the entire highway, and numerous special reports and other documents considered.

Officers of the Geological Survey regularly concerned with reviewing design submissions are O. L. Hughes, P. J. Kurfurst, D. E. Lawrence, B. C. McDonald, and N. W. Rutter, with the author as co-ordinator.

Topics on which advice has been provided on recommendations made by the Geological Survey reviewers have included:

- general routing of highway;
- changes in alignment to avoid problem areas such as gully and stream crossings, potentially unstable slopes, organic and high ice content soil, erosion problems and other foundation problems;
- quality of geotechnical information provided by D. P. W. 's consultants;
- location, sizing, and installation of through grade culverts for the passage of overland drainage under the highway;
- sources and qualities of construction materials;
- selection of river crossing locations;
- thickness of fill in areas liable to frost heave;
- terrain disturbance in relation to operating procedures;
- erosion prevention; and
- the stability of deep cuts and high fills.

Of these comments, the most useful have probably been those concerning routing, alignment changes, and geotechnical conditions and information.

140. PROTEROZOIC STRATIGRAPHY AND SEDIMENTOLOGY, TUCHODI LAKES MAP-AREA, B.C. (94K)

Project 730057

J.D. Aitken
Institute of Sedimentary and Petroleum Geology, Calgary

The presence of logistical support (under G.C. Taylor, Project 630017) provided opportunity to acquire familiarity with the Proterozoic succession of Tuchodi Lakes map-area, previously described by Bell (1966, 1968) and Stott and Taylor (1973).

The sequence of formations tentatively assigned to the Helikian by previous workers undoubtedly has a Purcell-like aspect. Of particular interest are four formations, three of them including carbonate rocks, that give clear evidence of deposition in relatively deep water, or on subtidal depositional slopes. The deeper-water origin of these deposits was recognized by Bell (1966), but neither his published account (1968) nor that of Taylor and Stott (1973) treats environment of deposition at any length.

The finely laminated, carbonaceous siltstones of the Tetsa Formation, with abundant micro-load casts and micro-flame structures, are clearly deeper-water deposits. The presence of slumped intervals and penecontemporaneous overfolds in the lower half point to deposition on or at the foot of a depositional slope for at least a part of the formation. The base of the Tetsa is erosional, and the presence in some sections of a basal, coarse diamictite (debris flow?) suggests sudden deepening.

The George and Henry Creek formations contain numerous massive beds of limestone and dolomite with graded, diamict fabrics. The interpretation of these beds as debris flows is strengthened by their association with intervals of directed slump-folds, and points to deposition on, or at the foot of a depositional slope. The massive beds of calcareous and dolomitic mudstone that characterize the Henry Creek Formation commonly contain isolated phenoclasts; a mass-flow interpretation for these beds is thus plausible, though not conclusive. Many of the algal stromatolites of the George Formation are branching columnar types with prostrate and dependent branches. An intertidal origin for such growth forms appears impossible; they must have originated in a subtidal environment.

Thick intervals of the Aida Formation consist of a well-developed limestone-shale (slate) rhythmite that displays partial Bouma sequences. Bell's designation of the Aida as flysch is justified.

The significance of these interpretations is that the Tuchodi Lakes succession, if broadly correlative with the Purcell Supergroup as suggested by Bell (1966, 1969) and Taylor and Stott (1973), represents in part environments more basinward than does, say, the Purcell succession of the Waterton area. This must be taken into account in any speculations on the configuration of the Helikian shelf-edge and the eastward extent of the Tuchodi Lakes succession in the subsurface.

Five clusters of oriented cores were collected as a reconnaissance attempt to date the Tuchodi Lakes Proterozoic succession using the paleomagnetic method.

Table of Proterozoic Formations, Tuchodi Lakes map-area (*after* Taylor and Stott, 1973)

AGE	Formation	Predominant Lithologies	Thickness in feet
Hadrynian	Unnamed	Mainly phyllite	4,000+
	Gataga	Slaty mudstone and siltstone; thin graded sandstones	4,500+
	Aida	Calcareous and dolomitic mudstone and siltstone; minor sandstone and limestone	3,470-7,100
	Tuchodi	Quartzite, dolomite, siltstone, mudstone	5,000+
	Henry Creek	Slaty calcareous mudstone; minor limestone, sandstone	700-1,500
HELIKIAN	George	Limestone, dolomite; minor sandstone, siltstone and mudstone	1,170-1,750
	Tetsa	Laminated, carbonaceous siltstone and shale; minor quartzite	1,030
	Chischa	Dolomite, quartzite	3,100

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STRATIGRAPHIC AND STRUCTURAL STUDIES, CENTRAL ELLESMERE ISLAND AND EASTERN AXEL HEIBERG ISLAND, DISTRICT OF FRANKLIN

Project 710003

H. R. Balkwill and R. M. Bustin,
Institute of Sedimentary and Petroleum Geology, Calgary

During the month of July, stratigraphic and structural studies of Mesozoic and Tertiary rocks on central Ellesmere Island and eastern Axel Heiberg Island were conducted from a base camp at Eureka, Ellesmere Island. (Original plans called for a two-week reconnaissance of Mesozoic rocks in the western part of the Sverdrup Basin, particularly at Mackenzie King Island and environs, but these plans were abandoned because of the presence of unseasonably widespread and deep snow.) Also, support was provided for stratigraphic studies by K. J. Roy, D. G. Wilson, W. S. Hopkins, G. R. Davies, and W. W. Nassichuk, and for Dr. E. Kemper, Federal Geological Survey, Hanover, Germany, who collected macrofossils from the upper part of the Deer Bay Formation for an on-going study with J. A. Jeletzky, of Early Cretaceous taxa and biostratigraphic zonation.

Some significant stratigraphic data are summarized in the following paragraphs and figures.

Cretaceous Section at Strathcona Fiord, Ellesmere Island

Southeasternmost exposures of Cretaceous rocks in the Sverdrup Basin near Strathcona Fiord (*see* Thorsteinsson, 1972); the section presented in Figure 1 was measured at latitude 78°33', longitude 82°57'. Cretaceous formations at that locality can be compared and contrasted with equivalent rocks in the central part of the Sverdrup Basin in the following ways:

1. The Isachsen Formation is very thin;
2. Shale, composing the lower part of the Christopher Formation, is very sandy, and is gradational upward from Isachsen Formation sandstone;
3. The Hassel Formation is very thin;
4. An interval in the middle of the Kanguk Formation is sandy, but most of that formation has the distinctively black, soft, jarositic aspect that characterizes Upper Cretaceous shales throughout the Canadian Arctic.

Eureka Sound Formation near Blacktop Mountain, Ellesmere Island

A thick, fairly well exposed section of the Eureka Sound Formation was measured at latitude 79°58', longitude 85°05' (*see* Thorsteinsson, 1971a). There are two noteworthy aspects: the succession is very thick (about 3,250 m); and it is composed dominantly of fine- to medium-grained, mature quartz sandstone, lacking significant amounts of lithic clasts or coarse fractions. The Eureka Sound strata at this locality seem to be part of a formerly widespread, very thick wedge of clastic rocks, derived from distant, regional uplift, rather than syntectonic products of local uplift.

'Beaufort Formation' west of Gibs Fiord, Axel Heiberg Island

The presence of faulted Tertiary cobble-conglomerates in eastern Axel Heiberg Island was reported by Tozer (1963, p. 31; 1970, p. 584; also Thorsteinsson, 1971b). Tozer assigned these rocks to the Eureka Sound Formation, but noted that the rocks are unlike the typically fine-grained Eureka Sound arenites (compare with Fig. 2), and suggested that the conglomerates might be part of a younger, distinct succession. A section measured at latitude 79°53', longitude 88°15' (Fig. 3) produced clear evidence to support Tozer's suggestion.

Clast-size distribution and indicators of transport show that the conglomerates are syntectonic deposits, shed eastward during uplift of adjacent Princess Margaret Arch, a structure that extends northward through much of Axel Heiberg Island. Clasts in the lower part of the succession are sandstone and siltstone; gabbro clasts are increasingly abundant in the middle and upper parts of the succession. This marks progressive erosion from young, stratigraphically high, Mesozoic intervals, lacking abundant gabbro dykes and sills, to deeper levels in which mafic intrusive rocks are thick and widespread and thus provided an important source for large clasts. Well-preserved spruce cones (*Picea banksii*: identified by L. V. Hills, University of Calgary) were collected from the upper part of the succession (Fig. 3). Thus, the rocks are at least partly Miocene, and at least partly coeval with the Beaufort Formation, a widespread interval of terrigenous clastic rocks on the Arctic Coastal Plain (Hills and Fyles, 1973). Palynological and sedimentological studies, in progress, may indicate whether any of the lower part of this succession is equivalent to the Eureka Sound Formation near Blacktop Mountain (Fig. 2).

The conglomerates are products of significant uplift, and are faulted. As a first-order conclusion, it is evident that Neogene tectonism was more significant and widespread in the eastern part of the Sverdrup Basin than previously known.

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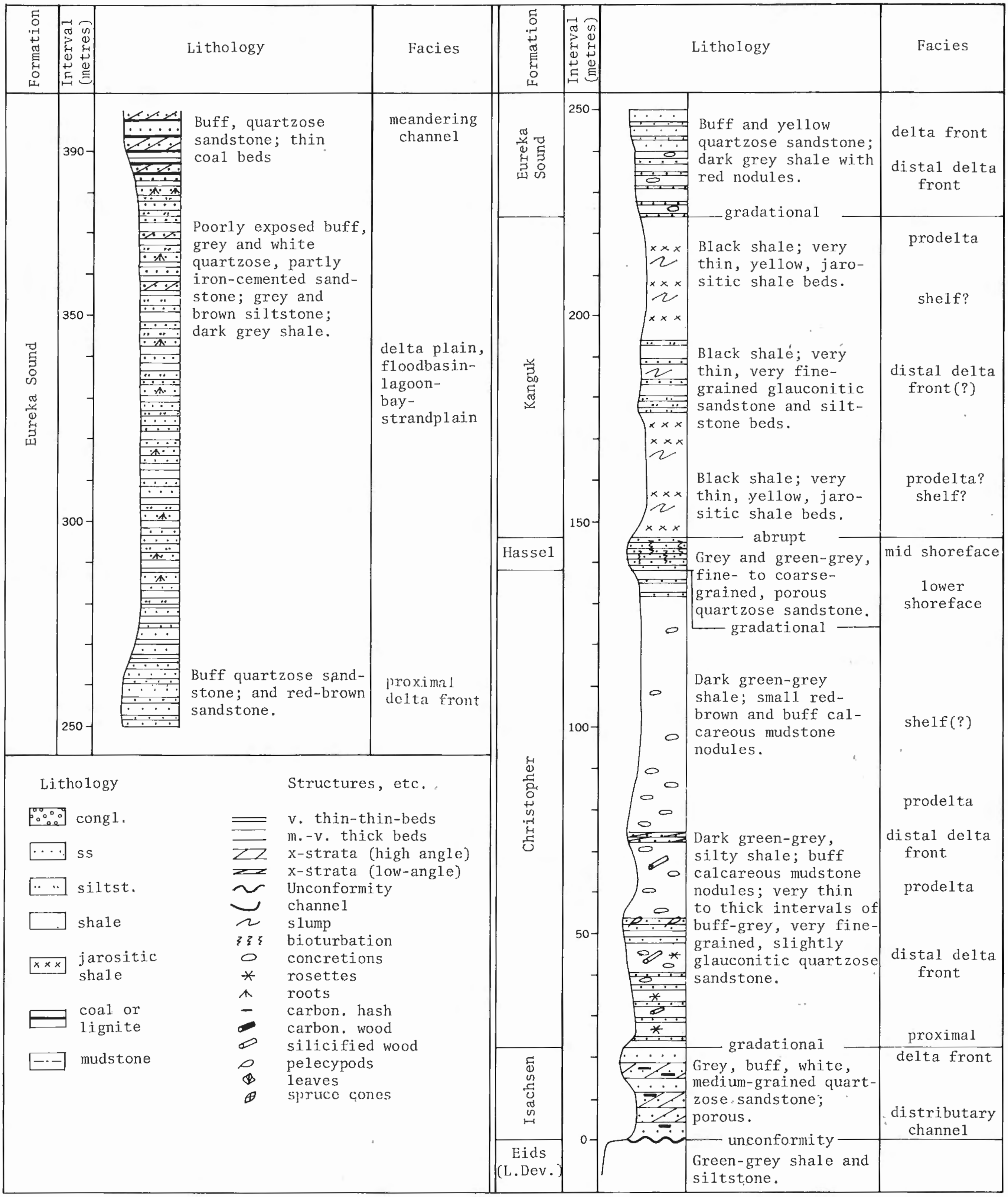

Figure 1. Cretaceous section near Strathcona Fiord, latitude 78°33', longitude 82°57'.

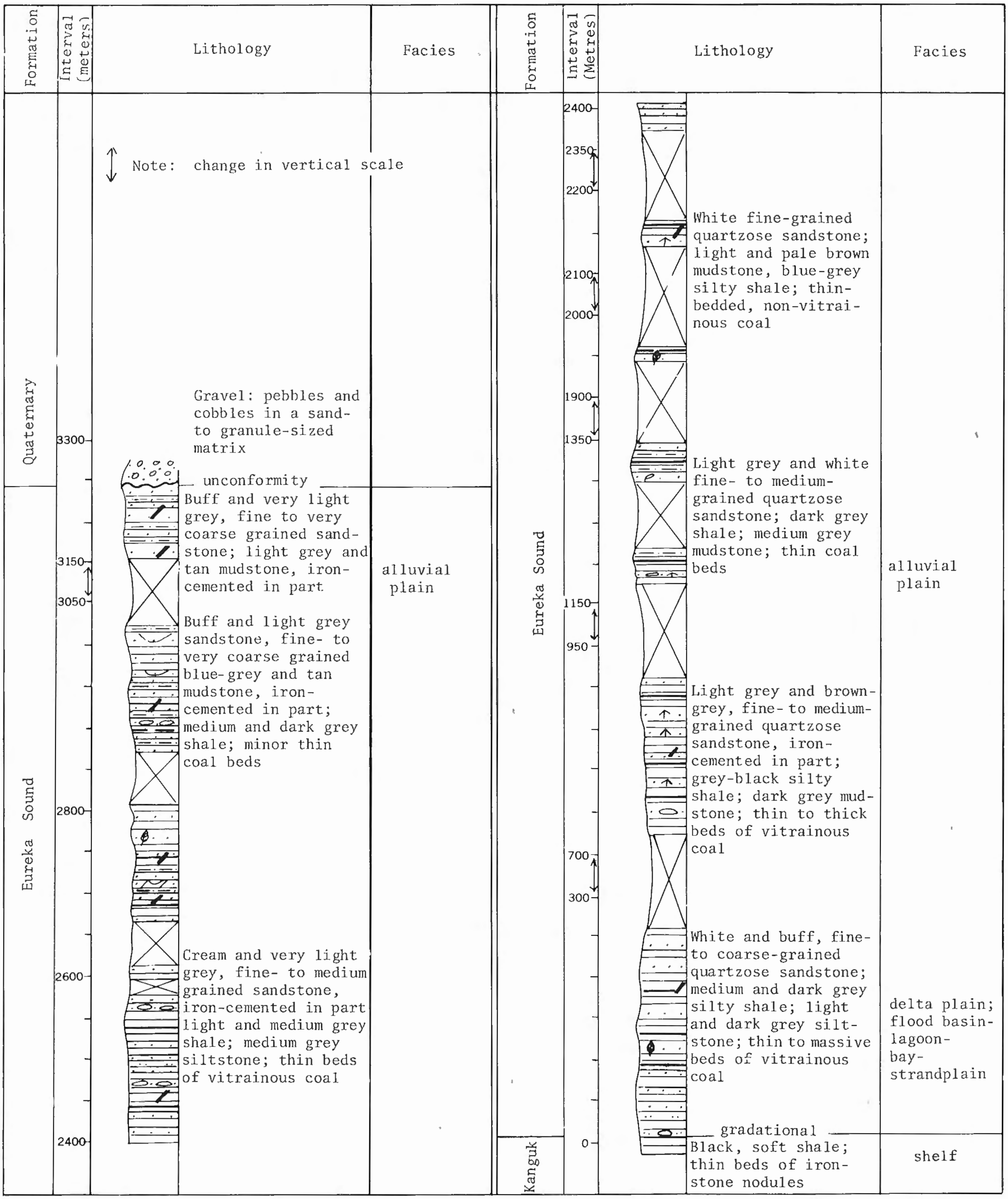

Figure 2. Eureka Sound Formation at latitude 79°58', longitude 85°05'.

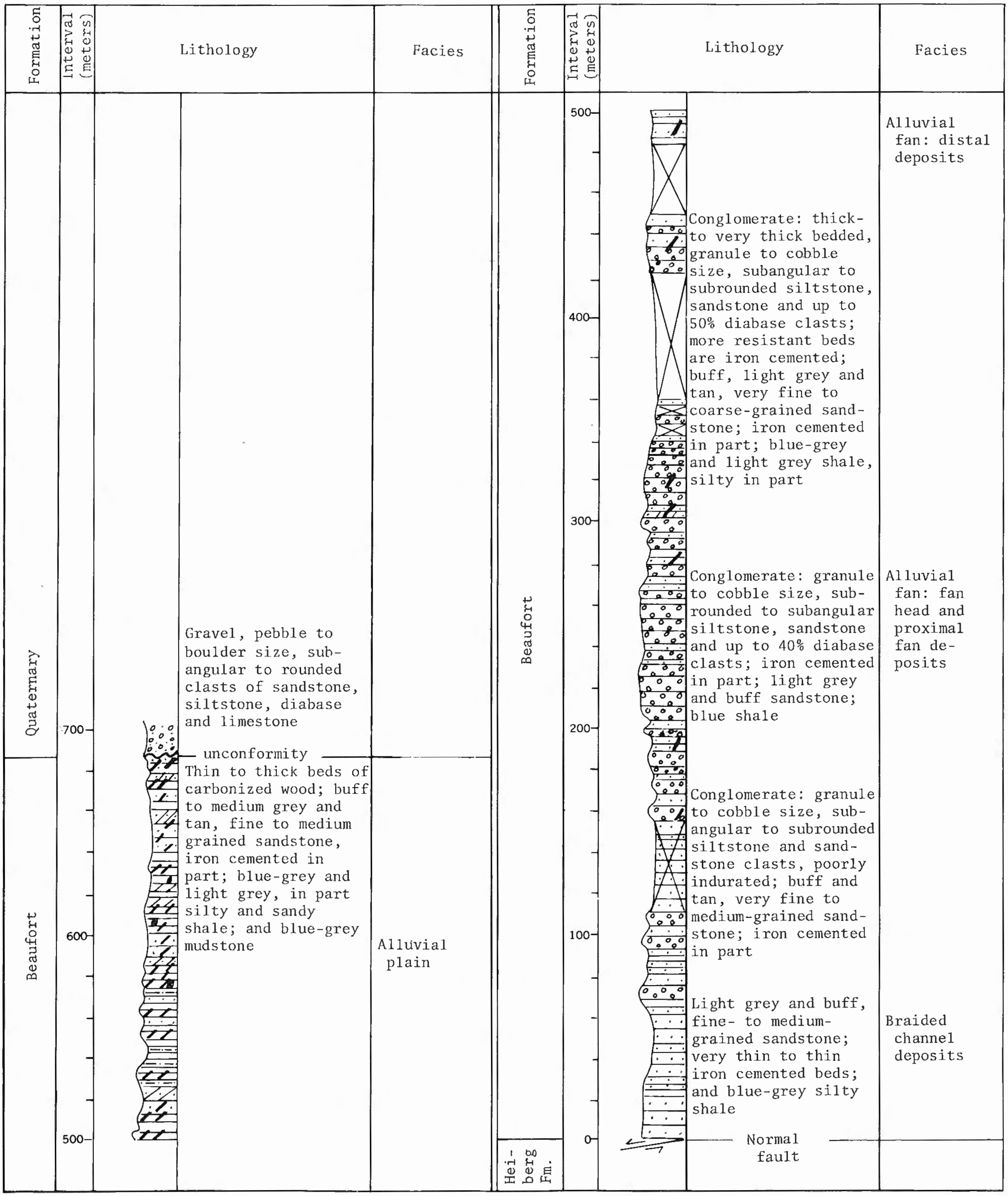

Figure 3. 'Beaufort Formation' at latitude 79°53', longitude 88°15'.

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1971b: Strand Fiord, District of Franklin; Geol. Surv. Can., Map 1301A.

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GEOLOGY OF THE CENTRAL PART OF ANTICOSTI ISLAND, QUEBEC

Projects 720072, 740084

M.J. Copeland[1] and T.E. Bolton

Since publication of 1969 field investigations of Anticosti Island (Bolton, 1972; Copeland, 1974), several access roads have been constructed in the MacDonald-Jupiter rivers and Vauréal-Salmon-Shallop rivers areas. Field work in July, 1974, defined the rock succession in this central part of the island and preliminary determinations were begun of characteristic mega- and microfaunal assemblages for each unit recognized. O.A. Dixon, University of Ottawa, accompanied the field party in an independent capacity and continued detailed study of bioherms in the Ellis Bay Formation (Dixon, 1974).

The Ordovician and Silurian rock units and geological boundaries recognized in this region as a result of the summer's field investigation are shown on Figures 1 and 2. Some of their more salient lithological and paleontological characteristics are included.

ORDOVICIAN (Upper)

Vauréal Formation (map-unit 1)

The upper 100 feet of the Vauréal Formation throughout the western half of the island consists of thin-bedded, fine-grained to granular limestone with abundant intraformational limestone conglomerate, and some lenses or thin interbeds of dense to semilithographic limestone, with greenish shale partings. In the central area, the shale content increases in the upper 60 feet of the formation exposed along the east bank of Observation River (Bolton, 1972, Fig. 5), Vauréal River canyon and lower reaches of Salmon River. The coastal section around Salmon River mouth contains the algae *Beatricea undulata* Billings and *B. nodosa* Billings, numerous trepostome bryozoans, the conularid *Climacoconus batteryensis* (Twenhofel) and the large coiled cephalopod *Apsidoceras magnificum* (Billings). The diagnostic ostracodes *Jonesites semilunatus* (Jones) and *Monotiopleura* sp. were observed in hand samples.

Ellis Bay Formation (map-unit 2)

Six members, three (1, 3, 5) of which are highly argillaceous, can be recognized in the western exposures of this formation. Within the central area, member 1 is less distinctive than farther west; limestone beds are numerous throughout the two lower members of the formation and only a few green shale beds are present. Topotypic specimens of the recently described branched sponge *Archaeoscyphia boltoni* Rigby and Nitecki (1973) were collected from this interval. Fifteen feet of greenish brown, fossiliferous, nodular limestone and shale characteristic of member 3 is present upriver from Vauréal River falls, but the unit is not as distinctive to the east along Salmon River. Green, nodular limestone and shale of member 5 is present along both rivers, but the characteristic gastropod *Hormotoma gigantea* Billings and ostracode *Tetradella anticostiensis* Copeland are only sparingly present in the eastern exposures along Salmon River and Salmon River road. On Vauréal River, bioherms with 'inter-reef' sandstone are present in members 4 and 6; only the latter member contains biohermal stromatoporoid and coral (*Calapoecia, Catenipora, Cyathophylloides, Palaeofavosites, Palaeophyllum, Propora*) accumulations on MacDonald-Jupiter Rivers road to the west and Salmon River to the east. Small colonies of the algae *Solenopora* are most abundant in the member 4 bioherm.

SILURIAN (Lower and Middle)

Becscie Formation (map-unit 3)

The road from 4 miles southeast of Vauréal River falls to Salmon River falls exposes the normal dense to granular limestone and dolomitic limestone with abundant intraformational conglomerate of the lower Becscie Formation. Corals (*Palaeofavosites* sp.) and Bryozoa (*Phaenopora superba* (Billings)) are present at numerous localities. The brachiopod *Virgiana barrandei* (Billings) occurs within the lower 50 feet of the formation near the contact of the Ellis Bay and Becscie formations at both ends of the road exposures and is also present in the same stratigraphic interval on the MacDonald-Jupiter rivers road. Fossiliferous, brown, sandy clay of the upper Becscie Formation is exposed on the Salmon-Shallop rivers road about 2 miles south of Salmon River bridge. This unit is more shaly and contains numerous corals where it occurs on the MacDonald-Jupiter rivers road in the valley of a small stream draining Lake Smith. The uppermost blue-grey, very fossiliferous shale unit of the Becscie Formation is exposed a short distance east of where the road meets Shallop River, and contains the brachiopod '*Camarotoechia*' *fringilla* (Billings), numerous corals and presently undetermined ostracodes.

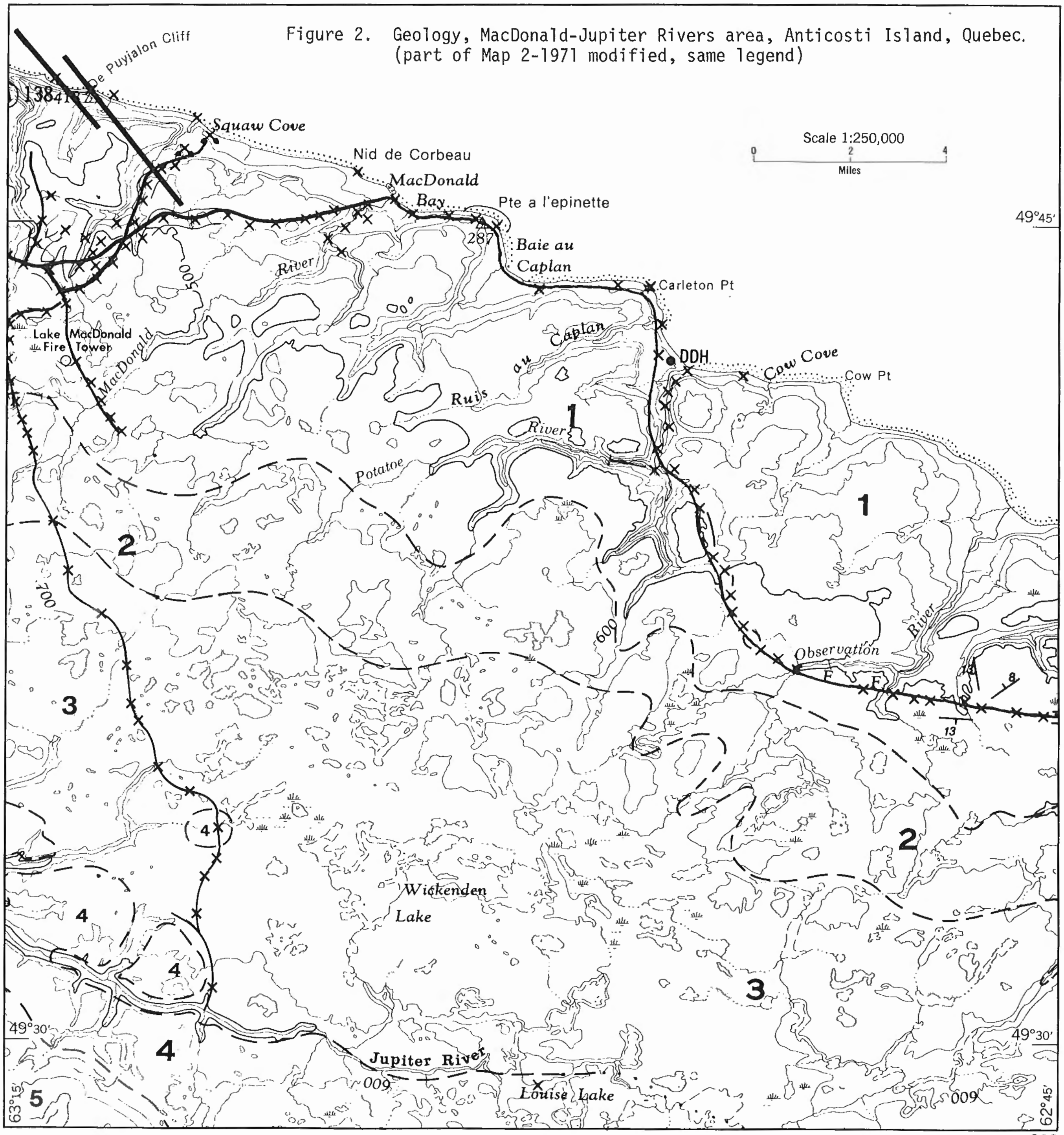
Gun River Formation (map-unit 4)

Basal limestone beds of the Gun River Formation, exposed where the road first passes near the Shallop River south of Salmon River, contain numerous brachiopods, cephalopods and corals. Beds of similar lithology, but less fossiliferous, occur in isolated exposures along MacDonald-Jupiter rivers road (Fig. 2). Fossiliferous lithographic limestone of the upper Gun River Formation is exposed on the Shallop River and road as shown on Figure 1. A crinoid (*Herpetocrinus* n. sp.), numerous brachiopods (atrypids, *Brachyprion*

[1]Regional and Economic Geology Division.

Figure 1.
Geology, Vauréal-Salmon-Shallop Rivers area, Anticosti Island, Quebec.
(part of Map 2-1971 modified)

Figure 2. Geology, MacDonald-Jupiter Rivers area, Anticosti Island, Quebec. (part of Map 2-1971 modified, same legend)



sp., '*Zygospira*' sp.), corals (heliolitids), gastropods, alga (*Cyclocrinites* sp.), trilobites (*Encrinurus* sp.) and ostracodes (*Bolbineossia* (*Brevibolbineossia*) sp., *Conbathella* spp.) were obtained from these beds. To the south, the river enters a broad valley where no rock is exposed, and as a result, the contact of the Gun River Formation and overlying Jupiter Formation was not observed. Strata of the lower Jupiter Formation were surveyed in 1966 along Shallop River 4 miles downstream from the end of the road. The formational contact is now considered to lie somewhat south of that shown by Bolton (1972, map 2-1971). No strata younger than that of the Gun River Formation were surveyed in the areas under discussion.

Considerations

Some lithological and paleontological variations within the Ordovician rocks are evident between western (Figure 3, column 1) and central (Figure 3, columns 2-4) Anticosti Island. Relative to the western area, shale content in central Anticosti Island increases in the upper member of the Vauréal Formation and progressively decreases in an easterly direction in the lower two to four members of the Ellis Bay Formation. Coral bioherms remain consistent throughout member 6 of the Ellis Bay Formation, and their occurrence in member 4 on Vauréal River may warrant investigation for their presence at this stratigraphic level farther west. A few sandstone beds, up to 2 feet thick, are found between the bioherms of this central area.

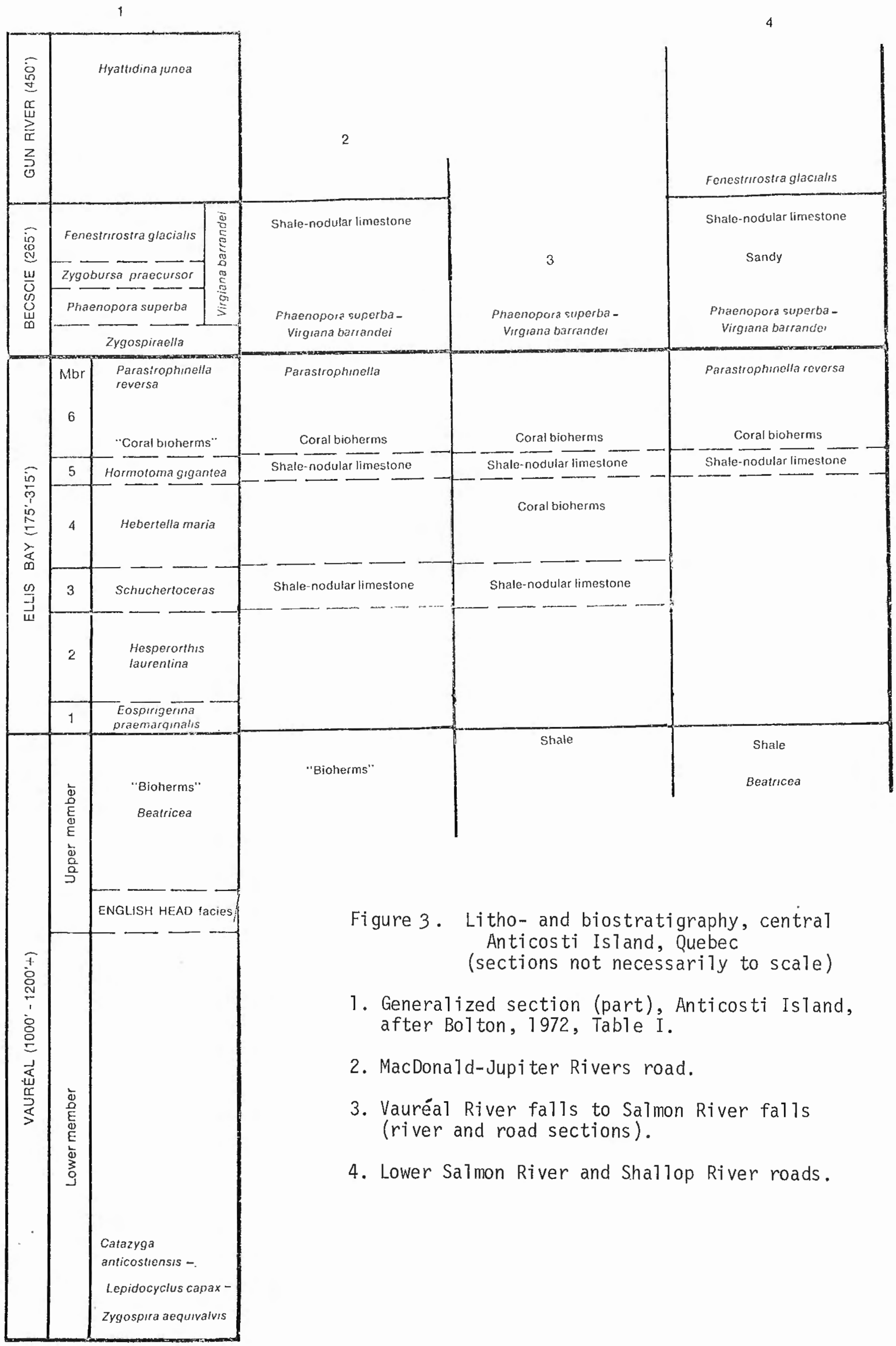


Figure 3. Litho- and biostratigraphy, central Anticosti Island, Quebec (sections not necessarily to scale)

1. Generalized section (part), Anticosti Island, after Bolton, 1972, Table I.

2. MacDonald-Jupiter Rivers road.

3. Vauréal River falls to Salmon River falls (river and road sections).

4. Lower Salmon River and Shallop River roads.

Lithofacies and faunas of Silurian rocks (Becscie and Gun River formations) remain relatively constant. *Virgiana barrandei* and *Phaenopora superba* occur in the lower limestone of the Becscie Formation in all sections and shale-nodular limestone with distinctive brachiopod and ostracode fauna marks the upper member of the formation. On Shallop River road, in fresh exposures, grey-brown sandy shale occurs at the base of the upper member. This unit was not observed elsewhere, but would weather rapidly in older exposures and might not be readily detected. Lithology and fauna of the overlying Gun River Formation is consistent in both western and central parts of the island. These strata, on Shallop River road, are somewhat more fossiliferous than elsewhere; future distinction between upper Gun River and lower Jupiter faunas in this area may prove difficult.

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143. STRUCTURAL INVESTIGATIONS IN CAMPBELL UPLIFT, DISTRICT OF MACKENZIE

Project 730054

L.D. Dyke[1]
Institute of Sedimentary and Petroleum Geology, Calgary

Introduction

Following investigations of White and Barn uplifts in northern Yukon (Dyke, 1971, 1973), the writer studied Campbell Uplift for one month during the 1974 field season. Scientific direction was provided by D.K. Norris. The furnishing of accommodation and field transportation by the Inuvik Research Laboratory is gratefully acknowledged.

The uplift is centred approximately ten miles (16 km) south of Inuvik and most of the exposure occupies an oval-shaped area, roughly 14 miles (22 km) long and 7 miles (11 km) wide, elongated in a northeast direction (*see* Fig. 1). The area is situated between the East Channel of the Mackenzie River and Campbell Lake and forms a slightly elevated terrain broken by numerous cliffs. The uplift probably occupies at least twice the area exposed but the southwestward continuation is obscured by the Mackenzie Delta. Exposures associated with the uplift occur along the east shore of Campbell Lake and as outliers to the southwest in the delta (not included on map). Glacial striae are responsible for a prominent set of north-trending lineations visible on airphotos of much of the main outcrop area.

Stratigraphic and structural traverses as well as measured sections were made to gather data for mapping at a scale of 1:50,000. In addition to structural geometry revealed by mapping, samples of the fracture fabric were taken and oriented specimens were collected for microscopic fabric study.

The uplift is most likely a surface expression of a much more extensive regional high, the northeast-trending Aklavik Arch (Norris, D.K., 1973). Though not of the abruptness of White or Barn uplifts, the structural relief expressed in Campbell Uplift is notable in view of the little deformed or undeformed character of the flanking rocks. The gently dipping flanks may result in greater trapping potential for hydrocarbons than is indicated for other uplifts within or adjacent to this sector of the Cordilleran orogenic system. The understanding of this structure may be helpful in identifying others that might be encountered by the drill under Mackenzie Delta.

Stratigraphic Setting

Campbell Uplift and the structural trend on which it lies separates the Mesozoic clastic accumulation of lower Mackenzie Delta and Kugaluk Homocline from a predominantly Paleozoic carbonate and clastic succession to the southeast. The uplift exposes the Paleozoic carbonates which occur in the subsurface to the southeast and probably to the northwest. Mesozoic clastics occur in the southeast flank as well, but not in the thicknesses seen to the north.

The oldest rocks seen have been dated by paleomagnetism as late Precambrian (Norris and Black, 1964). Although outcrops are scarce, they appear from regional considerations to be widespread in the region of the uplift. Examination of the best exposures together with airphoto interpretation has yielded a very tentative lithologic succession as follows (stratigraphically highest unit first): light grey to reddish brown quartzite, olive-green to dark brown sandstone, dark green to brown silty argillite, followed by dark red and olive-green slaty argillite, followed by massively bedded (i.e. greater than one metre thick) light orange-grey dolomite, frequently argillaceous to slightly silty. The grain size of the carbonate portions is usually less than one millimetre and commonly microcrystalline. The isolated outcrops account for approximately 2,000 feet (600 m) of Precambrian strata but much more is undoubtedly present. Inferred stratigraphic contacts shown on the map (Fig. 1) indicate only those areas underlain by the respective lithologies; they are not necessarily stratigraphic contacts.

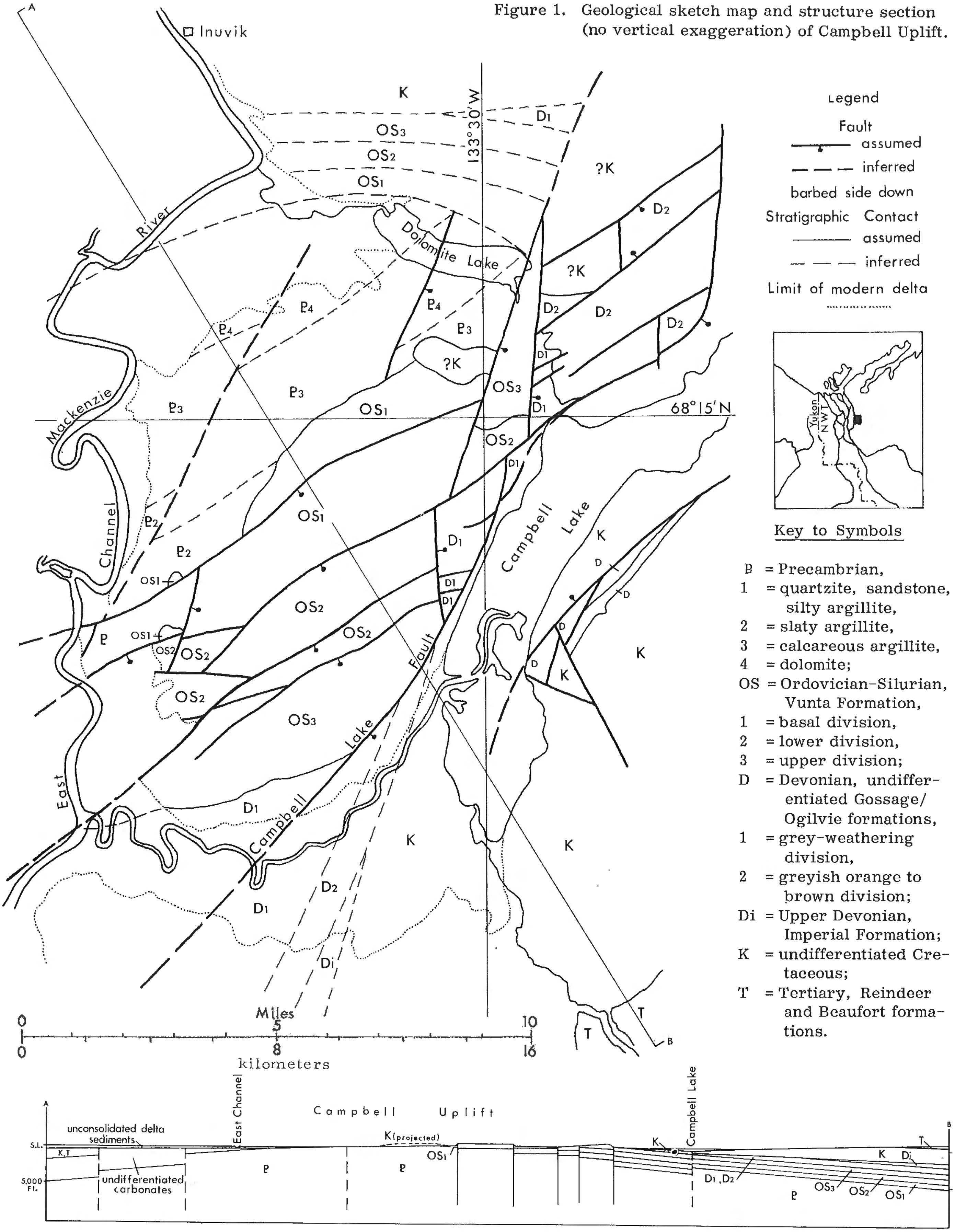
The Precambrian strata are overlain, probably with angular unconformity, by massive-bedded dolomite of probable Ordovician and Silurian age. This contact, although obscured, is mappable where mesas of light grey to greyish orange, coarsely crystalline dolomite occur in a terrain otherwise exhibiting nearby outcrops of slaty argillite. The contrast in degree of deformation between the often steeply dipping Precambrian and the nearly flat lying carbonate precludes a conformable contact. The unconformity is mapped also where similar dolomites are seen to form an irregular boundary with the area underlain by Precambrian strata. This contact is in contrast to the curvilinear nature of the common fault contacts seen on airphotos.

No complete section of the lower Paleozoic carbonate is exposed but examination of records from Amoco *et al.* Inuvik D-54 drillhole, located 2 miles (3 km) northwest of Inuvik, shows approximately 2,500 feet (750 m) primarily of dolomite overlying (Precambrian?) quartzite and slaty argillite. The distinction between the relative ages of the carbonate in the numerous fault-bounded blocks is hindered, moreover, by the lack of lithologic variation. However, a threefold division has been attempted and will be modified necessarily in the light of paleontological determinations.

The basal dolomites of the carbonate succession are identified as those interpreted to immediately overlie Precambrian strata. These are coarsely crystalline, light greyish orange dolomite occasionally con-

[1]Department of Geology, Texas A & M University, College Station, Texas 77843.

Figure 1. Geological sketch map and structure section (no vertical exaggeration) of Campbell Uplift.



taining faintly laminated, algal moundlike structures. Bedding is otherwise massive. The next two divisions are identified only as lying above the basal division and below carbonate units probably belonging to the Devonian Gossage/Ogilvie formations. The upper of these two divisions is a massive, mostly light to medium grey, coarsely crystalline dolomite, relatively resistant and mapped as being overlain by more recessive Gossage/ Ogilvie. By elimination, mostly dark grey, finely crystalline dolomites, comprising fault blocks between the upper unit and basal dolomite outcrops, are designated as the lower of the two divisions. Cuttings from the carbonate section of the Inuvik drillhole show colour changes that have influenced the subdivision. There, three divisions of roughly equal thickness can be made. A generally dark grey dolomite assigned to the Gossage/ Ogilvie Formation is underlain by light to medium grey dolomite correlated with the upper division. This in turn is underlain by more dark grey dolomite assumed to represent the lower division. Lithologies suggestive of the basal dolomite of the lower Paleozoic succession are not seen. All of the pre-Gossage/Ogilvie carbonates are tentatively correlated with the Vunta Formation of White Uplift (Norford, 1964).

Most of the carbonates assigned to the Vunta Formation are very likely Ordovician to Silurian in age although Cambrian may be present in the lowermost levels. At the southern end of the main outcrop area, Silurian fossils have been found in the uppermost beds interpreted to be Vunta. The closest exposed counterpart of this carbonate succession occurs at White Uplift in Richardson Mountains, 80 miles (130 km) to the southwest. There, the section Vunta through Ogilvie is well exposed, the total thickness being approximately 6,500 feet (2,000 m) (Norford, idem.). Fossil control yielded probable Early Ordovician to probable Late Silurian ages for the Vunta Formation and Cambrian sub-Vunta carbonate strata have been identified (Fritz, 1973). Dolomite intersected in the Richfield *et al.* Point Separation No. 1 well, located at the head of Mackenzie Delta, that lies beneath strata assigned to the Gossage Formation, is correlated with the Vunta (Tassonyi, 1969).

The upper unit assigned to the Vunta Formation as well as younger carbonate strata at Campbell Uplift occasionally display zones of non-tectonic breccia of two types. Whole outcrops can be seen that consist of subrounded to rounded, very fine grained clasts occurring in a fine-grained matrix of almost the same colour. On a much smaller scale, what appears at first sight to be folds or shattered zones is more likely brecciation. These zones are very localized and the surrounding strata are always completely undeformed. Both types of breccia may be collapse features caused by the filling in of solution cavities in once unconsolidated carbonate sediments.

Probable Lower Devonian strata of the Gossage Formation and Middle Devonian strata of the Ogilvie Formation outcrop between Dolomite and Campbell lakes and along the east shore of Campbell Lake (Norris, A.W., 1967). The paleontological definition for these formations does not seem to coincide with any distinct lithologic change and for the purpose of this investigation no distinction is made between them. However, a lithologic division is made below the paleontological boundary in the area between Dolomite and Campbell lakes. There, 0.5 metre or thicker, medium to light grey weathering beds of finely crystalline dolomite and limestone are overlain by more thinly bedded, medium brownish grey to greyish orange weathering carbonates. In dolomite, possibly occurring in the lower of these two Devonian units along the west shore of Campbell Lake, a minor occurrence of disseminated sphalerite was found (latitude 68°12'N, longitude 133°31'W). Its precise location may be found on NAPL airphoto A13406-210 at the following Cartesian co-ordinates measured with respect to the centre of the photograph where the positive Y-axis corresponds to the north direction: $X = -2.58$ cm, $Y = 1.40$ cm.

Upper Devonian Imperial Formation strata are inferred to be present in the area. They are erosionally thinned and locally removed beneath Cretaceous clastic strata at the uplift (Norris, D.K., pers. comm., 1974). They are approximately 5,000 feet (1,500 m) thick in the Point Separation well (Tassonyi, 1969).

Rhythmically interbedded, dark grey, fine-grained, quartz- and chert-rich, crossbedded sandstone and fissile black shale disconformably overlie the carbonates. The sandstone commonly contains load casts (*see* Fig. 2) and occasional plant remains occur in the shales. On a major, unnamed creek entering the south end of Campbell Lake, this sequence has been dated as Aptian-Albian (Norris, D.K., in press). Very similar strata are exposed in a borrow pit (*see* Fig. 3) within a few hundred feet stratigraphically of the Devonian carbonates on the east shore of Campbell Lake.

The complete blanketing of the uplift with Cretaceous strata is confirmed by the presence of extremely weathered black shale containing abundant orange-weathering ironstone concretions near the crest of the uplift (*see* Fig. 1 and Norris, D.K., 1973, Figs. 9 and 10). The shale contains a well-preserved foraminiferal assemblage of late Early Albian age (Chamney, T.P., pers. comm., 1974). This material, forming a low hill, rests with angular unconformity on the Precambrian and overlaps the Precambrian-lower Paleozoic unconformity. Gently dipping Cretaceous rocks occur on the north flank of the uplift but their true thickness on the crest is obscured by cover. Before deposition of the Cretaceous, peneplanation of the uplift must have been essentially complete since no textural change (coarsening) is seen in the overlying rocks adjacent to the uplift. Load casts in the sandstone beds (*see* Fig. 2) on the southeast flank, moreover, show current flow in an average direction of 230° (parallel to Aklavik Arch) indicating a northeasterly source.

Immediately north of Inuvik, the undifferentiated Cretaceous clastic rocks dip beneath Upper Cretaceous Tent Island and Tertiary Reindeer Formations to form the Kugaluk Homocline (Norris, D.K., 1973). On the southeast flank, sands of the undifferentiated Reindeer and Beaufort Formations are seen to overlie unconformably the Aptian-Albian clastics (*see* Fig. 5, Norris, D.K., in press).

Figure 2. Load casts in probable Aptian-Albian sandstone from borrow pit along Dempster Highway on east side of Campbell Lake. Hammer is one foot long.

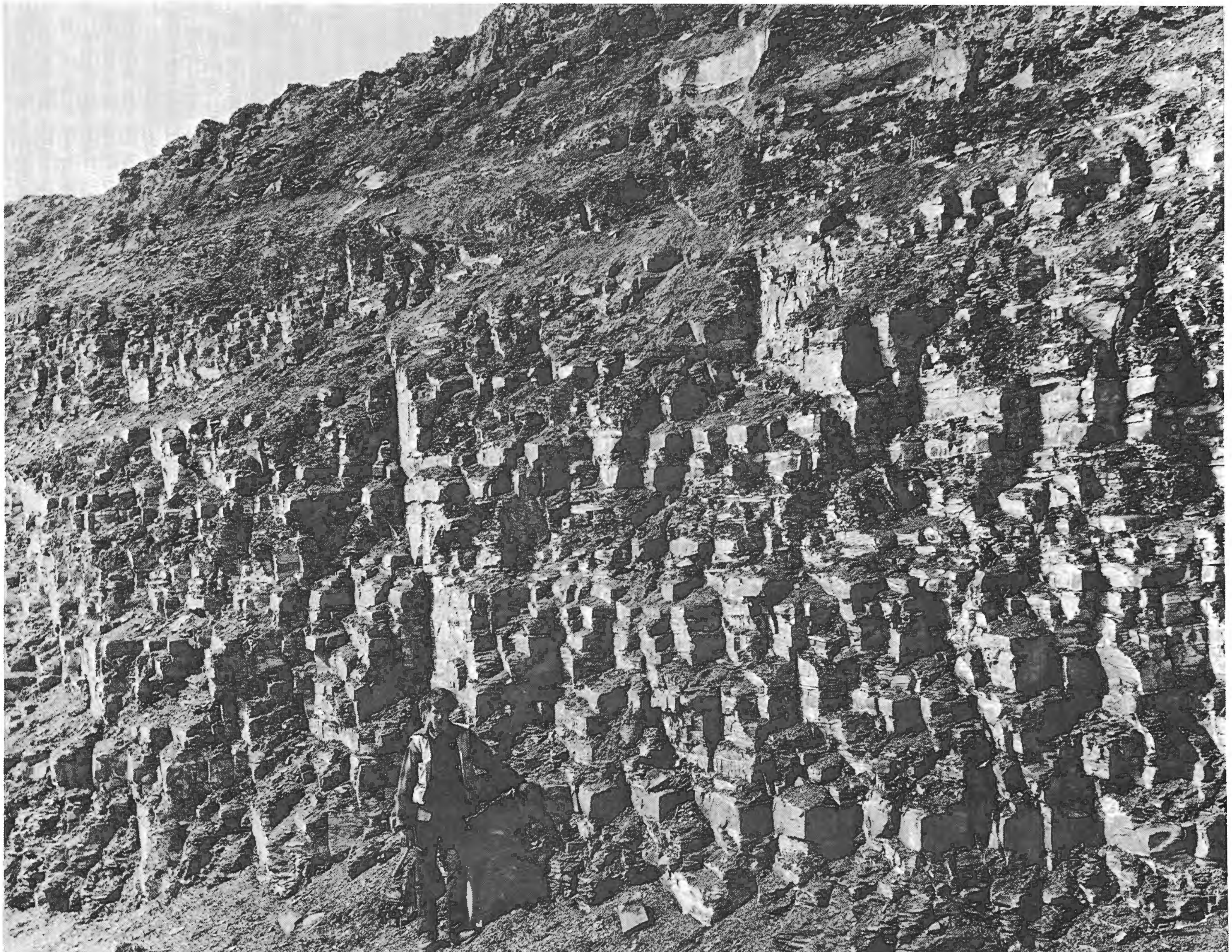


Figure 3. Well-developed fracture fabric in probable Aptian-Albian sandstone and shale in borrow pit along Dempster Highway on east side of Campbell Lake.

Structural Framework

Campbell Uplift is not a distinctly fault-bounded structure in the fashion of White and Barn uplifts. Rather, it is an elongated, dome-like feature, cut mainly by numerous, northeast-trending vertical faults and probably representing a structurally high point on Aklavik Arch. Consequently, a core, comprising a fault-bounded or partly fault-bounded package of rocks, cannot be identified. Precambrian rocks, however, outcrop in the structurally highest part of the uplift. There, at least two periods of tectonic activity can be demonstrated. The Paleozoic succession, lying unconformably on the Precambrian, dips away on all sides at a small angle, though probably more abruptly to the northwest and southeast than along the trend of the Arch. In addition to the Inuvik borehole, a shallow hole drilled by the National Research Council, 4 miles (6 km) southwest of Inuvik (Johnson and Brown, 1961) penetrated the northwest flank of the uplift. There, dolomite was encountered under a shallow veneer of unconsolidated delta sediments. In turn, both the Paleozoic and the Precambrian succession are overstepped by Cretaceous clastic strata and the Upper Devonian Imperial Formation is cut out on the flanks of the uplift.

The Precambrian strata display the most severe deformation although they do dip gently at some places. Mesoscopic kink-folding in the thinly bedded argillite accompanied by folding on a larger scale occurs at some localities, both about north- to northeast-trending axes. This deformation is almost certainly pre-Ordovician in age and likely Precambrian.

All Phanerozoic strata show only shallow dips, generally ten degrees or less. The Paleozoic succession is cut by several vertical faults that produced significant dip-slip offset. Indirect evidence exists for strike-slip offset. These faults divide the carbonates into several blocks, all of which have nearly constant bedding orientations. Two fault sets are apparent, the more prominent of which is oriented in a northeasterly direction, roughly parallel to the trend of the Aklavik Arch. The other is oriented roughly north-south, is restricted to Precambrian strata and for the most part seems to offset the major trend. The northeast-trending faults appear to drop the Paleozoics such that progressively younger strata are encountered in the fault blocks southeastward from the Precambrian core. The faults of this trend may have an average dip-slip displacement of 500-1,000 feet (150-300 m) whereas collectively the total structural relief produced by them probably amounts to 3,500-5,000 feet (900-1,500 m). Laramide doming of the uplift may very well double this. This downdropping appears to be reversed, however, by the fault bounding the Devonian exposure on the east shore of Campbell Lake. The lake is the site of a graben that is probably floored with Cretaceous strata (*see* Fig. 4).

Tectonic activity related to the Late Devonian (Ellesmerian) orogeny that was active in northern Yukon (Norris, D.K., 1973) was possibly responsible for uplift and bevelling of the rocks at the sub-Cretaceous unconformity. However, evidence for renewed activity during the Laramide orogeny is documented by the sub-Tertiary unconformity. Consequently, the uplift was originally a Paleozoic feature that was strongly rejuvenated during the Laramide.

Gentle folding is present in the Cretaceous rocks exposed along the major creek flowing into the south end of Campbell Lake. There, the fold axes appear to swing from north to northeast trends in the direction of the uplift. This suggests an influence of structural relief in the carbonates on fold orientation. Vertical movement on the faults may have produced the relief, which very likely was not present immediately prior to the Laramide, resulting in the present but eroded structural configuration. The gently folded, Cretaceous clastics are not seen to be faulted. A simple decrease in the density of faulting off the flanks of the uplift is a more probable explanation than the restriction of faulting to pre-Cretaceous strata. The northwest flank probably is faulted also. A 4,500-foot (1,350 m) depth to Precambrian strata in the Inuvik borehole forces an anomalously steep dip on the Precambrian-Paleozoic unconformity if it is interpreted as an unbroken surface. Faulting with downdropping to the northwest would appear to be present, mimicking the style of the southeast flank.

A few of the northeast-trending faults wholly in the carbonates appear to die out along strike. Similarly, the fault bounding the Devonian exposures along the east shore of Campbell Lake appears to lose stratigraphic separation northward, implying mainly dip-slip movement. Examination of individual fracture fabric samples taken from the Paleozoics commonly shows the existence of two prominent fracture sets, both perpendicular to bedding. However, when these samples are plotted to form a synoptic stereoscopic projection, a single pronounced concentration emerges, parallel to the major northeast-trending fault orientation. The individual fracture fabric samples, having two well-developed sets, suggest conjugate shear fractures with a horizontally oriented, causative maximum principal stress direction. The fact that one orientation is especially common and parallel to the major fault orientation is an indication that horizontal shear or strike-slip also may have played some part in the movement picture on these faults. The Cretaceous clastics, moreover, display a strongly developed fracture fabric (*see* Fig. 3), one component of which parallels the dominant fracture and fault orientation in the Paleozoics. This suggests that at least some movement on these faults took place during the Laramide.

The likelihood that the uplift may be considerably larger than the area exposed is suggested, in part, by the projection of several members of the major fault array southwestward. There, they still appear to be cutting lower divisions of the Paleozoic succession. However, when projected, they must be run into outliers of Devonian strata situated between five and ten miles (8-16 km) to the southwest. Because of poor outcrop, these outliers are not observed to be cut by major faults. Some of the faults possibly die out in this direction and a southwest component of dip in the Paleozoics between the main exposure and the outliers

Figure 4. View to the north from top of carbonate outlier on east side of Campbell Lake. Lake occupies graben between fault-bounded Devonian strata in distance and Devonian strata in foreground.

must then exist if higher strata are to be encountered. These outliers suggest a southwestern termination to the uplift.

The southernmost major fault is one of those projected. On the basis of scarce uppermost Lower Devonian outcrop on its southeastern side (Norris, D.K., pers. comm., 1974), a shallowly southeast-dipping succession of Devonian and Cretaceous strata is interpreted to bound its southern exposed length. Due north of this lies the area of Precambrian rocks and its hypothetical northern boundary, a shallowly north- to northwest-dipping Paleozoic flank. The boundary is interpreted to swing southwestward based partly on drill-hole data and partly on structural grain of the uplift. The main outcrop area displays some asymmetry in that fault blocks exposing progressively lower stratigraphic levels seem displaced to the northeast, i.e. older and older strata are introduced along the southeast flank as one moves northwestward. This pattern could be accomplished by several mechanisms but the simplest would be right-lateral movement on the faults of the dominant orientation if the uplift was once a simple dome.

In the extreme northeast part of the uplift, the uppermost exposed beds of the lower and middle Paleozoic succession are encountered. The exact relationship between the interpreted northwest flank and the Devonian strata of the northeast end is obscured. A fault contact between the two seems most likely, perhaps in the form of the north-trending array that separates Precambrian from the upper part of this Paleozoic assemblage.

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144. BROAD CORRELATIONS OF SOME LOWER AND MIDDLE CAMBRIAN STRATA IN THE NORTH AMERICAN CORDILLERA

Project 650024

W.H. Fritz
Regional and Economic Geology Division

During the summer of 1974 a visit was made to a number of classical Cambrian fossil localities and other outcrops in the North American Cordillera. Stratigraphic and fossil data were gathered in order to strengthen correlations and to identify regional trends. These data are placed in a correlation framework that admittedly needs testing, and will unquestionably be altered in the future. The framework is based upon a combination of a Lower Cambrian fossil zonation by Fritz (1972a), a concept of large Cambrian sedimentary cycles by Aitken (1966), and a concept of large Cambrian sedimentary belts by Palmer (1960) and by Robison (1960). Figure 1 illustrates the manner in which these three elements have been combined.

The large cycles have been named "grand cycles" by Aitken, who has defined them (1966, p. 405) as follows: "...depositional cycles..., each comprising 300 to 2,000 feet of strata and two or more fossil zones.... Each...commences at an abrupt basal contact, and consists of a lower, shaly half-cycle gradationally overlain by a carbonate half-cycle." In an illustration (p. 423) accompanying his concept, Aitken shows the limestone upper half-cycles thickening seawards much more rapidly than the shaly lower half-cycles, and the limestone half-cycles terminating abruptly against shale at their outermost (seaward) edges. Aitken's concept is based on Middle Cambrian through Lower Ordovician strata in the southern Canadian Rocky Mountains.

Aitken's cycles in Canada are in a carbonate belt which is the northern extension of what Palmer (1960) and Robison (1960) have defined as a "middle carbonate belt" in the eastern Great Basin. This belt is described as a large belt of relatively clean carbonate that is flanked on the western (seaward) side by an "outer detrital" belt of dark coloured shales and limy siltstones, and on the eastern (craton) side by an "inner detrital" belt of light coloured shales, siltstones, and sandstones.

In the following discussion, the observed strata (Figs. 2, 3) are assigned to three Lower Cambrian cycles (Fig. 1; A, B, C), and each cycle is traced from south to north. In order to bridge the great distance between the Idaho sections and sections in the Yukon and the Northwest Territories, reference is made to intermediate sections in the Mount Robson area (Fritz, 1972b) and the Cariboo Mountains (Young, 1972) in British Columbia. Strata are related to the Lower Cambrian theoretical framework shown in Figure 1 by referring stratigraphic units seen in the field to numbered positions in the figure. Only those portions of sections actually measured are presented in Figures 2 and 3. More complete sections in the various areas can be found in the literature cited.

Grand Cycle A

Lithologic Units. Strata as old as those in Lower Cambrian grand cycle A may not be present in the Proveedora Hills, Mexico or in the Marble Mountains of California (Fig. 2, nos. 1, 2), but rocks of this age

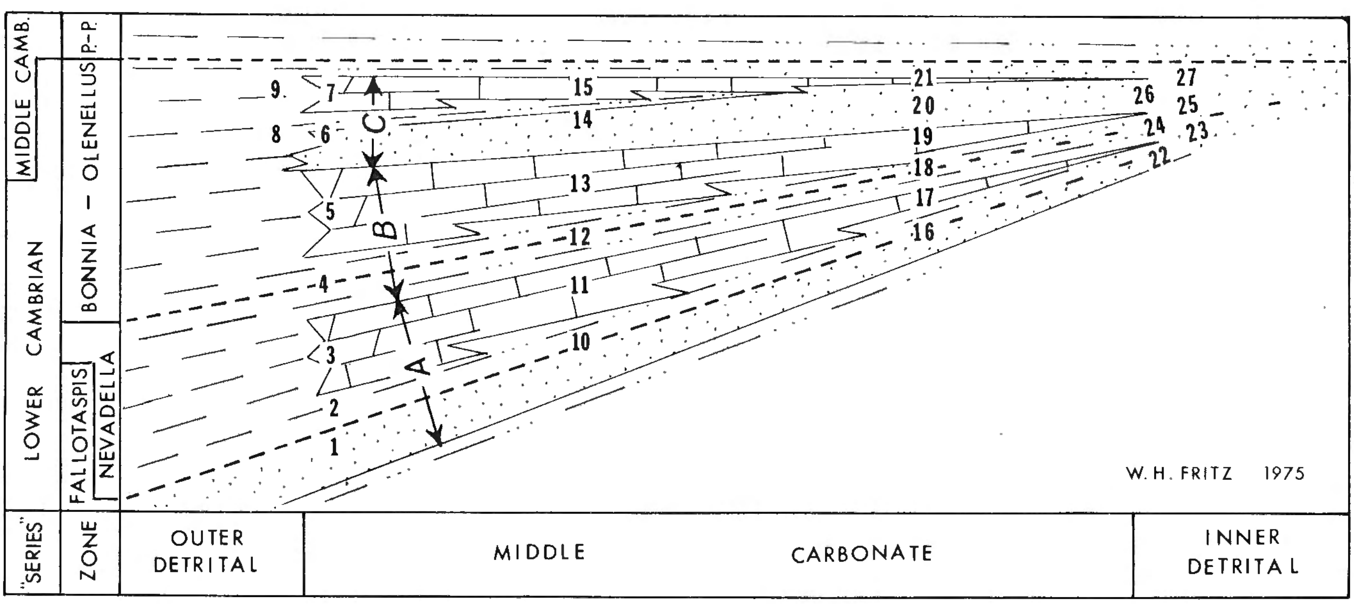


Figure 1. Theoretical model showing distribution of Lower Cambrian strata. Grand cycles are marked A, B, and C. Numbers refer to the position of strata mentioned in the text.

are well exposed in the White-Inyo Mountains of California and are partially exposed on Slate Ridge, Nevada (Fig. 2, nos. 3, 4). In the White-Inyo Mountains the lower half-cycle consists of the Andrews Mountain and Montenegro members of the Campeto Formation, and the upper half cycle consists of the lower carbonate unit of the Poleta Formation. These three units were also seen in the Weepha Hills and at Miller Mountain, Nevada, but there moderate thermal alteration and tectonic deformation have erased some of the lithologic and most of the faunal details, and no attempt was made to measure sections. Gross lithologies, however, suggest a close correlation between the cycles in the latter two areas and in the White-Inyo Mountains and Slate Ridge sections, not only for grand cycle A, but for cycles B and C. As the strata in all three units exhibit shallow water features, and as the lower carbonate of the Poleta exhibits no reef-edge lithologies, all four California and Nevada exposures are placed well within the middle carbonate belt at approximately the positions of 10 and 11 in Figure 1.

Quartzite old enough to be correlated with grand cycle A may be present in the Kasiska Quartzite Member of the Brigham Quartzite (Oriel and Armstrong, 1971) in the Portneuf Range, Idaho and in the lower portion of the Cash Creek and Clayton Mine Quartzite in the Bayhorse region, Idaho (Fig. 3, nos. 6, 7). The Kasiska is clearly Lower Cambrian or older as the second overlying member, the Sedgwick Peak Quartzite contains the Lower-Middle Cambrian boundary. Using stratigraphic position, and discounting the possibilities of major unconformities, Hobbs *et al.* (1968) have tentatively assigned the Cash Creek to the Lower Cambrian and the Clayton Mine to the Lower Ordovician. Both quartzites consist of fine to coarse quartz grains with local admixtures of feldspar that are as high as 25 per cent. There is very little argillaceous material present, and except for the local high percentage of feldspar, these formations closely resemble the Lower Cambrian Gog Quartzite of the southern Canadian Rocky Mountains and the mainly Lower Cambrian Brigham Quartzite of Idaho and Utah. The two quartzites in the Bayhorse region will be discussed later in the text. These quartzites and the Brigham Quartzite in the Portneuf Range belong to the inner detrital belt, and therefore are not readily divisible into cycles. If all three cycles have their equivalent in these quartzites, then their position in the model shown in Figure 1 would be localities 22-27.

Grand cycle A in the Mount Robson area, British Columbia (Fritz, 1972b, Fig. 1) consists of a lower half-cycle represented by the McNaughton Formation and an upper half-cycle represented by the lower carbonate member of the Mural Formation. In the Cariboo Mountains, British Columbia (Young, 1972), the lower half-cycle is the Yanks Peak and Midas formations, and the upper half-cycle is the lower carbonate member of the Mural. Cycle A at both localities is placed at 10 and 11 in Figure 1.

Near the headwaters of the Ketza River, Pelly Range, Yukon Territory (Fig. 3, no. 8), the lower half-cycle is represented by quartzite unit a and shale unit b (Wheeler *et al.*, (1960). The upper half-cycle (unit c) is partially represented by limestone and locally dolomite that laterally pass into shales and dark, thin-bedded limestone belonging to the outer detrital belt (*see* Read, this publication, report 7). This lateral transition from carbonate to shale is thought to mark the outer edge of the carbonate belt in the upper half-cycle, and therefore the complete cycle is placed at localities 1, 2 and 3 in Figure 1. The uppermost portion of unit c is represented by light greenish grey siltstone that overlies the carbonate. This siltstone is believed to belong to the lower half-cycle of grand cycle B. The relationship between the greenish grey siltstone and the expected overlying Cambrian strata is erased at the upper Ketza outcrops by a sub-Mississippian unconformity.

In the Godlin River section, Mackenzie Mountains, Northwest Territories (Fig. 3, no. 9) the lower half-cycle is represented by quartzite unit 12 and siltstone unit 13 (Blusson, 1971) and the upper half-cycle by the lower 1,190 feet of the Sekwi Formation. This portion of the Sekwi contains both dark, platy limestone with slump breccias and with interbedded shales and thick-bedded reef carbonates, and therefore the whole cycle is placed at approximately the same position (Fig. 1, nos. 1-3) as the Ketza River section.

Fossil control. Shelly fossils have not been found in the Cordillera in strata as old as those at the base of grand cycle A. Trace fossils are locally abundant near or in these strata, but an effective trace fossil zonation has yet to be established in this interval. Therefore the method for choosing the base of grand cycle A was to first estimate the position of the oldest correlatable zone boundary, the boundary between the *Fallotaspis* and *Nevadella* zones, and then place the base of the cycle at the base of the first underlying quartzite unit. The boundary between the *Fallotaspis* and *Nevadella* zones is bracketed with fossils in the White-Inyo Mountains and Godlin River section. Fossils considered to be low in the *Nevadella* Zone, and thus close to the boundary were found in the Mount Robson and Cariboo Mountains sections, and can be projected from nearby outcrops into the Ketza River section.

The top of grand cycle A is drawn at the upper contact of the light coloured, thick-bedded limestone at the top of the upper half-cycle. This contact is 100 to 300 feet below the boundary between the *Nevadella* and *Bonnia-Olenellus* zones in the White-Inyo, Slate Ridge, Mount Robson, Cariboo Mountains, and Godlin River sections. *Laudonia*? sp., an early *Bonnia-Olenellus* Zone genus is present in the greenish grey shales near the Ketza River section. This find suggests that here too the *Nevadella-Bonnia-Olenellus* zones boundary lies close above the top of the upper half-cycle.

In the Proveedora Hills, *Laudonia* sp. was collected well within a carbonate unit at the top of the Puerto Blanco Formation, which suggests that the boundary between the *Nevadella* and *Bonnia-Olenellus* zones may lie in the recessive, sandy unit below. If subsequent fossil finds prove this to be true, then the thick-bedded limestone unit representing the lowest exposures of the Puerto Blanco may be tentatively assigned to the upper half of grand cycle A.

Grand Cycle B

Lithologic Units. As just implied, recognition of this cycle is uncertain in the Proveedora Hills because of the lack of diagnostic fossils and the lack of exposed strata below the Puerto Blanco Formation. If the cycle is present, it is probably represented by the medial recessive unit (lower half-cycle) and upper limestone unit (upper half-cycle) of the Puerto Blanco Formation. Fine sandstones in the recessive unit and thin, wavy bedded limestone in the upper limestone unit suggest placing the tentatively recognized cycle at localities 18 and 19 in Figure 1.

No strata as old as these in grand cycle B are present in the Marble Mountains.

In the White-Inyo Mountains and Slate Ridge the lower half-cycle is represented by the middle unit of siltstone and shale in the Poleta Formation. Abundant shallow water features in both halves of the cycle indicate a position of approximately 12 and 13 in the model shown in Figure 1.

In the Mount Robson area and the Cariboo Range, the middle shale unit and the upper carbonate unit of the Mural Formation closely resemble the middle and upper units of the Poleta Formation, and are placed at approximately the same position in Figure 1.

It has been stated earlier that the greenish grey shale in the upper portion of unit c at the Ketza River section in the Pelly Mountains is assigned to the lower half of grand cycle B.

In the Godlin River section in the Mackenzie Mountains, the predominantly shale and siltstone unit 1,190 to 1,915 feet above the base of the Sekwi Formation is assigned to the lower half-cycle and an undesignated amount of the thin-bedded limestone in the remaining, upper portion of the Sekwi is assigned to the upper half-cycle. In a comparison of this section with ten other unpublished Sekwi sections in the Mackenzie Mountains, the writer has failed to recognize any regional clastic unit comparable to the lower half-cycle of grand cycle C, and without such a shale the upper half of grand cycle B cannot be separated from strata equivalent to overlying grand cycle C. Grand cycle B at the Godlin River section is placed at localities 12 and 13 in Figure 1.

Fossil control. It has been mentioned under grand cycle A that the boundary between the *Nevadella* and *Bonnia-Olenellus* zones lies in the interval 100 to 300 feet above the base of grand cycle B in five widely spaced sections and may occupy this position in a sixth. *Laudonia*, an early *Bonnia-Olenellus* Zone index genus is present within what may be the upper half-cycle in the Proveedora Hills (Fig. 2, no. 1, loc. marked "L"). This genus is present a short distance below the upper half-cycle at Slate Ridge, and in the middle of the lower half-cycle in the Godlin River section. Strata at the top of grand cycle B and immediately above in the lower half-cycle of C are poorly fossiliferous and therefore difficult to date. In the next range west of the White-Inyo Mountains (Last Chance Range) the writer collected *Olenellus laxoculus*? Fritz a short distance above the top of grand cycle B. In the Cariboo Range the first occurrence of *Bonnia* sp. is in the upper portion of the carbonate cycle in B. In the Godlin River section, localities near the top of the Sekwi contain *Olenellus laxoculus* Fritz, *Wanneria logani* (Walcott), and species of *Bonnia* slightly younger than those seen in the upper beds of cycle B in the Cariboo Range. These fossils suggest that strata at the top of grand cycle B and just above belong to the middle portion of the *Bonnia-Olenellus* Zone and the limestone at the top of the Sekwi is equivalent to what is elsewhere detrital strata in the lower half of grand cycle C.

Grand Cycle C

The lower half of this cycle in the Proveedora Hills consists of pink and light grey weathering quartzite of the Proveedora Formation and light brown weathering limestone of the Buelna Formation. The upper half-cycle is the dark grey weathering limestone of the Cerro Prieto Formation that contains abundant algal bodies belonging to the genus *Girvanella*.

In the Marble Mountains, the lower half-cycle overlies Precambrian granite. Most of the half-cycle consists of an unnamed quartzite, and is capped by a thin siltstone unit, the Latham Shale. The upper half-cycle is the Chambless Limestone that is similar to the Cerro Prieto in lithology and *Girvanella* content, but is somewhat thinner. The cycle at both the Proveedora Hills and Marble Mountains is placed at localities 20 and 21 in Figure 1.

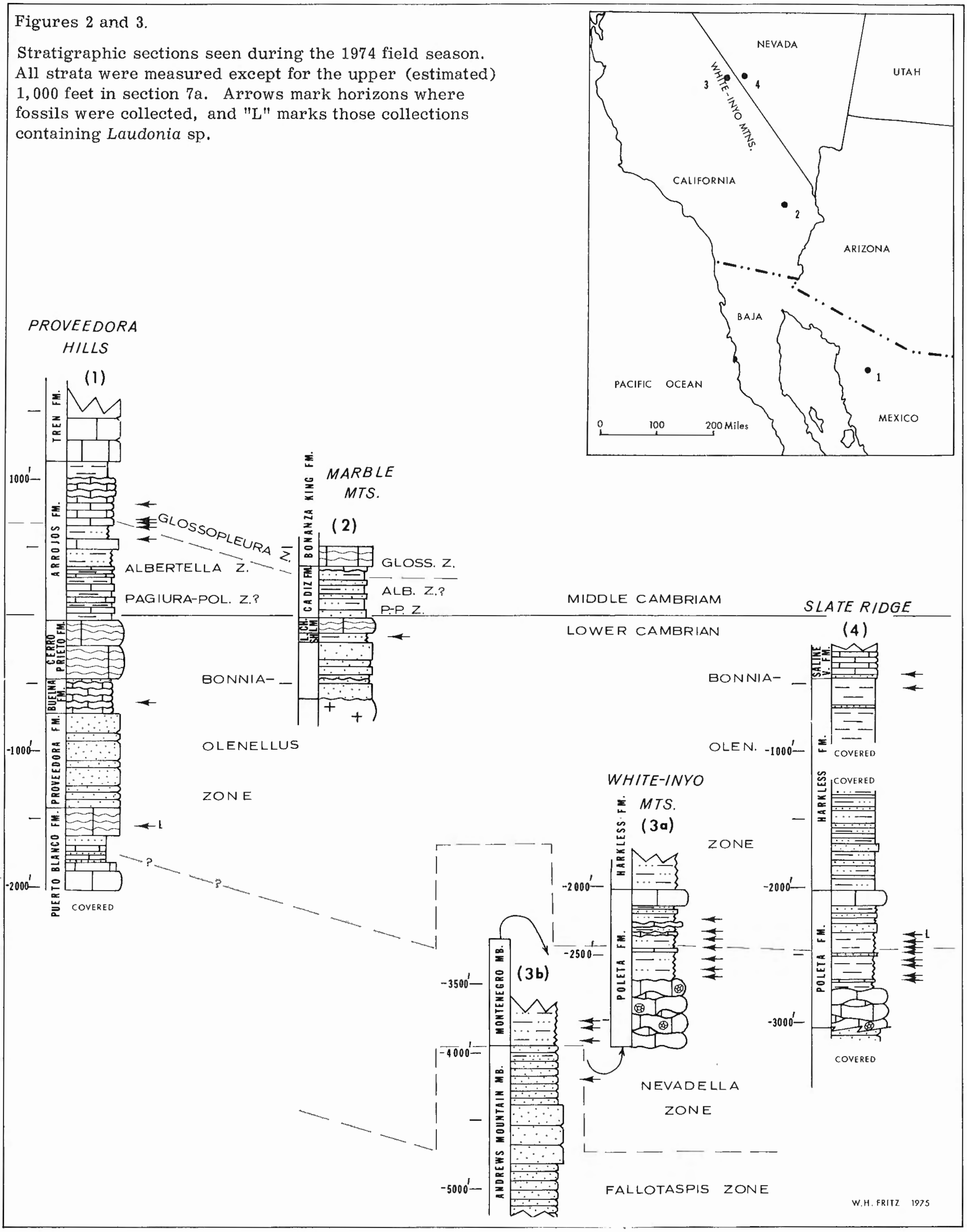
The Harkless and Saline Valley formations consist mainly of fine-grained sandstone and shale (Nelson, 1962), and they constitute the lower half-cycle in the White-Inyo Mountains and at Slate Ridge. The upper half-cycle is the Mule Springs Formation, which Nelson (1962, p. 142) described as "...massive to well-bedded blue-grey limestone containing abundant concretionary algal structures (*Girvanella*)." The cycle in the two areas is placed at localities 14 and 15 in Figure 1.

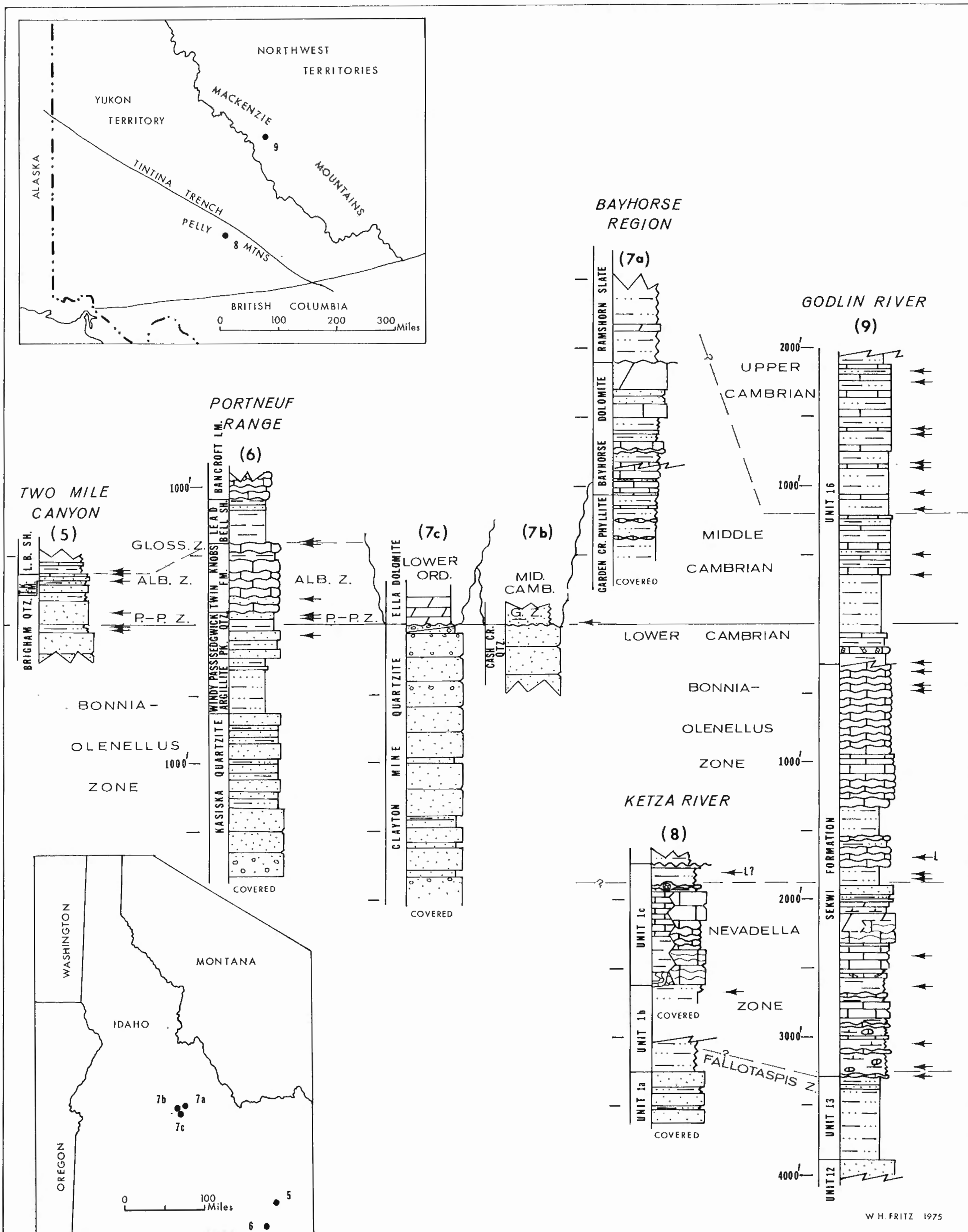
In Two Mile Canyon and in the Portneuf Range, Idaho (Fig. 3, nos. 5, 6) the equivalent of grand cycle C may be present within the inner detrital belt. In Two Mile Canyon an undesignated portion of the Brigham Quartzite constitutes the lower half-cycle, and a thin, recessive siltstone containing uppermost Lower Cambrian fossils is thought to be the equivalent of carbonates of the upper half-cycle that were deposited farther seaward. In the Portneuf Range, *Olenellus gilberti*? Meek was found in quartzite believed to be high in the lower half-cycle which is overlain by shale that is believed to correlate with the latest Lower Cambrian siltstone in the Two Mile Canyon section. The position of cycle C strata mentioned in the above two areas is shown at localities 26 and 27 in Figure 1.

The lower half-cycle in the Mount Robson area consists of the Mahto Formation of predominantly fine- and medium-grained quartzite. The upper half-cycle is the Hota Formation composed of medium grey, thin- to thick-bedded limestone with abundant *Girvanella*? sp. at the type section on Calumet Creek. Within the area and traced to the south (Fritz and Mountjoy, in

Figures 2 and 3.

Stratigraphic sections seen during the 1974 field season. All strata were measured except for the upper (estimated) 1,000 feet in section 7a. Arrows mark horizons where fossils were collected, and "L" marks those collections containing *Laudonia* sp.





NORTHWEST
TERRITORIES
YUKON
TERRITORY
ALASKA
MACKENZIE
MOUNTAINS
TINTINA TRENCH
PELLY
MTNS
BRITISH COLUMBIA
0 100 200 300 Miles
BAYHORSE
REGION
(7a)
RAMSHORN SLATE
DOLOMITE
BAYHORSE
GARDEN CR. PHYLLITE
COVERED
GODLIN RIVER
(9)
UPPER
CAMBRIAN
MIDDLE
CAMBRIAN
LOWER CAMBRIAN
BONNIA-
OLENELLUS
ZONE
UNIT 16
SEKWI FORMATION
UNIT 13
UNIT 12
PORTNEUF
RANGE
(6)
BANCROFT LM.
LEAD BELL SH.
TWIN KNOBS FM.
SEDGWICK PK. QTZ.
WINDY PASS ARGILLITE
KASISKA QUARTZITE
COVERED
TWO MILE
CANYON
(5)
L. B. SH.
BRIGHAM QTZ.
GLOSS. Z.
ALB. Z.
P.-P. Z.
BONNIA-
OLENELLUS
ZONE
(7c)
LOWER
ORD.
ELLA DOLOMITE
CLAYTON MINE QUARTZITE
COVERED
(7b)
MID.
CAMB.
G. Z.
CASH CR. QTZ.
KETZA RIVER
(8)
L?
NEVADELLA
ZONE
UNIT 1c
UNIT 1b
UNIT 1a
COVERED
FALLOTASPIS Z.
WASHINGTON
MONTANA
IDAHO
OREGON
0 100 Miles
W.H. FRITZ 1975

press), the Hota changes first to massive dolomite at Mumm Peak, and then to dark, thin-bedded limestone between Cinnamon Peak and Whitehorn Mountain. This lateral change within the Hota suggests that here the upper half-cycle is near the reef edge, and therefore the cycle is assigned to positions 6 and 7 in Figure 1. Southeast of Mount Robson area, the Hota is known as the Peyto Limestone (upper) Member of the Gog Quartzite. In the Cariboo Mountains, both the Mahto and Hota are displaced by dark shales of the outer detrital belt (Fig. 1, locs. 8 and 9), that constitute the lower portion of the Dome Creek Formation (Campbell *et al.*, 1973, Fig. 3).

It was mentioned in the description of grand cycle B that grand cycle C cannot be identified in the Godlin River section. Here the writer believes that the Lower Cambrian dark shale and platy limestone overlying the Sekwi are strata equivalent in age to the upper part of the lower half-cycle and all of the upper half-cycle. The writer presently believes that these strata represent the southern extension of the Road River trough (Fritz, 1974) that here displace "normal" middle carbonate limestone. It is not believed that the dark limestone and shales represent the outer detrital belt because there are no reef-edge carbonates between the dark strata and the underlying Sekwi Formation, no distinctive reef-edge trilobites were found below the upper Sekwi contact, and an aircraft flight over strata to the west suggest that reef-edge carbonates equivalent to grand cycle C lie in that (seaward) direction.

Fossil control. The sparse fossils at the base of the lower half of grand cycle C have been mentioned under grand cycle B. Near to top of the lower half-cycle, where fossils are more plentiful, *Olenellus puertoblancoensis* (Lochman) was found near the middle of the Beulna Formation where it had been earlier reported by Cooper *et al.* (1952, p. 19). This species is believed by the writer to represent a late position within the *Bonnia-Olenellus* Zone. In the Marble Mountains *Olenellus gilberti* Meek, a trilobite of approximately the same age, first appears near the middle of the Latham Shale (near the top of the lower half-cycle) and ranges through and just above the top of the Chambless Limestone (upper half-cycle; Mount, 1974, p. 49). A late *Bonnia-Olenellus* Zone faunule has been described by Palmer (1964) from the upper half of the lower half-cycle on Slate Ridge. This faunule is from low in the Saline Valley Formation, and its moderately high position in the zone is suggested by the presence of *Zancanthopsis* and a species of *Bonnia* that bears but one pair of spines on the tail. The genus *Goldfieldia* was first described from this location and is not known from older strata. This genus was also found by the writer in the dark shale and limestone immediately overlying the Sekwi Formation in the Godlin Lake section.

In the Mount Robson area, between Cinnamon Peak and Whitehorn Mountain, *O. puertoblancoensis*? was found in float near the top of the upper half-cycle (Hota Fm.; Fritz and Mountjoy, in press). To the south, along the Banff-Jasper highway, *O. puertoblancoensis* is present within the upper half-cycle (Peyto Fm.), and in the Mackenzie Mountains, Northwest Territories, *O. puertoblancoensis* occurs in the type Sekwi (Fritz, 1972a) in the interval 50 to 100 feet below the Lower-Middle Cambrian boundary.

At numerous areas inspected, the Lower-Middle Cambrian boundary is just above or at the top of the upper half-cycle. Cooper *et al.* (1951, p. 9) found *Salterella*, a Lower Cambrian genus, a short distance above the top of the upper half-cycle (Cerro Prieto Fm.) in the Proveedora Hills. Mount (1974, p. 49) places the Lower-Middle Cambrian boundary 10 feet above the upper half-cycle (Chambless Ls.) in the Marble Mountains. The top of the upper half-cycle (Mules Springs Fm.) in the White-Inyo Mountains section is believed by Nelson (1962, p. 140, 142) to mark the Lower-Middle Cambrian boundary in that area, but he believes the boundary is as much as 200 feet above the half-cycle at Miller Mountain 50 miles to the north. In the Mount Robson area the Lower-Middle Cambrian boundary is believed to be at or very near the top of the upper half-cycle, because Middle Cambrian fossils were found immediately above the Hota at the type locality for the formation, and Lower Cambrian fossils were found 45 feet below (Fritz and Mountjoy, in press). In the southern Canadian Rocky Mountains, south of Mount Robson, Rasetti (1951, p. 90) has placed the boundary at the top of the upper half-cycle (Peyto Member), but locally, on Mount Weed, the writer found *Olenellus* 20 feet above the half-cycle in the lower beds of the Mount Whyte Formation. It has been mentioned that in the Mackenzie Mountains grand cycle B cannot be separated from grand cycle C. Here, at the type section of the Sekwi Formation, the Lower-Middle Cambrian boundary is at or near the top of the nearly continuous limestone succession that comprises the Sekwi Formation (Fritz, 1972a, Fig. 3). Eighteen miles to the northwest, the upper limestone beds of the Sekwi are displaced by dark limestone and shale (unit 16) at the Godlin River section. Carbonate beds at the top of the Sekwi are believed to correlate with the middle portion of the lower half-cycle.

Summary of correlations. A new approach to broad correlations of Lower Cambrian strata has been made by relating stratigraphic sections to three sedimentary cycles. Further work on this concept is obviously needed, and preliminary results indicate that progress can best be made by continuing to concentrate efforts on the middle carbonate belt. North of Mount Robson, problems will be encountered in recognizing the upper portion of the medial cycle and both halves of the upper cycle. The best fossil control presently available lies in the lower half of the medial cycle and at the top of the uppermost cycle.

Correlations: Bayhorse region, Idaho - southern Canadian Rocky Mountains, Canada

It is not the purpose of this report to attempt a broad, regional correlation of Middle Cambrian strata, but it should be pointed out that there is a striking similarity between the fossiliferous Lower and Middle

Cambrian succession in the southern Canadian Rocky Mountains and the barren, questionably dated rocks in the Bayhorse region, Idaho (Fig. 3, no. 7). The type localities for formations constituting the succession in Canada lie on the north side of Montania, a large Cambrian positive area in Montana that crosses the border into southwestern Alberta and southeastern British Columbia. If the suggested correlation proves correct, then the occurrence of similar and contemporaneous strata in the Bayhorse region can be used as an aid to establishing the western edge of Montania.

In the Bayhorse region near the Beardsley Mine, Ross (1937, p. 12-17) erected three formations which he called (ascending order) the Garden Creek Phyllite, Bayhorse Dolomite, and the Ramshorn Slate. The first two formations were questionably assigned to the Cambrian and the last to the Ordovician. The Beardsley Mine succession closely resembles the Mount Whyte Formation, Cathedral Dolomite, and Chancellor Formation in Canada. The first two of these formations belong to the early Middle Cambrian, and the last formation is in part equivalent to the first two and in part younger.

All of the relatively clean quartzite in the Bayhorse region was assigned by Ross (1937, p. 17, 18) to his Kinnikinic Quartzite, which he placed in the Middle (?) Ordovician. Most, but not all, of this quartzite resembles the Lower Cambrian Gog Quartzite in Canada that directly underlies the Mount Whyte. Later, the Gog-like quartzite in the Bayhorse region was removed from the Kinnikinic by Hobbs *et al.* (1968) and placed by them into new units, the Clayton Mine Quartzite, the Cash Creek Quartzite, and a "lower quartzite". These quartzites were respectively assigned (1968, p. 7, 17, 19) the following ages: questionably Early Ordovician, "probably to the Early or Middle Cambrian", and to an undesignated age older than the Cash Creek.

If the strata in question in the Bayhorse region are to be interpreted in the light of a Canadian correlation, it is suggested that a structural interpretation be included as well. Combining the two, the type Clayton Mine Quartzite (Fig. 3, no. 7c) is considered to be a Lower Cambrian quartzite on the west flank of Montania that is separated by a major unconformity from the overlying Ella Dolomite of Lower Ordovician age. The Cash Creek Quartzite (Fig. 3, 7b) is believed to be equivalent to the Clayton Mine Quartzite, but to belong to a thrust sheet that originated farther west. The Cash Creek Quartzite lies below a lesser unconformity in which only two Middle Cambrian zones (*Plagiura-Poliella, Albertella*) are missing in the overlying silty sandstone. The succession exposed near the Beardsley Mine (Fig. 3, no. 7a) is considered to be in a thrust plate that has come from still farther west. There Middle Cambrian strata (Garden Creek, Bayhorse and Ramshorn formations) are believed to have been deposited over Lower Cambrian sand (Clayton Mine Quartzite) after little or no erosion. The latter supposition is based only on a correlation with the Canadian section, as the base of the Garden Creek Phyllite is not exposed in the Bayhorse region.

The "lower quartzite" described by Hobbs *et al.* (1968, p. 21) was not studied by the writer, and therefore will not be discussed here.

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145. AN ESTIMATE OF RIGHT-LATERAL DISPLACEMENT ON DONNA RIVER FAULT, NORTHWESTERN DISTRICT OF MACKENZIE, N.W.T.

Project 550004

J.A. Jeletzky
Institute of Sedimentary and Petroleum Geology

When describing principal faults of the northeastern Richardson Mountains (Jeletzky, 1961, p. 545-561, Fig. 2), the writer was unable to offer any reasonably substantiated estimate of the right-hand horizontal displacement on the Donna River fault zone because the structures on its opposite sides, as a rule, are unrelated. The only possible exception noted at that time was a syncline apparently severed by the fault zone. As stated by Jeletzky (1961, p. 548, Fig. 2): "The unnamed larger northerly trending syncline that crosses lower Donna River about one-half mile east of the fault zone and is cut off by the latter about one mile farther south (Jeletzky, 1960, geol. map) could, indeed, be the continuation of the Donna River syncline. The Donna River syncline itself seems, however, to continue for at least several miles north of lower Donna River on the west side of the fault zone. This and the distribution of the formational contacts on both sides of the fault zone suggest a horizontal offset of this synclinal axis in excess of four to five miles". However, as pointed out by D.K. Norris (written comm., August, 1974), this claim is erroneous. The structure shown to cross "lower Donna River about one-half mile east of the fault zone" is an anticline which is shown accordingly by Jeletzky (1960, Fig. 1; 1961, Fig. 2). The writer wishes to use this opportunity to correct this "slip of the mind" in his 1961 paper.

A recent study of aerial photographs (*see* photos A12861-180 to 178), supplemented by some additional study of outcrops between the lower canyon of Donna River and the western margin of Mackenzie Delta during the 1973 field season, provided some evidence strongly suggesting that the right-lateral offset of Donna River fault zone is in the order of six miles (9.7 km). This evidence is presented below.

Horizontal offsets of several stream beds as much as three-quarters of a mile (1.2 km), the alignment and orientation of a series of small lakes, and the presence of zones of strongly sheared and deformed Lower Cretaceous rocks between the lower canyon of Donna River and the northern group of gypsum piercement structures discovered by Kent and Russell (1961, Fig. 1) clearly indicate that this group of structures is situated on the northwestern side of Donna River fault zone (Fig. 1). At the same time, Jeletzky's (1960, geol. map; 1961, p. 545, Fig. 2) work in the lower canyon of Donna River leaves no doubt that the so-called southern gypsum piercement structure of Kent and Russell (1961), discovered by Jeletzky (1960, p. 23, 25, geol. map), is situated on the southeastern side of the same zone. The trace of the north-trending Donna River fault zone now is placed about one-eighth of a mile (0.2 km) west of the southwestern end of exposures of the Donna River gypsum structure where the stream bed forms a short but sharp, Z-like bend suggesting a right lateral offset of about 300 yards (274 m). These relationships are clearly indicated in Figure 1. Shattered, nearly vertical strata of the Coal-bearing division outcrop inside the bend on the right (south) bank and east of a covered interval about 250 feet (75 m) wide. This interval appears to contain the trace of the Donna River fault zone since, on its western side, slightly sheared, easterly dipping, concretionary shales of the Upper shale-siltstone division are exposed (*see* Jeletzky, 1960, Fig. 1; this paper, Fig. 1). The above positioning of the fault's trace is indicated also by a close alignment of the above-mentioned covered interval with all other known exposures of the trace of Donna River fault zone, trends of offset streams, and those of chains of small lakes in the adjacent part of the area (*see* Fig. 1).

Kent and Russell's (1961, Fig. 1) conclusion that the Donna River fault zone is deflected northeastward just north of the top of Mount Gifford and crosses the lower Donna River canyon, on that course, about 1 mile (1.6 km) east of the gypsum structure is considered to be in error. As pointed out by Jeletzky (1960, Fig. 1), the rocks of the Coal-bearing division do not exhibit any appreciable lateral offsets and are, for the most part, only moderately folded and faulted within that northeast-trending bend of Donna River where the gypsum structure is situated. These rocks become increasingly dislocated westward of this bend. The same moderate folding and faulting characterizes the rocks of the Coal-bearing division farther east within a southeast-trending bend of Donna River, about 2 miles (3.2 km) long, where Kent and Russell (1961, Fig. 1) place the northeastern extension of the Donna River fault zone. All faults cutting these bends of the Donna River and, locally, causing considerable deformation of rocks of the gypsum structure and of the Coal-bearing division in its banks, are minor to moderately large. They appear to be northeast-trending second and third rank subsidiaries of the previously described 360^{o}- to 020^{o}-trending Donna River fault zone occurring on the west side of the gypsum structure. These structural relationships are illustrated by Figure 1 which represents a modification of the locality map for the gypsum piercement structures of the Donna River area published by Kent and Russell (1961, Fig. 1).

In the writer's opinion, the above-mentioned structural relationships strongly suggest that the northern group of gypsum piercement intrusions is but a part of the southern gypsum piercement intrusion displaced right laterally along the Donna River fault zone for the distance of about 6 miles (9.7 km). The Donna River fault zone appears to be the master

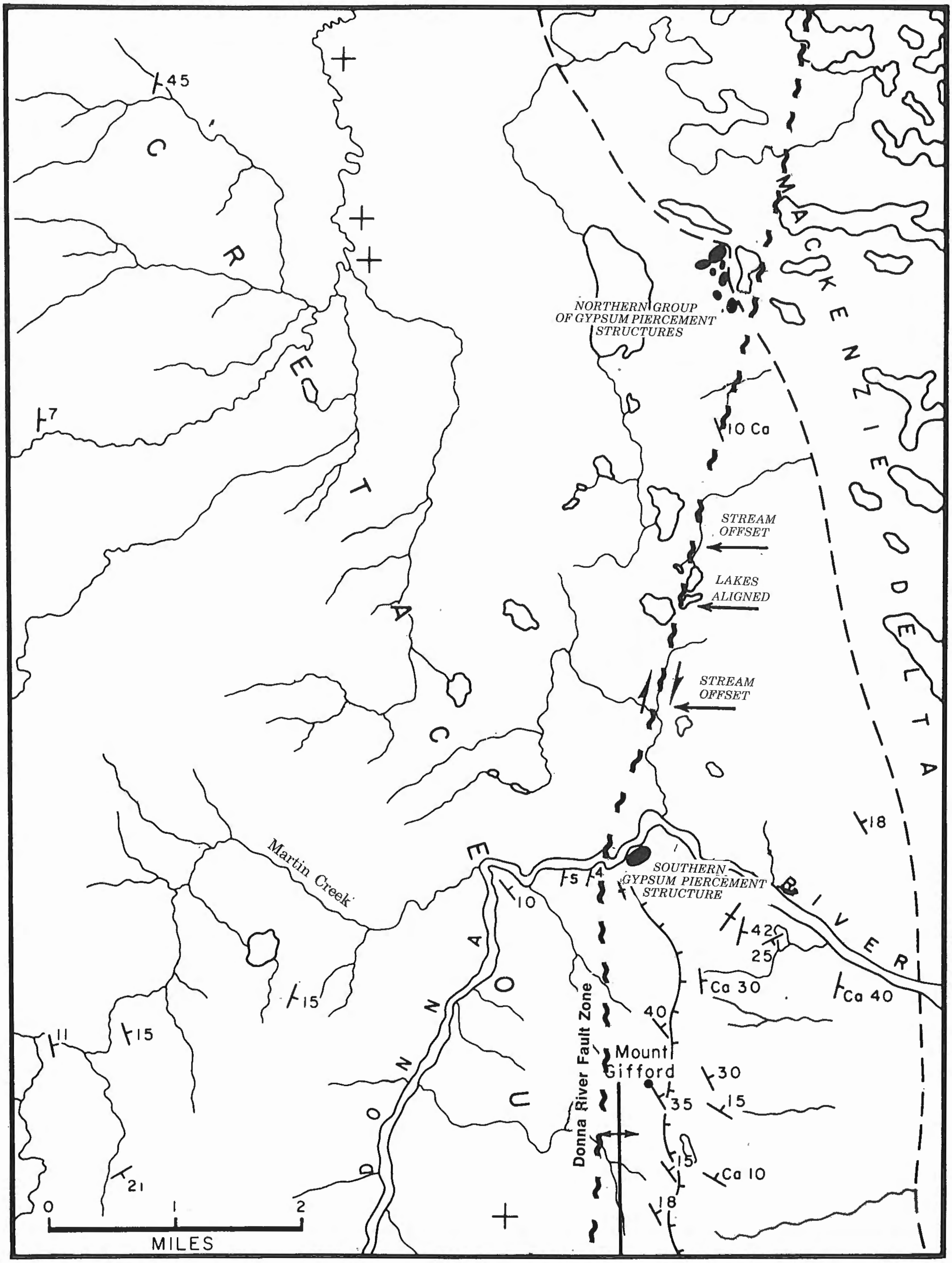

Figure 1. Inferred trend of Donna River fault zone between Mount Gifford and the western margin at Mackenzie Delta and its structural relationship with the gypsum piercement structures discovered by Jeletzky (1960) and Kent and Russell (1961). Modified from Kent and Russell (1961, p. 586, fig. 1).

fault of the strike-slip fault system of the eastern slope of the northern Richardson Mountains (Jeletzky, 1961, p. 575). This quite reasonable estimate of the post-mid-Lower Cretaceous (*see* Jeletzky, 1960, p. 25, 26; 1961, p. 572, 573) horizontal displacement gives, therefore, an indication of the scale of maximum strike-slip movements in this area on the Donna River fault zone.

The above structural re-interpretation of the gypsum piercement intrusions accounts for the apparent lack of the characteristic outline of a piercement dome or a diapir fold in the southern structure as well as the strong shearing and distortion of rocks within and around this structure observed by Jeletzky (1960, p. 25). According to this re-interpretation, the now known gypsum piercement structures of the lower Donna River arose as a single group, apparently predating the Donna River fault zone. Unless this zone is an ancient basement structure (which is still a feasible, though unsubstantiated hypothesis, as pointed out by Jeletzky, 1961, p. 578) re-activated by post-mid-Early Cretaceous (?Tertiary) orogeny, there does not seem to be any reason to think that these gypsum piercement structures (Jeletzky, 1961, p. 572): "invaded a pre-existing zone of weakness in strongly sheared and faulted Lower Cretaceous rocks immediately east of Donna River fault zone". The evidence now available favours the alternative suggestion of Jeletzky (1961, p. 572) that these structures; "might have been older piercement domes or diapiric structures intersected and distorted by the Donna River fault zone".

The general post-mid-Early Cretaceous (?Tertiary) dating of the piercement breccia (Jeletzky, 1960, p. 24, 25; 1961, p. 572) suggests a still younger post-mid-Early Cretaceous (?late Tertiary and/or Quaternary) age for the principal strike-slip movements of the Donna River fault zone. This suggestion agrees well with the evidence previously presented by Jeletzky (1961, p. 545) that: "at least some of the major faults of the eastern slope of the Richardson Mountains appear to be still active". It finds additional support in a recent summary of seismic data on northwestern Canada compiled by Stevens and Milne (1974, p. 151, Figs. 1, 3). This conclusion applies to the segment of the Donna River fault zone discussed here since some of the small creeks crossing its trace in the area between Mount Gifford and the western edge of Mackenzie Delta exhibit recent (at any rate post-Glacial) right-lateral offsets of their valleys up to three-quarters of a mile (1.2 km) (*see* Fig. 1 and airphotos A12861-180 to 178 inclusive).

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146. GRINNELL PENINSULA, DEVON ISLAND, DISTRICT OF FRANKLIN (59B, C; 69A, D)

Project 670016

J. Wm. Kerr
Institute of Sedimentary and Petroleum Geology, Calgary

During the 1974 field season, approximately one month was devoted to the gathering of additional structural, stratigraphical and paleontological control required in the production of a 1: 125,000 geological map of Grinnell Peninsula of Devon Island, N.W.T. The writer, in addition, maintained a base camp and provided logistical support and advice for (a) a study of the Emma Fiord Formation by W.W. Nassichuk and G.R. Davies, (b) conodont studies by C.R. Barnes and G. Nowlan, and (c) a clastic sediment study by A.F. Embry.

Near the northern end of Grinnell Peninsula at approximately 77°02'N, 95°40'W is a particularly thick and well-exposed sequence of rocks ranging from Cambrian through Lower Ordovician. The lower part of this section probably includes equivalents of the Cambrian Parrish Glacier Formation and the Lower Ordovician Copes Bay Formation, which together total more than 3,500 feet (1,065 m) of rocks. The overlying Baumann Fiord Formation is approximately 2,000 feet (610 m) thick and contains abundant stromatolite cycles and evaporites. The Eleanor River Formation also is present in this section, exhibiting three members that are widespread on the peninsula; lower and upper resistant limestone members, and a middle recessive, fissile, argillaceous limestone member.

An excellent section, including strata from the uppermost Baumann Fiord Formation to the Bathurst Island Formation, occurs on the coast of northwestern Grinnell Peninsula south of Mount Percy at approximately 76°42'N, 96°45'W. Approximate thicknesses in feet are: Bathurst Island Formation, 2,300 +; Cape Phillips Formation, 1,550; Irene Bay Formation, 84; Thumb Mountain Formation, 918; Bay Fiord Formation, 1,660±; Eleanor River Formation, upper - 320; middle - 800; lower - 445; Baumann Fiord Formation (partial section) 400 +.

An angular unconformity of Silurian age occurs in a narrow, north-south belt on western Grinnell Peninsula, near the facies boundary between shales of the Cape Phillips Formation to the west and carbonates of the Allen Bay Formation to the east. The new Cape Storm Formation (Kerr, in press), which overlies this unconformity, cuts through the Allen Bay, Cape Phillips and Irene Bay formations to lie directly on the Thumb Mountain Formation.

A coaly and shaly, mainly nonmarine formation occurs on northern Grinnell Peninsula at about 76°53'N, 95°20'W, and is assigned to the Emma Fiord Formation. It is about 450 feet (137 m) thick, and yielded spores identified by McGregor (pers. comm., 1974) as Viséan (Lower Carboniferous). The Emma Fiord Formation lies unconformably on Silurian rocks and is overlain with probable unconformity by the Pennsylvanian Canyon Fiord Formation.

A thick succession (approximately 6,500 feet) of Upper Devonian clastic rocks are present in a syncline east of Tucker River at approximately 76°42'N, 93°25'W. A.F. Embry (pers. comm., 1974) reports that the upper sandstone member of the Okse Bay Formation reported there by McLaren (1963) is equivalent to the Griper Bay Formation. The uppermost part of the Griper Bay equivalents here yielded brachiopods of probable Famennian (latest Devonian) age. It overlies the older Okse Bay Formation with the contact probably being unconformable, although there is no visible angularity. Farther west, this writer has discovered three isolated occurrences of quartz sandstone that lie with angular unconformity on Middle Devonian and older rocks. These are assigned to the Griper Bay Formation and are at approximately 76°29'N, 94°12'W, 76°28'N, 93°55'W; and 76°35'N, 94°10'W. It appears, therefore, that the Griper Bay Formation of Grinnell Peninsula lies on an unconformity which has little or no angularity in the east, but becomes angular farther west on the Cornwallis Fold Belt.

Rocks of southeastern Grinnell Peninsula are treated by Morrow (1973) and more extensively by Morrow and Kerr (in prep.).

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A MIDDLE DEVONIAN SANDSTONE UNIT, GRANDVIEW HILLS AREA, DISTRICT OF MACKENZIE

Project 700060

W.S. MacKenzie, A.E.H. Pedder and T.T. Uyeno
Institute of Sedimentary and Petroleum Geology, Calgary

The presence of arenaceous sediments between the Middle Devonian Ramparts Limestone and equivalent beds, and the Upper Devonian Canol Shale has long been known. They have been assigned generally to the Upper Devonian and referred to as "basal Fort Creek Sandstone", "basal Canol Formation Sandstone", or "lower part of the Canol Formation". As such, they have been considered to be the initial products of the Late Devonian transgression of the area. However, there is evidence now, especially from measured sections near Lac Charrue and on Gassage River (Fig. 1) to challenge these views. Faunas from both the arenaceous beds and from minor limestone units within them indicate correlation with the upper part of the full Ramparts section (zones of *Stringocephalus aleskanus* and *Leiorhynchus hippocastanea*) south of Fort Good Hope. Furthermore, there is fossil evidence to indicate that the upper surface of the arenaceous unit probably was eroded prior to deposition of the overlying Canol Formation. The unit's lower boundary is conformable with the Hare Indian Formation in the west, and with bedded limestone of the Ramparts Formation in the east. The writers intend to name this unit and further document its faunas in a forthcoming publication; for the present, they wish to stress that it is a part correlative of the full Ramparts Formation and predates the Middle/Upper Devonian disconformity.

Thickness and Lithology

The arenaceous beds have a maximum thickness of about 70 feet (21 m) in the subsurface north of Gossage River; the thickest outcrop section known is near Lac Charrue (Fig. 1) and is 45 feet (18 m) thick. The unit consists mainly of detrital quartz siltstone and very fine grained sandstone with intervals of silty shale containing interbeds of siltstone and discontinuous beds and lenses of silty bioclastic limestone. Burrowing and reworking of the sediment, presumably by marine organisms, are conspicuous in the arenaceous part of the sequence, and fine crossbedding can be seen intermittently throughout the unit. Insoluble residues and thin sections from the siltstones and sandstones show well-sorted, subangular and subrounded quartz grains, a few flakes of mica, traces of pyrite and rare crystals of stable heavy minerals such as tourmaline and zircon. Siliceous, tightly cemented beds failed to disintegrate when treated with acid. Quartz content of the arenaceous rocks is estimated to be greater than 95 per cent, making them quartz arenites by definition of Williams *et al.* (1954).

The limestone, which usually occurs as lenses in the silty shale parts of the unit and as more laterally persistent beds in the less shaly parts, is all extremely silty and sandy. These beds contain 50 per cent or more of noticeably well-sorted quartz grains, mostly with an average diameter of about 100 microns. Except where concentrated by burrowing organisms and where they have collected in the concave parts of fossil shells to form geopetal fabrics in the rock, the quartz grains are evenly distributed within a matrix of fine lime mud and broken fossil shells.

Diagenesis

Modification of sand particle size by diagenetic overgrowth of quartz, in optical continuity with the detrital grains, is prevalent throughout the arenaceous sequence, and has obliterated practically all original grain boundaries. Hematite coating and staining, though uncommon, has been a factor in preserving the original dimensions of some grains by inhibiting development of the quartz overgrowths.

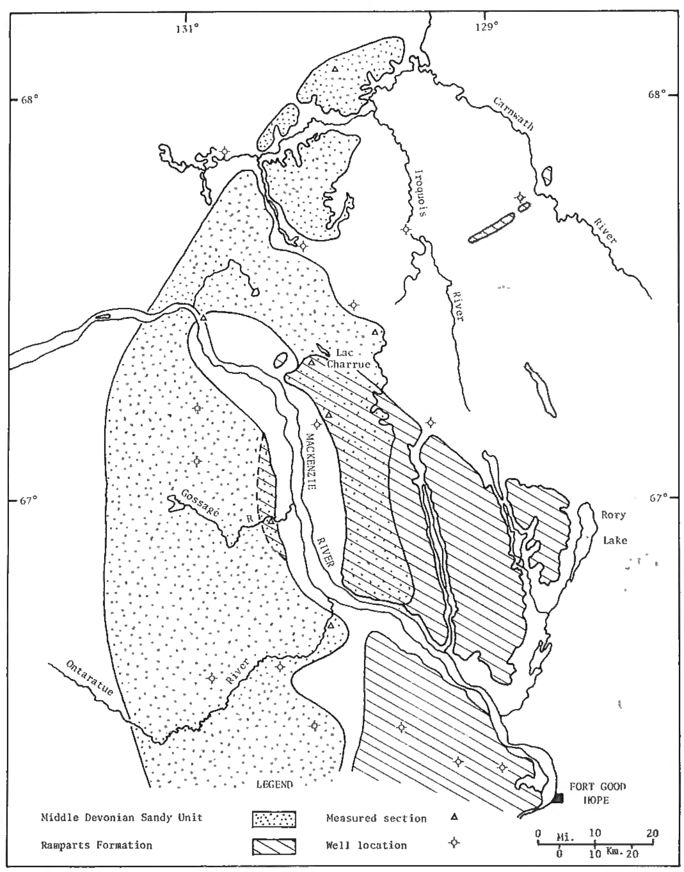

Figure 1. Present distribution of the Middle Devonian sandy unit and Ramparts Formation in the Grandview Hills area.

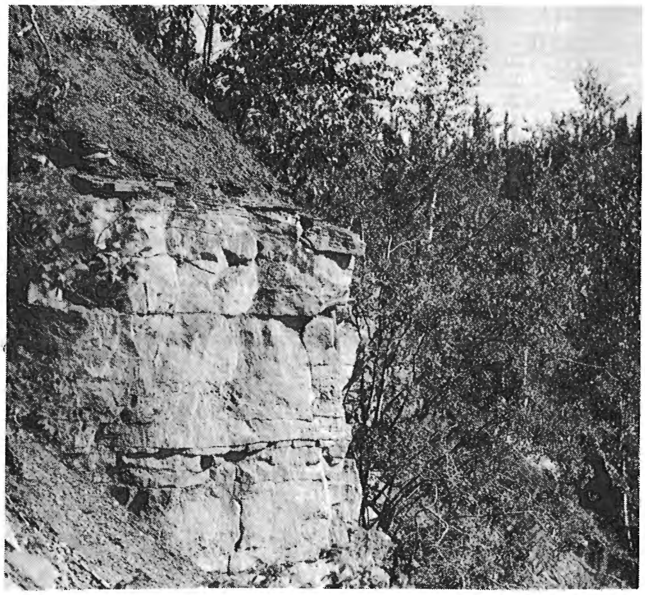

Figure 2. Outcrop of upper beds of the Middle Devonian sandy unit and shales of the overlying Canol Formation. About 8 miles (13 km) south of Lac Charrue. Photo by M.E. Ayling.

Figure 3. Outcrop of the upper 13 feet (4 m) of the principal composite section of the Middle Devonian sandy unit. About 1-½ miles (3 km) southwest of Lac Charrue. Photo by W.S. MacKenzie.

In this respect, though much finer grained, the sandstone appears almost identical in thin section to the Devonian Oriskany sandstone of Pennsylvania, a well-sorted marine sand with original grain boundaries absent or very indistinct (Pettijohn *et al.*, 1972, p. 244, Figs. 6-27). Increase in intensity of diagenesis has created non-porous mosaics of equant interlocking crystals showing occasional pyramidal crystal terminations and straight crystal boundaries, and in some areas small completely silicified patches have developed.

Source and Depositional Environment

The ubiquitous occurrence of whole and broken skeletons of marine animals throughout the arenaceous, argillaceous, and calcareous beds of the sandy sequence indicates that the sediments are indigenous to a marine environment. Broken fossil fragments commonly have sharp corners and so have not likely been moved far from their source. In contrast, whole skeletons, mainly of thick-shelled brachiopods, appear to represent faunal assemblages that were able to anchor themselves in the fine sand, and live in moderately turbulent water. Apart from occasional columnals, crinoids, which are commonly associated with brachiopods elsewhere in quiet water environments where carbonate sediments can accumulate, are not present in the sandy beds.

Figures 4-9 (opposite)

Middle Devonian corals from sandy unit cropping out on both sides of a creek, approximately 1-½ miles south of Lac Charrue; 67°20'45"N, 130°09'15"W.

4, 5. *Temnophyllum decaeni* Pedder, X3. GSC 17843, GSC Loc. C-19858, 33-34 feet above base, 11-12 feet below top of unit.

6. *Cystiphyllum* sp. nov., X1.75. GSC 17844, GSC Loc. C-19862, 38-39 feet above base, 6-7 feet below top of unit.

7, 8. *Argutastrea arguta* Crickmay subsp. nov., X2. GSC 17845, GSC Loc. C-19859, 33-34 feet above base, 11-12 feet below top of unit.

9. Gen. et sp. nov., X2. GSC 17846, GSC Loc. C-19584, 14-18 feet above base, 27-31 feet below top of unit.


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Calcareous parts of the arenaceous unit contain, in addition to colonial corals, remains of smaller animals such as ostracodes, trilobites, bryozoans, brachiopods, tentaculitids, styliolinids, and conodonts. Geopetal fabrics within the coral colonies suggest that many were preserved in growth position in the sediment. The small fossils and skeletal fragments, which make up an estimated 50 per cent of some rocks, probably lived at or near where they are preserved. Lack of significant abraision indicates little or no post-depositional movement of fossil shells.

The dominantly arenaceous parts of the unit consist of supermature siltstone and very fine grained sandstone; the degree of maturity being indicated by an almost complete absence of less stable accessory minerals such as feldspar and mica and by the sparse occurrence of such ultrastable heavy minerals as zircon and tourmaline. According to Folk (1968, p. 102) good size sorting, a characteristic of the sandy unit, is also an index of maturity in sandstones. The restricted nature of the heavy mineral suite suggests a reworked or recycled sand which of necessity must have been older than late Middle Devonian.

The Mount Cap and Old Fort Island sandstone formations of Cambrian age which lap onto the Canadian Shield in the east and which occur in subsurface as a thin blanket overlying and filling in basement irregularities west of the Shield are suggested as a likely source for the recycled Devonian sands. Thin sections of parts of the Old Fort Island sandstone formation have a texture and grain size similar to sands in the arenaceous beds of this paper although the accessory mineral suite is slightly more abundant and more varied. These Cambrian formations, now partly exposed along the periphery of the Canadian Shield and at relatively shallow depths in the subsurface west of it, are themselves mature quartz arenites, characteristic of deposition in a relatively stable platform environment. They were probably exposed to erosion in late Middle Devonian time by basement warping or moderate tectonic uplift.

The writers envisage the arenaceous beds as having been laid down on a wide, gently sloping shelf. Before the sands began to accumulate, carbonate banks were developing close to shore at the same time as shales were being deposited farther seaward. Basement warping or mild tectonic uplift in the east exposed older sandstones to erosion thus providing a source of quartz clastic material which was swept toward the sea and laid down on seaward parts of the Ramparts Formation carbonate bank and still farther seaward on adjacent marine shale of the Hare Indian Formation. Turbulence in the relatively shallow, more agitated water that prevailed during this period of deposition carried away easily-eroded fragments from the carbonate bank and mixed them with the sand.

Fauna and Age of the Unit

The most important sections from the point of view of faunal content occur on both sides of a creek, approximately one and one-half miles south of Lac Charrue. Here the sandy unit is 45 feet (18 m) thick and includes fossiliferous calcareous beds.

Figures 10-27 (opposite)

Middle Devonian brachiopods, molluscs and conodonts from sandy unit cropping out on both sides of a creek, approximately 1-½ miles south of Lac Charrue; 67°20' 45"N, 130°09'15"W.

10, 14. *Warrenella occidentalis timetea* Crickmay, X1. GSC 17847, GSC Loc. C-19863, 43-44 feet above base, 1-2 feet below top of unit.

11-13. *Leiorhynchus hippocastanea* (Crickmay), X1.25.
11, 12: GSC 17848;
13: GSC 17849, both from GSC Loc. C-19864, 43-44 feet above base, 1-2 feet below top of unit.

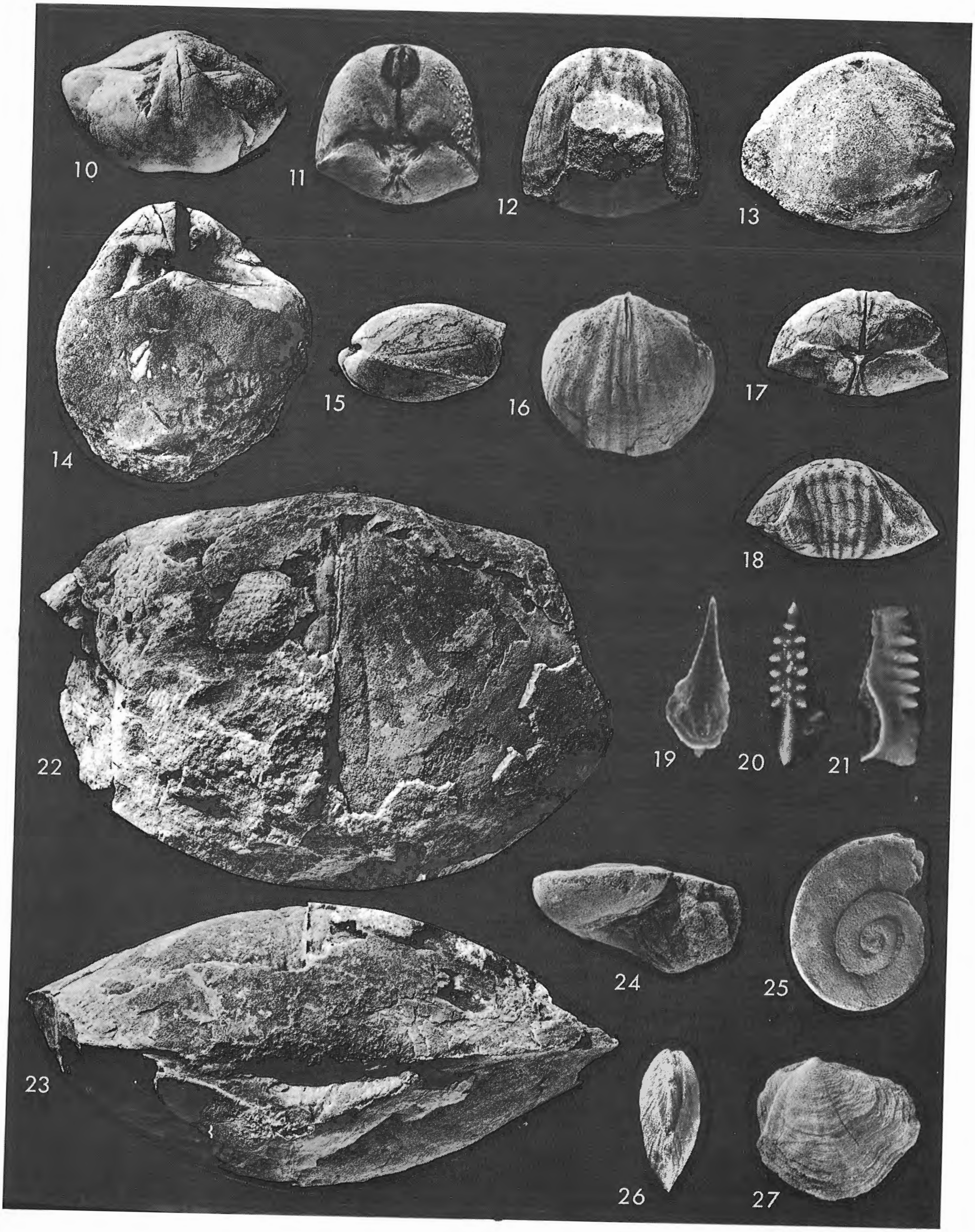
15-18. *Leiorhynchus* sp. cf. *L. rhabdotum* Crickmay, X1.25.
15, 18: GSC 17850, GSC Loc. C-10066 unrecorded level in unit;
16, 17: GSC 17851, GSC Loc. C-19863, 43-44 feet above base, 1-2 feet below top of unit.

19-21. *Icriodus eslaensis* van Adrichem Boogaert, X40. GSC 35343, GSC Loc. C-19855, 28-29 feet above base, 16-17 feet below top of unit.

22, 23. *Stringocephalus aleskanus* Crickmay, X1. GSC 34162, GSC Loc. C-19854, 33-34 feet above base, 11-12 feet below top of unit.

24, 25. *Buechelia tyrrelli* (Whiteaves), X1. GSC 34163, GSC Loc. C-10067, unrecorded level in unit.

26, 27. *Paracyclas antiqua* (Goldfuss), X1. GSC 34164, GSC Loc. C-10067, unrecorded level in unit.



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The fossils show no or very little pre-burial damage. Furthermore, the bivalve and brachiopod shells are articulated and the sediments inside them are identical with the external matrix. Thus they are certainly essentially autochthonous.

Faunas collected from 14 to 31 feet above the base and 14 to 31 feet below the top of the unit include: *Thamnopora* sp., *Alveolites* sp., *Aulopora* sp., a new genus of rugose coral known also from the Ramparts Formation (Fig. 9), *Argutastrea arguta* Crickmay n. subsp. (Figs. 7, 8), *Temnophyllum decaeni* Pedder (Figs. 4, 5), *T. richardsoni* Meek?, *Schizophoria mcfarlanei* (Meek), *Rhyssochonetes* sp., *Devonoproductus* sp. cf. *D. minimus* Crickmay, *Desquamatia(?)* sp. ex gr. *D. (?) hormophora* Crickmay, *Cyrtina* sp., *Stringocephalus aleskanus* Crickmay (Figs. 22, 23), *S.* n. sp., *Buechelia* sp., *Dechenella* sp., *Pedinodechenella* n. sp., *Icriodus eslaensis* van Adrichem Boogaert (Figs. 19-21), *Pelekysgnathus* n. sp., *Polygnathus pseudofoliatus* Wittekindt and *P. xylus* Stauffer. These faunas indicate the *Stringocephalus aleskanus* megafaunal zone and the *Polygnathus varcus* conodont zone, of late Givetian age.

The fauna present from 37 to 39 feet (11-12 m) above the base and 6 to 8 feet (1.8-2.4 m) from the top consists of *Tabulophyllum* sp., *Cystiphyllum* sp. (Fig. 6), *Devonoproductus* sp., *Leiorhynchus* n. sp., *Emanuella* n. sp., *Buechelia tyrrelli* (Whiteaves) (Figs. 24, 25) and *Paracyclas antiqua* (Goldfuss) (Figs. 26, 27). Although this assemblage is less diagnostic than the underlying fauna, it is certainly Middle Devonian.

The youngest fauna known from the unit occurs in the upper three feet (1 m) of the unit, as it is developed one and one-half miles (2.4 km) south of Lac Charrue. In other sections, such as the one on Gassage River, it is absent and, if present, apparently was removed by pre-Canol erosion, since at these localities the fauna with *Leiorhynchus* n. sp. occurs at the top of the unit. This youngest assemblage, which normally is preserved as casts and moulds, is less varied but includes the following brachiopods diagnostic of the *hippocastanea* Zone: *Leiorhynchus hippocastanea* (Crickmay) (Figs. 11-13), *L.* sp. cf. *L. rhabdotum* Crickmay (Figs. 15-18) and *Warrenella occidentalis timetea* Crickmay (Figs. 10, 14).

Acknowledgments

We are grateful to D. G. Cook for first drawing our attention to the important section near Lac Charrue and providing some fossils therefrom. We are also grateful to A. R. Ormiston for identifying trilobites from this section and confirming their Middle Devonian age.

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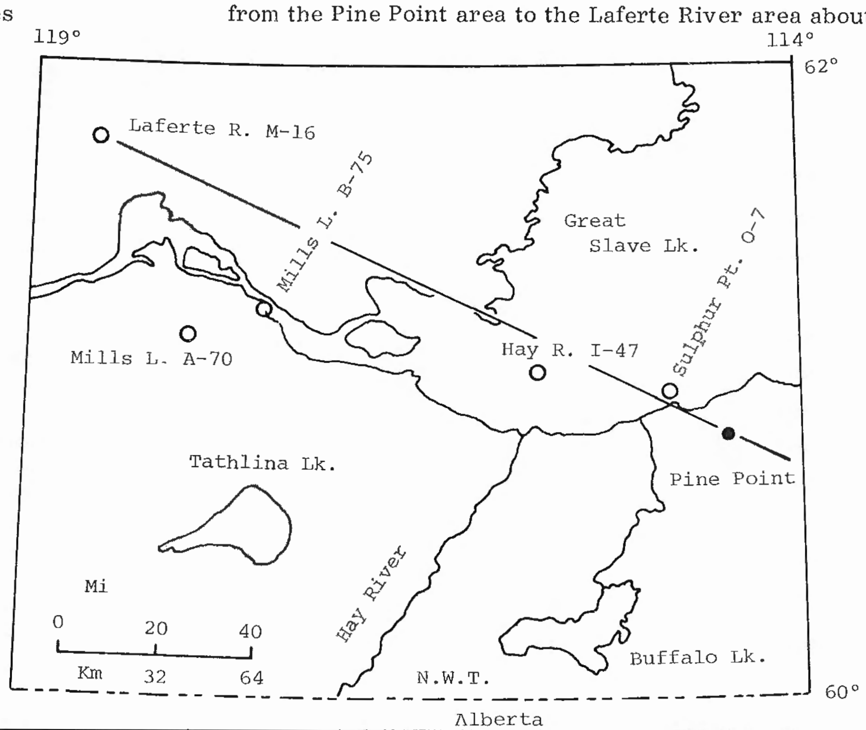
DEVONIAN METALLIFEROUS SHALES, PINE POINT REGION, DISTRICT OF MACKENZIE

Project 710033

R.W. Macqueen, G.K. Williams, R.R. Barefoot and A.E. Foscolos
Institute of Sedimentary and Petroleum Geology, Calgary

Diagenetic models proposed for the origin of zinc-lead mineralization in platform carbonate rocks commonly involve "basinal" shale as an important metal source (Jackson and Beales, 1967; Beales and Onasick, 1970, and others). Accordingly we have analyzed twelve subsurface samples of basinal shales and mudstones which are laterally equivalent to part of the Pine Point dolomite, within which some of the richest zinc-lead deposits of the Pine Point ore-field occur. Although data are preliminary, high values of zinc, lead and uranium oxide obtained in analyses of samples from the Bituminous Member of the Pine Point Formation, and the Horn River Formation, warrant immediate publication.



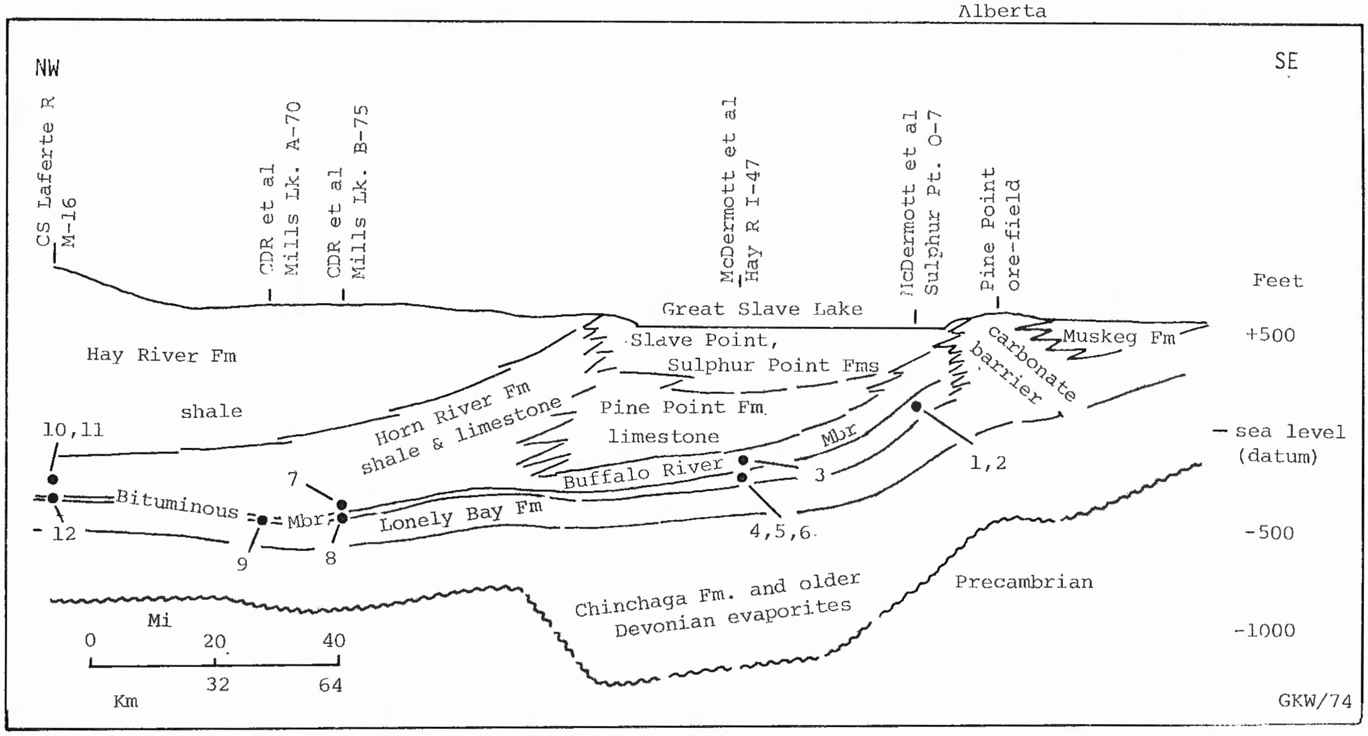


Figure 1

Index map showing location of sampled wells, and line of cross-section shown above. Stratigraphic information from wells projected to section. Locations of samples 1-12 shown in cross-section.

Geological Setting and Samples

Figure 1 includes a diagrammatic cross-section from the Pine Point area to the Laferte River area about

150 miles (240 km) northwest, and shows the stratigraphy of the area to Precambrian basement. An index map also is included, showing well locations; sample locations are shown on the cross-section. The Bituminous Member (Norris, 1965) is an organic-rich shale of possible starved-basin origin, and is a useful subsurface marker because of its high radioactivity. To the north, Bituminous Member shale and mudstone merge with similar rocks of the Horn River Formation. Pine Point Formation Buffalo River Member shale and mudstone are generally much poorer in organic matter than Bituminous Member rocks. Most of the samples analyzed are from the Bituminous Member. The exceptions are sample 3, from the Buffalo River Member; and samples 7, 10 and 11 from the Horn River Formation. All samples are from stratigraphic units that are laterally equivalent to part of the carbonate complex at the Pine Point ore-field. Samples analyzed are from subsurface cores taken within the five wells shown (Fig. 1; locations given in Table 1). Cores are stored at the Institute of Sedimentary and Petroleum Geology, Calgary.

Analytical Methods

X-ray diffraction analysis was used to obtain semi-quantitative mineralogical composition of the samples

Table 1.

Stratigraphic data on Devonian shale and/or mudstone samples analyzed, and composition in organic matter and mineralogy.

Sample[1] No.	Well	Location	Depth	Stratigraphic unit	Composition (%)								
					OM[2]	C[3]	D[3]	Q[4]	F[4]	P[4]	I[4]	K[4]	K/Ch[4]
1	McDermott *et al.* Sulphur Point O-7	65°57'N; 114°45'W	340 ft	Bituminous Mbr., Pine Point Fm.	3.6	56.8	2.0	38	0	0	0	0	0
2	"	"	345 ft	"	6.3	31.3	33.3	22	2	2	3	0	0
4	McDermott *et al.* Hay River I-47	61°01'N; 115°38'W	760 ft	"	13.7	53.5	1.5	27	0	0	4	0	0
5	"	"	810 ft	"	9.9	32.4	9.5	45	0	3	tr	0	0
6	"	"	814 ft	"	11.2	25.9	23.5	27	4	3	5	0	0
8	Central Del Rio Mills Lake B-75	61°14'N; 117°29'W	1465 ft	"	12.3	47.6	0	37	0	2	1	0	0
9	Central Del Rio Mills Lake A-70	61°09'N; 117°56'W	2101 ft	"	15.8	49.7	1.5	25	1	0	7	0	0
12	Cities Service Laferte River M-16	61°46'N; 118°34'W	1184 ft	"	8.5	65.4	4.5	15	1	1	3	2	0
3	McDermott *et al.* Hay River I-47	61°01'N; 115°38'W	740 ft	Buffalo River Mbr., Pine Point Fm.	1.9	60.2	2.7	27	0	3	5	0	0
7	Central Del Rio Mills Lake B-75	61°14'N; 117°29'W	1457 ft	Horn River Fm.	40.8	19.9	2.8	24	2	4	5	2	0
10	Cities Service Laferte River M-16	61°46'N; 118°34'W	1070 ft	"	7.0	2.1	2.1	70	3	3	8	0	5
11	"	"	1090 ft	"	3.7	0.6	0.6	64	4	3	15	0	9

[1] Samples are listed in stratigraphic order within wells, which are listed from southeast to northwest (Fig. 1); samples are grouped in Tables 1 and 2 according to stratigraphic unit.

[2] Organic matter calculated from organic carbon values given in Table 2, using a factor of 1.36. This factor was determined by Thermogravimetric analysis of sample 7, which yielded an organic matter value of 40.8%, and has an organic carbon value of 30.1% as determined by Leco induction furnace (Table 2).

[3] Calcite (C) and dolomite (D) calculated from mineral carbon values given in Table 2; proportions present assigned using X-ray diffraction peak-height ratios.

[4] Quartz (Q), feldspar (F), pyrite (P), illite (I), kaolinite (K), and kaolinite and/or chlorite (K/Ch): semi-quantitative mineralogy determined by X-ray diffraction analysis using Philips X-ray diffractometer, CuKα radiation in conjunction with LiF curved crystal monochromator. Percentage values given are based on peak-height ratios of fraction of sample remaining after subtraction of sum of values of organic matter + calcite + dolomite. Peak-height ratios depend on degree of crystallinity of minerals, size of minerals in the rock sample, and organic matter present. X-ray diffraction analyses by A. G. Heinrich and A. E. Foscolos, Geochemistry Section, Institute of Sedimentary and Petroleum Geology, Calgary.

(Table 1). Zinc, lead, and K_2O content were determined by atomic absorption spectrophotometry; organic and mineral carbon, along with sulphur, were determined using Leco induction equipment. These procedures are outlined in Tables 1 and 2, and are described by Foscolos and Barefoot (1970a, b). Uranium oxide was determined by fluorometry as outlined in Table 2.

Results

Mineralogical results in Table 1 show the shale and mudstone analyzed to be rich either in quartz or carbonate, with minor amounts of feldspar, pyrite, and clay minerals. Major and trace element results in Table 2 show that Bituminous Member rocks and sample 7 from the Horn River Formation share two properties: a) organic carbon is variable but appears to be relatively high, and b) metal values, particularly zinc and uranium oxide, are anomalously high. These results suggest a strong positive correlation between metal content and amounts of organic carbon. Comparison of K_2O content of all samples with the amount of illite indicated in X-ray diffraction analyses suggests that potassium is present well in excess of what the clay mineral fraction can accommodate.

Discussion

The presence of large amounts of zinc and uranium oxide within some of these samples is of considerable interest. Zinc and uranium oxide values, and possibly lead values, appear to be directly related to amounts of organic carbon, which are a measure of the amount of organic matter present. The organic matter is probably hydrocarbon rather than coaly material or carbohydrate, as determined from the high decomposition temperature (±375°C) given by material from sample 7 during thermogravimetric analysis. Organic fractions of black shale deposits similar in many respects to those reported on here are enriched in zinc and less

Table 2.

Composition of selected Devonian shales and/or mudstones, Pine Point Region, N. W. T.

Stratigraphic unit	Sample[4]	Zn[1] (ppm)	Pb[1] (ppm)	U_3O_8[2] (ppm)	K_2O[1] (%)	S[3] (%)	Carbon (%)[3] Organic	Carbon (%)[3] Mineral
Bituminous Mbr., Pine Point Fm.	1	80	41	8	0.80	0.4	2.6	7.1
	2	208	25	8	2.34	1.2	4.6	8.1
	4	1312	0	6	3.40	1.9	10.9	6.6
	5	992	0	36	4.22	1.8	7.3	5.1
	6	1296	0	20	4.42	1.9	8.2	6.6
	8	640	0	4	2.27	1.2	9.0	5.7
	9	208	0	40	3.29	1.3	11.6	6.2
	12	960	0	44	1.36	0.8	6.3	8.4
Buffalo River Mbr., Pine Point Fm.	3	56	0	4	2.80	0.6	1.4	7.6
Horn River Fm.	7	3216	82	60	2.68	2.1	30.1	2.8
	10	240	34	16	4.24	0.9	5.2	0.5
	11	272	0	4	5.55	1.0	2.7	0.2

[1] Determined by atomic absorption. Procedure: each sample, weighing about 1 gram, was crushed to less than 100 mesh, mixed, dried; 100 mg of each sample was mixed with a boric acid-lithium carbonate flux, fused, and dissolved. The resulting solution was analyzed for Pb, Zn, and K_2O by direct aspiration with a Perkin-Elmer 303 atomic absorption spectrophotometer, taking into account both background and interference effects. U.S. Geological Survey standards AGV-1 and GSP-1 were used as references: Zn values obtained were 85 ppm (lit. 84) and 100 ppm (lit. 98) respectively; Pb values were 28 ppm (lit. 35) and 33 ppm (lit. 51) respectively; K_2O values were 2.88% (lit. 2.92) and 5.60 (lit. 5.55) respectively. *See* Foscolos and Barefoot (1970b).

[2] Determined by fluorometer. Procedure: a sodium fluoride-sodium carbonate fluorescent flux was made from the solution prepared for atomic absorption; fluorescence was measured using a Jarell Ash fluorometer. As a check, a coal ash sample assayed at 30 ppm yielded a value of 28 ppm U_3O_8 by fluorometer.

[3] Determined by Leco induction furnace. Procedures are outlined in Foscolos and Barefoot (1970a).

[4] Accuracy as a percentage of the values stated is estimated as follows: Zn, ± 2%; Pb, ± 5%; U_3O_8, ± 5%; K_2O, ± 1%; S, ± 5%; organic and mineral carbon, ± 2%. Analysts R. R. Barefoot and A. E. Foscolos, Geochemistry Section, Institute of Sedimentary and Petroleum Geology, Calgary.

commonly in lead and uranium according to Vine and Tourtelot (1970); these authors regard such elements as mobile.

Alternatively, the metals could occur with interstitial potash-rich chlorides, suspected to be present on the basis of K_2O contents. Illite alone cannot account for all the K_2O present. The amounts of zinc and uranium oxide determined are too large to be present in base exchange positions within the minor amounts of clay minerals (Table 1) or to be derived as contaminants from drilling fluids. No sulphides other than pyrite were detected by X-ray diffraction.

The analyses presented raise a number of interesting questions. Are the zinc and lead in a mobile fraction (organic matter, or chloride complexes), or trapped (sulphides)? Following diagenetic models of zinc-lead mineralization, are rocks of the approximate stratigraphic level of the Bituminous Member a possible source of zinc and lead at the Pine Point ore-field? Is there a possible depletion in metals within shale and mudstone at this stratigraphic level as the Pine Point ore-field is approached? Does the presence of the metals in the rocks analyzed reflect large-scale exposure of metal-rich terrane in the Canadian Shield during deposition of the metal-rich sediments? How do the shales and mudstones analyzed compare with others of the Horn River, Fort Simpson, Besa River, or Road River formations, all of which are basinal equivalents of Paleozoic platform carbonates in western Canada? These questions must be viewed in the broader context of basin history, including initial deposition and dewatering, burial history, hydrocarbon generation and fluid migration, and diagenetic mineralogical changes. Further work is planned.

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149. STRATIGRAPHIC RELATIONSHIPS AT THE WESTERN EDGE OF THE MIDDLE CAMBRIAN CARBONATE FACIES BELT, FIELD, BRITISH COLUMBIA

Project 720050

I. A. McIlreath
Institute of Sedimentary and Petroleum Geology, Calgary

Near Field, British Columbia, the marginal and associated facies of a regional carbonate complex outcrops in the Middle Cambrian Cathedral Formation. The nature of this carbonate edge, here formally called the "Cathedral Escarpment", has been previously outlined (McIlreath, 1974). Presented here are observations on the general preservation of fossils and the nature of a particular limestone unit in the basinal facies which subsequently filled the basin adjacent to the Cathedral Escarpment.

In the Wapta Mountain area, the Cathedral Escarpment accounts for both the localization and the preservation of the famous Burgess Shale fauna. Firstly, as Fritz (1971) has shown, the Burgess Shale fauna is found in the thick, or basinal facies of the Stephen Formation immediately adjacent to the escarpment. Similar concentrations of fossils, mainly trilobites but including a few soft-bodied forms as well, are found at four other localities, each of which is adjacent to the embayed Cathedral Escarpment; these are the famous Mount Stephen "fossil beds" (McIlreath, 1974), and localities on Mount Field, Mount Stephen, and the west flank of Mount Odaray. Trilobites of the species that crowd these localities are found elsewhere in the basinal or "thick" facies of the Stephen Formation, but nowhere in such numbers. Clearly, the escarpment in some way provided a favourable environment.

Secondly, at Fossil Ridge the competent carbonate rocks of the Cathedral Escarpment caused the Wapta Mountain thrust fault to be deflected upward, so as to pass above the Cathedral Formation (Fig. 1), as suggested by J. D. Aitken (pers. comm., 1972), and confirmed by recent detailed mapping by the writer. As a result of this deflection, fossils between the fault and the Cathedral Escarpment have not undergone the extensive deformation and destruction seen in fossils collected farther basinward.

Following establishment of the Cathedral Escarpment and associated carbonate facies, the adjacent basin was filled predominantly with slightly calcareous, nonfissile mudstone and limestone. One of these limestone units is of particular importance in that it contains trilobites which also occur in the adjacent carbonate platform-shelf facies, thereby allowing Fritz (1971) to establish that the minimum depth of water in the basin was 680 feet (207 m) during deposition of this limestone. Fritz (ibid.) named this particular limestone the "boundary limestone" since faunules of the *Glossopleura* and

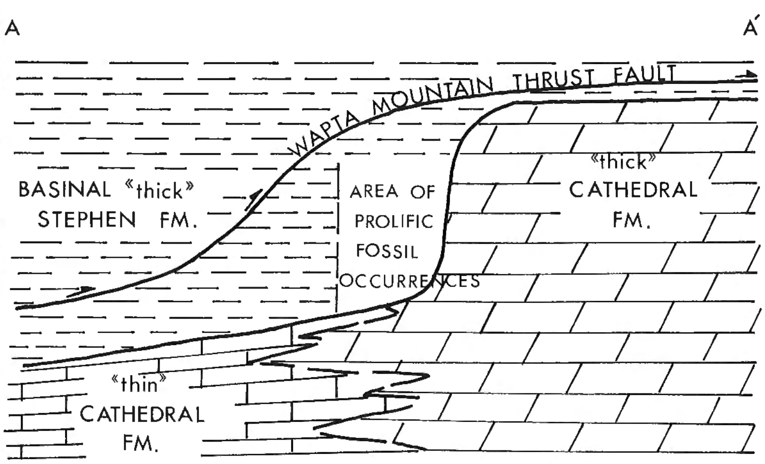
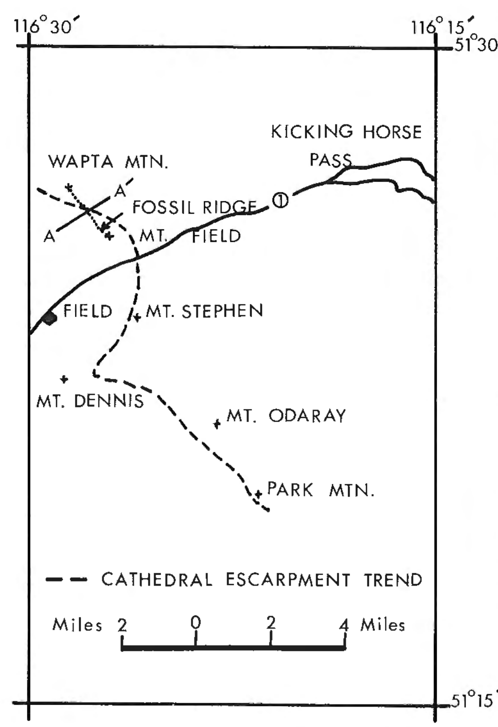


Figure 1. Schematic stratigraphic cross-section (A–A') illustrating area of prolific fossil occurrences in the basinal Stephen facies and the deflection of the Wapta Mountain thrust fault.



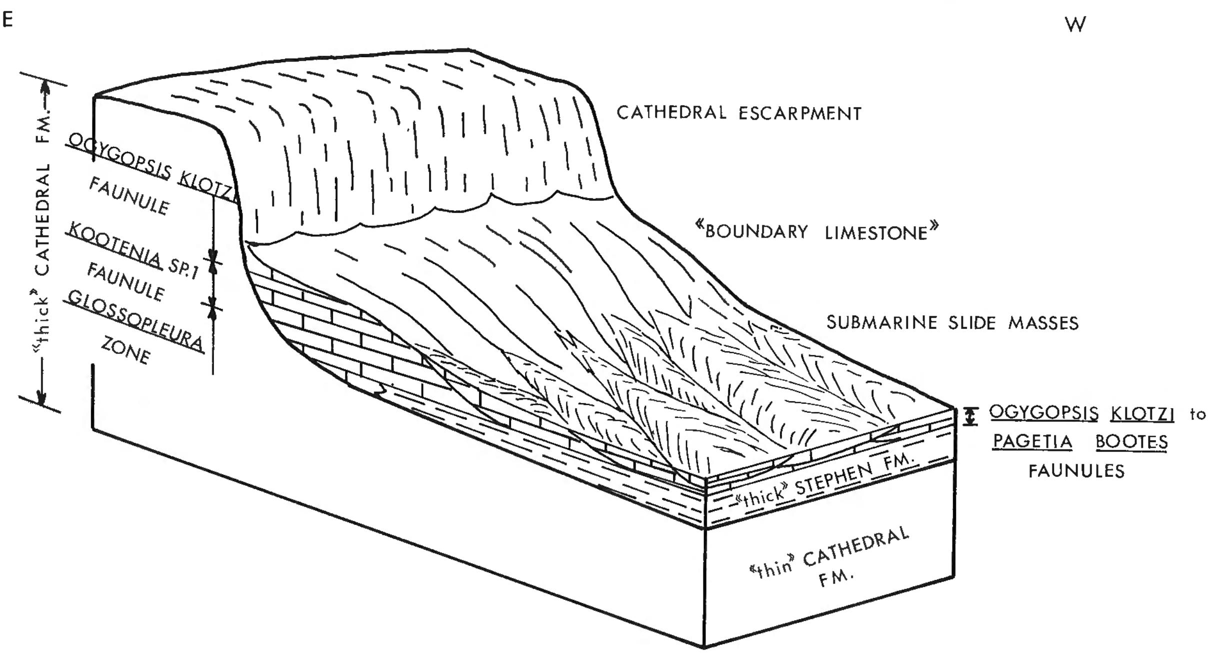


Figure 2. Schematic model illustrating nature of accumulation of «boundary limestone».

Bathyuriscus-Elrathina zones are present at the base and top, respectively.

The boundary limestone is best exposed on the north face of Mount Stephen. Here, recent detailed study by the writer has shown that it varies in thickness from more than 300 feet (90 m) adjacent to the Cathedral Escarpment to less than 30 feet (9 m) approximately 0.8 mile (1.3 km) basinward. Where the unit is thickest adjacent to the escarpment, the lithology varies from predominantly thin-bedded lime mudstone to massive bioclastic pelletoid packstone. Much of the particulate component may have originated on the adjacent carbonate shelf and then been swept over the marginal edge. Trilobites are especially plentiful here with species collected by the writer and identified by W.H. Fritz (pers. comm., 1974) as being from the *Glossopleura* Zone in the basal part succeeded by successively younger species from the *Kootenia* sp. 1, *Ogygopsis klotzi* and *Pagetia bootes* faunules of the *Bathyuriscus-Elrathina* Zone.

The lithology of the thinnest (most westerly) part of the unit contrasts markedly with the thick, easterly part, which consists of thin-bedded, dark grey to black lime mudstone. This mudstone is cut by repeated, well-defined slip surfaces demarcating the base of individual lensoid-shaped, submarine slump masses. These slump masses thicken toward their basinal end and are directed into the basin. Rare trilobites found within these mudstones consistently belong to the *Ogygopsis klotzi* or *Pagetia bootes* faunule (identified by Fritz, pers. comm., 1974).

By tracing slip surfaces along the north face of Mount Stephen, and keeping in mind the faunal content of the slip-bounded masses, one can demonstrate that, away from the escarpment, the boundary limestone consists of a series of prograding, *en echelon* stacked slide masses with the youngest being farthest basinward (Fig. 2). Presumably these mudstones are derived from the flank of the thicker accumulation at the toe of the carbonate escarpment which began to form earlier in *Glossopleura* time. Therefore, it is only near the Cathedral Escarpment that the boundary limestone contains fauna both of the *Glossopleura* and *Bathyuriscus-Elrathina* zones.

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150. GEOLOGY OF BANKS ISLAND, DISTRICT OF FRANKLIN

Project 720061

Andrew D. Miall
Institute of Sedimentary and Petroleum Geology, Calgary

Introduction

Four and one half weeks were spent on Banks Island studying all the pre-Beaufort sedimentary rocks exposed in the area. The author benefited from the independent work of A.S. Greene (senior assistant), who measured many of the stratigraphic sections.

Some of the principal results of the field work are described below.

Structural Setting

In an earlier report (Miall, 1974b), several new structural elements were defined and named, on the basis of gravity data (Stephens *et al.*, 1972) and subsurface well control (Miall, 1974a, c). Field work in southern Banks Island (in particular sedimentologic studies of the Isachsen Formation) has suggested that, as in northern Banks Island, a relationship exists between the configuration of structural elements, as interpreted from gravity, and Cretaceous paleogeographic trends. The sedimentologic evidence will be discussed briefly in a later section. Four new structural units are described below and are shown in Figure 1.

Cape Lambton Uplift is a north-south trending feature, at the core of which the oldest rocks on Banks Island are exposed, namely the lower cherty carbonate member of the Glenelg Formation (Hadrynian). The uplift is delimited to the east by a fault which juxtaposes Glenelg strata against the Christopher Formation. On the flanks of this uplift is Nelson Head Graben (described, but not formally named by Thorsteinsson and Tozer, 1962), a small feature infilled with Cretaceous rocks, which probably underwent active fault movements during the Cretaceous.

De Salis Uplift and Cardwell Basin are complementary structures in the southeast quadrant of Banks Island. The evidence for the existence of the uplift (apart from gravity data) is limited to a present-day exposure of Precambrian rocks at Pass Brook (loc. 11, Fig. 1), near the culmination of this structure. There are no other convincing stratigraphic or sedimentologic data which would indicate that De Salis Uplift was tectonically active during the Cretaceous. By contrast, there is good paleocurrent evidence indicating that on the east flank of Cardwell Basin the direction of local paleoslope during Isachsen times was close to what is the present-day direction of structural dip, suggesting that the basin was defined by at least Early Cretaceous time. It is, therefore, a depositional as well as a structural basin.

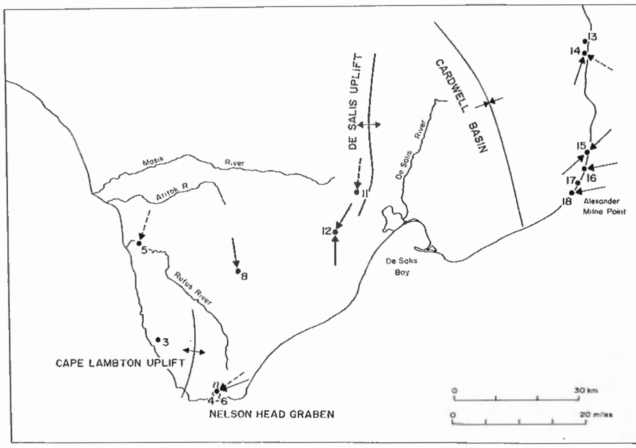

Figure 1. Southern Banks Island, showing structural elements, locations of outcrops of Isachsen Formation with field station numbers, and Isachsen (plus early Christopher?) paleocurrent trends. Paleocurrent data include planar and trough crossbedding (solid arrows) and ripple-marks (dashed arrows). Numerical data and location names are given in Table 1. North to top of page.

Hadrynian Stratigraphy

Two sections were measured through portions of the Glenelg Formation. At Cape Lambton, 87 m (285 ft.) of a lower cherty carbonate member are exposed. Small domal stromatolites are present and the unit is brecciated locally and extensively silicified. Pyrite mineralization was noted also. The upper sandstone member is exposed at Nelson Head, where it has been intruded by several thick diabase sills. A section 393 m (1,290 ft.) thick was measured excluding any thickness of diabase. The sandstone is quartzose, fine to medium grained and contains abundant medium-scale planar crossbedding, much of which is deformed or overturned as a result of penecontemporaneous soft-sediment deformation (Fig. 2). Parting lineation also is abundant. Fifty-three azimuth readings were obtained from the directional sedimentary structures, and these give a mean azimuth of 320° and a vector magnitude (expressed in terms of per cent) of 65 (method of Curray, 1956). Interbedded with the sandstone are units of interlaminated, very fine grained sandstone and dark red sandy siltstone containing abundant small-scale ripple-marks. The sandstone units within the upper member of the Glenelg are interpreted as fluvial or deltaic in origin, and the interlaminated units are thought to have been deposited under the influence of tides. The sedimentary successions and interpreted environments are similar to those described by Young (1973) from his work on the Glenelg in Victoria Island.

Mesozoic and Tertiary Stratigraphy

The major part of the 1974 field work consisted of stratigraphic and structural mapping of the Mesozoic and Tertiary rocks in the two parts of Banks Island where reasonably abundant exposure is available: south of latitude 72°N and within the general area of Northern Banks Basin. The sedimentology of the coarser clastic units in the latter area was summarized in an earlier report (Miall, 1974b). Field work in 1974 confirmed most of these earlier results, although it is now known that most of the outcrops of sand in the Antler Cove area that had been assigned to the Isachsen Formation (Miall, 1974b) in fact should be reassigned to two younger units, as described below.

1. Isachsen Formation

The same general succession of lithologies and sedimentary structures recognized in Thomsen River area (Miall, 1974b) is present also in the area of Cape Alexander Milne, in southern Banks Island. Elsewhere there are major differences in the stratigraphy, as follows: At Rufus River (loc. 5, Fig. 1) in part of Nelson Head Graben, and on the flanks of the plateau eroded in the Devonian rocks 72 km (45 miles) north-northwest of Johnson Point, the basal Cretaceous beds are more typical of the Christopher Formation than of the Isachsen, i. e. they are composed predominantly of shale and siltstone with minor sand interbeds. A similar relationship at Cape Crozier has long been known (Thorsteinsson and Tozer, 1962, p. 61). All these localities may have been uplifted throughout Isachsen time. At Sandhill River (loc. 15, Fig. 1), a section 165 m (541 ft.) thick was measured above the Precambrian basement. Sands, silts, shales and coal beds are interbedded throughout this section, a succession unlike either "typical" Isachsen or "typical" Christopher. Lastly, on the west side of Nelson Head Graben, the Isachsen contains a coarse basal sandstone unit 87 m (285 ft.) thick which is entirely absent on the other side of the graben 1.6 km (one mile) to the east (Fig. 3). The unit is pebbly throughout, and contains several lenses of boulder conglomerate with clasts up to 50 cm in diameter, all composed of Glenelg sandstones (Fig. 4).

The interpretation which has been made from the Sandhill River and Nelson Head data is that Cape Lambton Uplift was a local source area during Isachsen time. Subaerial alluvial fan sedimentation took place in a tectonically active Nelson Head Graben and high sinuosity

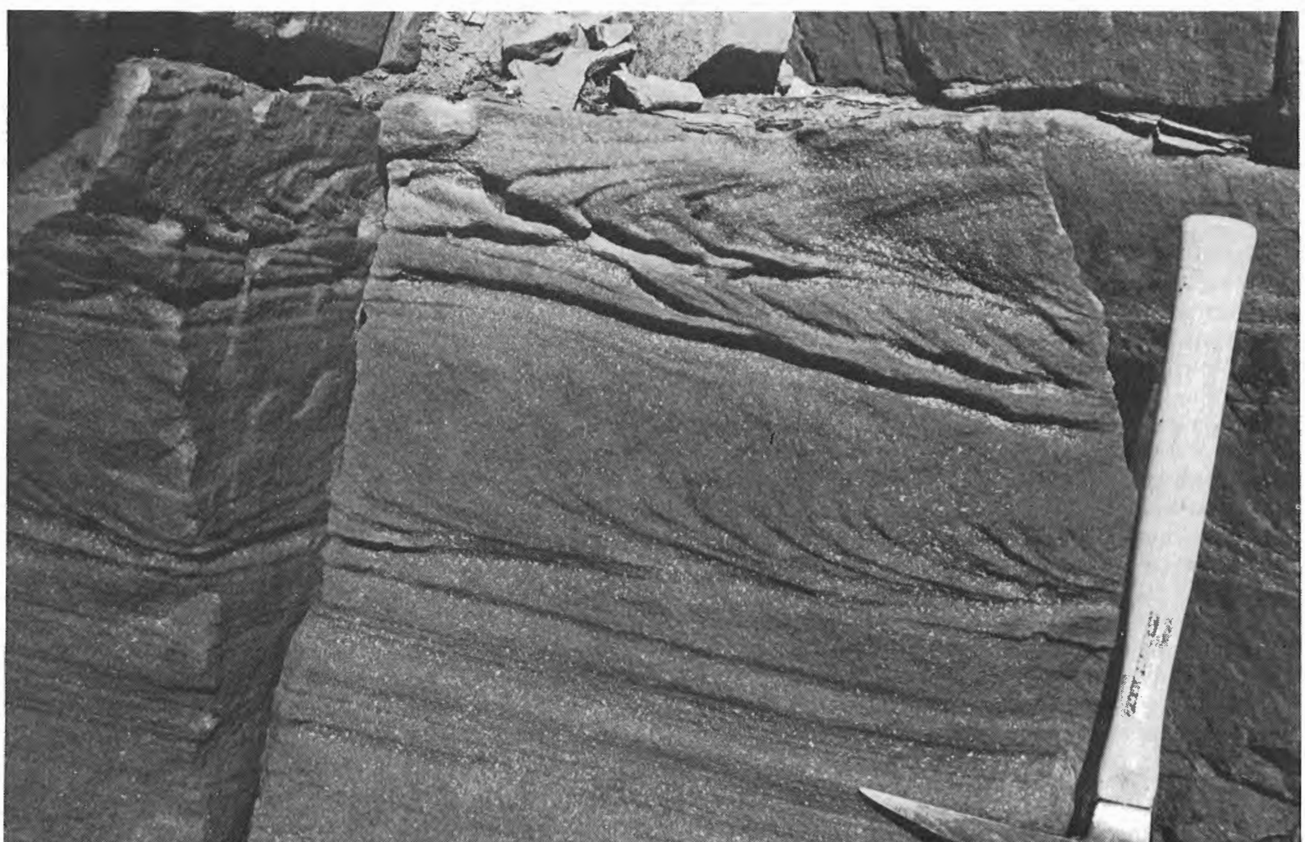

Figure 2. Deformed planar crossbedding in the sandstone member of Glenelg Formation, Nelson Head.

Figure 3. Thinly bedded, soft, carbonaceous shales and fine- to medium-grained sands of Christopher type, resting on the Glenelg Formation, east side of Nelson Head Graben.

Table 1

Paleocurrent data for the Isachsen and lowest Christopher Formations of southern Banks Island

Loc. no.	Loc. name	Struct. scale	n	Θ	L	S^2	P
4, 6	Nelson Head	ℓ	5	248	89.5	760	0.018
4, 6	Nelson Head	s	8	234	73.0	2120	0.014
5	Rufus River	s	14	197	92.4	520	$<10^{-5}$
8	Nelson River	ℓ	8	171	86.5	1020	0.003
11	Pass Brook	s	29	187	25.9	9020	0.144*
12A	Sandhill River	ℓ	10	211	70.5	2400	0.007
12B	Sandhill River	ℓ	19	0	83.0	1260	$<10^{-5}$
14	Schuyter Point	ℓ	4	20	53.7	4230	0.316*
14	Schuyter Point	s	5	303	98.8	35	0.008
15A	Alexander Milne Pt.	ℓ	17	49	67.7	2550	$<10^{-3}$
15B	Alexander Milne Pt.	ℓ	16	228	88.8	870	$<10^{-5}$
16	Alexander Milne Pt.	ℓ	13	262	71.0	2300	0.001
18	Alexander Milne Pt.	ℓ	22	261	88.2	900	$<10^{-7}$

n = number of observations;
Θ = vector mean azimuth;
L = vector magnitude per cent;
S^2 = variance;
P = probability of randomness (Rayleigh test);
* = mean azimuth not significant at 95% confidence level;
ℓ = large scale (trough and planar) cross-stratification;
s = small-scale (ripple) cross-stratification.

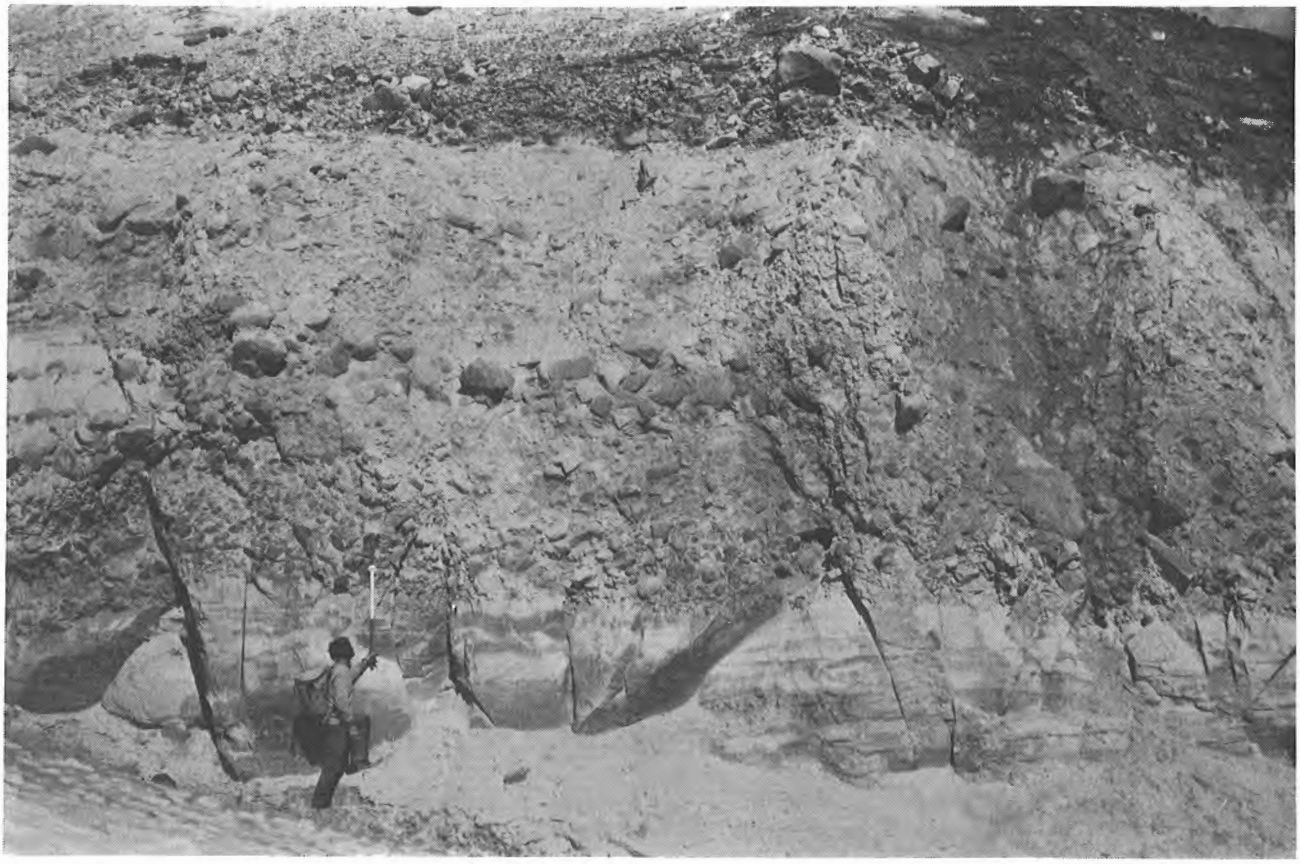

Figure 4. Boulder conglomerate at top of a 75-m (246 ft.) thick basal Isachsen sandstone, west side of Nelson Head Graben. Locations at which Figures 3 and 4 were taken are approximately one mile apart.

fluvial sedimentation occurred in the Sandhill River area while the Rufus River area remained part of the uplift until Christopher time. The upper part of the Sandhill River section may be of Christopher age.

Paleocurrent data (Table 1) are now known to be generally bimodal throughout much of Banks Island. In addition to location 26 of the 1973 section (reported *in* Miall, 1974b, Figs. 2, 3), location 30 (1973) and locations 12 and 15 (1974, *see* Fig. 1 of this report) have yielded strongly bimodal results. In each case, one mode is interpreted as the result of a craton-derived fluvial system, and the other may have several origins. In Northern Banks Basin, a fluvial system flowing along the trough axis is indicated, whereas in southern Banks Island the second mode, a northward-directed fluvial system, may be a part of the run-off from Cape Lambton Uplift. The data indicating southward-directed paleocurrents at locations 5 and 8 (Fig. 1) were obtained from beds of Christopher type, which may be partly of marine origin. Therefore, it may be inappropriate to include these particular results in any synthesis of Isachsen paleogeography.

Of the sand units mapped at Antler Cove, only location 35 (*see* Fig. 2 *in* Miall, 1974b) is now thought to be, in fact, Isachsen Formation. Locations 1, 4-6, 7, 9 and 11 (op. cit.) have been dated as Maastrichtian in age, and probably are equivalent to the "white sand" of Jutard and Plauchut (1973). These formational reassignments are based on unpublished palynological work by W. S. Hopkins, Jr., more of which is currently under way using 1974 field samples.

2. Christopher Formation

Several sections were measured in this unit, the thickest of which was located at Atitok River (Fig. 1) where 182 m (597 ft.) of beds are exposed. The formation is probably, in fact, in the order of 300 m (1,000 ft.) thick in this area.

Several previously unpublished fossil localities were discovered during the course of the field work, all of which yielded pelecypods. At several localities, ammonites were collected and, at one locality near Masik River, a crustacean(?) specimen was obtained.

3. Hassel Formation

The Hassel Formation is believed to be absent in southern Banks Island. Apparently it also is absent near Investigator Point, on the west side of Mercy Bay (northern Banks Island). Good exposures are present on the lower Thomsen River, and were described by Miall (1974b). Outcrops visited in 1974 include one located 6.4 km (4 miles) southeast of Cape Crozier (loc. MLA-74-44, Lat. 74°28'N, Long. 121°03'W). Others are present on Able Creek and Muskox River, but provide little new information beyond that already reported. They include the thickest section of Hassel measured by the author, at 27 m (89 ft.).

4. Kanguk Formation

The red-weathering bituminous shale member at the base of the Kanguk yielded macrofossils at one locality. These include crushed inoceramid pelecypods and delicate bones and fins of a marine vertebrate, as yet unidentified. The collections were made near Muskox River (loc. MLA-74-104, Lat. 73°44'N, Long. 120°24'W). Most of the material is preserved in large spheroidal, calcareous concretions.

The Kanguk contains two sand members, one is present in the subsurface and was reported on elsewhere (Uminmak well, *see* Miall, 1974c). The other occurs at the top of the formation and was referred to as the "white sand" by Jutard and Plauchut. It is particularly well exposed in the Antler Cove region (outcrops formerly referred to Isachsen Formation, as discussed above). Lithologies and sedimentary structures in both these members suggest a similar mode of origin to that of Hassel Formation, i.e. tidal sand bars.

5. Eureka Sound Formation

As part of a statistical study of cyclic deltaic sedimentation in the Eureka Sound Formation, nine sections, totalling 513 m (1,683 ft.) were measured during the 1973 field season and enabled a cyclic model for the formation to be developed using Markov chain analysis (Miall, 1974b). During the 1974 season, seventeen sections totalling 900 m (2,953 ft.) were measured within the formation in Northern Banks Basin. The new field data should provide for a considerable expansion and elaboration of this study.

The outcrop sections of Northern Banks Basin may be divided into those of Paleocene age, occurring along the flanks of the basin, and those of Eocene age, near the axis of the basin. Several trends have been detected between these two groups of outcrops. They are as follows: with decreasing age

1. sand/shale ratio increases
2. mean sand bed thickness increases
3. percentage of section composed of clastic cycles increases
4. sand/shale ratio within the cycles increases.

All these trends indicate that the influx of sand detritus increased in quantity and extended farther into the basin from Paleocene to Eocene time, presumably in response to continued uplift in the source area. Large-scale deltaic progradation into the basin clearly must have occurred during Paleogene time, in addition to the smaller-scale progradation which is demonstrated by the coarsening upward clastic cycles of Miall (1974b).

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151. MOUND-LIKE CARBONATE ROCKS OF EARLY CRETACEOUS (ALBIAN) AGE ADJACENT TO HOODOO DOME, ELLEF RINGNES ISLAND, DISTRICT OF FRANKLIN

Projects 680064 and 710069

W.W. Nassichuk and K.J. Roy
Institute of Sedimentary and Petroleum Geology, Calgary

Hoodoo Dome is a closed structure about six miles (9.7 km) wide and ten miles (16.1 km) long centred on Meteorologist Anticline which extends for at least forty miles (64.3 km) on Meteorologist Peninsula, southeastern Ellef Ringnes Island (Fig. 1). The entire dome probably was induced by diapirism but contorted evaporitic rocks outcrop only in a roughly circular, 3.9 km^2 (1.5 sq. mi.) upland on the western edge of the dome (Fig. 2). These evaporitic rocks (anhydrite and gypsum) were derived from the Carboniferous Otto Fiord Formation which is widespread in interior regions of the Sverdrup Basin. McLaren (1963) reported the occurrence of a variety of Carboniferous brachiopods and a solitary coral from a limestone block derived from the piercement near the southeastern edge of the evaporite mass. The Otto Fiord has been studied in considerable detail throughout the basin by Davies and Nassichuk (in press) and will not be dealt with here. The purpose of this paper is to describe carbonate mounds which occur in the Christopher Formation adjacent to evaporites in Hoodoo Dome and which suggest that Hoodoo Dome was a positive topographic feature during the Early Cretaceous.

Sandstone belonging to the Lower Cretaceous (Neocomian) Isachsen Formation surrounds evaporitic rocks on Hoodoo Dome except along the southern edge of the evaporitic mass where shale of the slightly younger Cretaceous (Albian) Christopher Formation has been downfaulted against the evaporites (Fig. 1). In this area, two isolated mound-like bodies of fossiliferous, argillaceous limestone occur within the Christopher Formation; precise stratigraphic relationships of the mounds are rendered obscure by limited outcrop locally and by general structural complexity in the area. Comparable limestone bodies, however, are unknown elsewhere from the Christopher. Sedimentological implications that might be drawn from the occurrence of these mounds adjacent to evaporitic rocks in Hoodoo Dome are described in a preliminary manner in this report. The two mounds probably occupy a common stratigraphic level and are 30 m (98.4 ft.) apart from one another; bedding in the larger of the mounds dips 50 degrees northward toward evaporites. The smaller mound, roughly circular in plan, has a diameter of about one m (3.3 ft.) and a relief of 0.3 m (0.98 ft.). It is composed of dark grey, fetid, rubbly limestone weathering pale brown; it contains an abundance of pelecypods and fewer ammonoids in a dense matrix of bioclastic debris and some minor quartz grains cemented by clear calcite. Some vugs are lined with lamellar calcite; centres of vugs and some fossils contain sparry calcite. The other mound is elongate in plan, measuring about one metre by three m (3.8 by 9.8 ft.) and has a relief of about 2 m (6.6 ft.) (Fig. 3). It is a biolithite, and

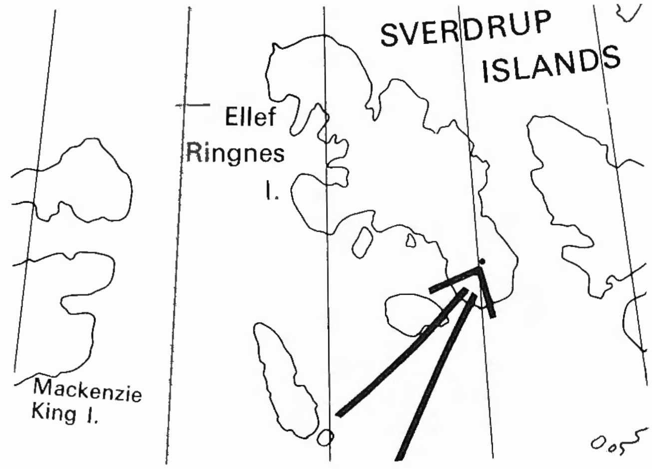

Figure 1. Index map showing location of Hoodoo Dome.

is more than 50 per cent composed of serpulid worm tubes. These tubes are calcareous and were secreted by individual worms. The tubes and minor wood fragments are cemented by multi-generation lamellar calcite cement which in part fills small caverns. Limestone in this mound is dark grey, vuggy and fetid; some vugs, lined with sparry calcite, are filled with bitumen. Some of the worm tubes are filled with concentric layers of calcite and others with clear sparry calcite while still others contain a pale green micrite. Most tubes show geopetal filling along the horizontal axis indicating a position of recline while others have geopetal fillings indicative of a vertical growth position. In the field, tubes appear parallel to or slightly oblique to bedding. Cement between tubes resembles that which fills some tubes; that is, multi-generation lamellar and botryoidal calcite indicative of open-space filling. Faecal pellets are common in and between tubes (Fig. 6).

Jeletzky (pers. comm., 1974) identified the ammonoids and pelecypods from GSC locality C-33731, in the smaller of the two mounds, as *Arcthoplites* (sensu lato) n. sp. indet [rare], *Callizoniceras* (*Colvillia*) ex aff. *crassicostata* Imlay, 1961 [rare], and nuculid pelecypods (gen. et sp. indet.) [mass occurrence]. Jeletzky suggested an Early Albian age and correlation with the upper but not the uppermost part of the Christopher Formation. According to Jeletzky, comparable faunas are not known from elsewhere within the Sverdrup Basin but have been reported from the basal part of Albian sequences on Anderson Plain, east of the Mackenzie Mountains (Jeletzky, 1964) as well as northern Alaska (Imlay, 1961). The exact position of both the Anderson Plain and northern Alaska faunas in the Standard Succession of Lower Albian ammonite

Figure 2. Air photograph showing relationships between Cretaceous evaporites (Co) and Cretaceous rocks near the western edge of Hoodoo Dome, Ellef Ringnes Island; K_i = Isachsen Formation, K_c = Christopher Formation, K_h = Hassel Formation and K_k = Kanguk Formation. Arrow indicates position of carbonate mounds.

Figure 3

Outcrop of larger of two mounds described in the text as containing serpulid worm tubes.

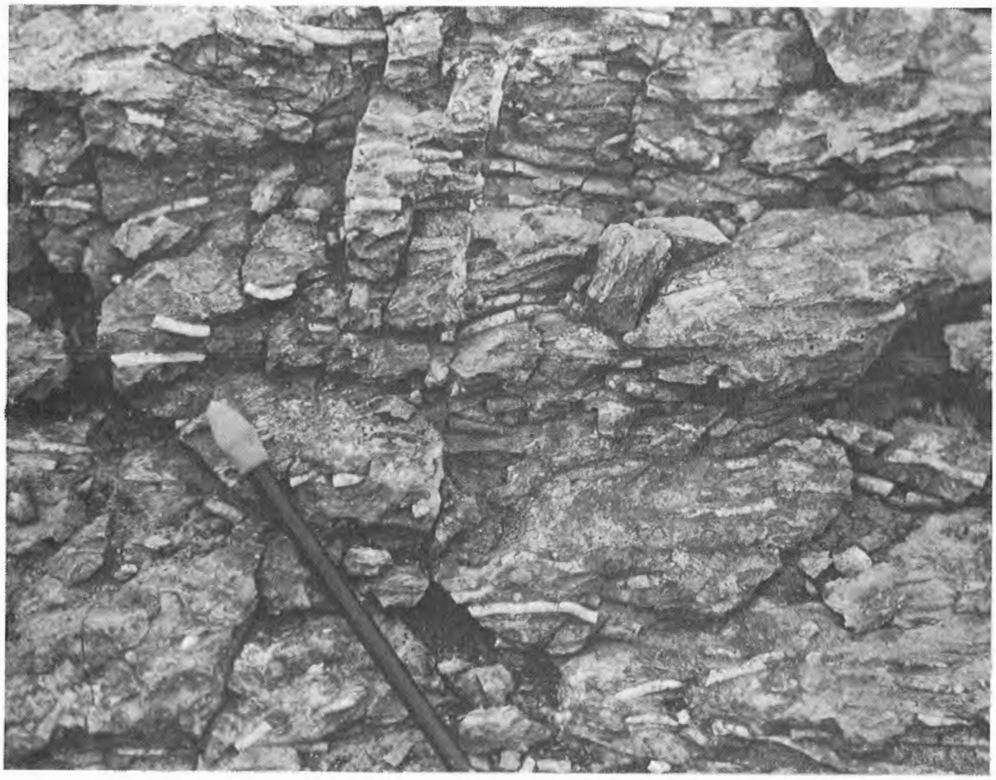

Figure 4

Closeup photograph showing serpulid worm tubes from mound shown in Figure 3.

zones remains uncertain. However, they seem to be better referable either to the *Sonneratia* (sensu lato)? n. sp. A zone or to the *Cleoniceras* aff. *subbaylei* zone than to any of the overlying Lower Albian zones of the Canadian standard (Jeletzky, 1964). Jeletzky also suggested that the Hoodoo Dome fauna occurred in an ?inner neritic or ?lower littoral facies; that is, shallower than 'normal' Christopher deposition. The abundance of the fauna identified in this report by Jeletzky at Hoodoo Dome and its general absence elsewhere in the Christopher Formation might reflect also, particularly on the basis of ammonites, nothing more than preferential preservation in a favourable environment. Similar observations have been made by Nassichuk (in press) for faunas that are abundantly developed in Carboniferous shelf carbonate mounds on Ellesmere Island but which are sparsely preserved in contemporaneous deeper water, basinal black shale.

Classification of fossil Serpulidae is rendered complex in that studies of recent members of the family have shown that different genera may form tubes of the same shape and this also may be true for Cretaceous species. For this reason, the serpulids are described here only in general terms to record their occurrence, and detailed taxonomy must be dealt with elsewhere. By way of a preliminary comparison, however, Hoodoo Dome serpulid tubes show a rather strong resemblance to *Jereminella* Lugeon from Cretaceous rocks in France and at least a superficial resemblance to *Serpula quadristriata* Goldfuss from Upper Jurassic strata in Germany. Individual tubes are cylindrical and maintain a more or less common diameter throughout their length; they range in diameter from 5 mm to 9 mm and some attain a length of 80 mm. Tubes are straight or slightly curved and have a preferred orientation so that they appear to be colonial. Tubes have two thin concentric laminar layers but only the inner layer, darker in colour than the outer, is preserved on most specimens. The inner layer consists of fine calcite sheaths parallel with the longitudinal axis; the surface contains a network of fine discontinuous parting lines. The outer layer is thicker than the inner and consists of clear calcite.

The Christopher Formation generally comprises marine shale in interior regions of the Sverdrup Basin but minor sandstone may be intercalated with shale nearer the edge of the basin. On Ellef Ringnes Island, thin limestone beds, up to 45 cm thick, are interbedded with shale near the base of the formation in the general vicinity of Isachsen Dome (Heywood, 1955). Similar observations of thin limestone beds or calcareous concretionary beds in the shale have been made near Hoodoo Dome by McLaren (1963), near Dumbbells Dome by Blackadar (1963), and near Malloch Dome by Greiner (1963). Stott (1969) also reported thin limestone beds from near the base of the Christopher on Ellef Ringnes Island. Nowhere in the literature has reference been made to mound-like carbonate bodies within the formation. McLaren (1963), however, reported lamellar structures from limestone bands in the Christopher shale near Hoodoo Dome. These structures may be similar to the multi-generation lamellar cement found in the mounds described in this report.

Serpulids have not been described previously from Cretaceous rocks in Arctic Canada but Imlay (1961) described species of *Spirorbis* Daudin and *Ditrupa* Berlekey from Arctic regions in northern Alaska. A number of occurrences have been recorded from elsewhere on this continent, particularly in eastern and

Figure 5. Thin-section showing worm tubes encased in multi-generation lamellar calcite cement from serpulid worm tube mound shown in Figure 3.

Figure 6. Thin-section showing serpulid worm tubes, some with geopetal fill, and faecal pellets cemented by multi-generation lamellar and sparry calcite indicative of open-space filling; from serpulid worm tube mound shown in Figure 3.

southwestern regions of the United States. Serpulids have long been known in New Jersey (Weller, 1907) and neighbouring states (Richards and Shapiro, 1963) but occurrences reported from the Glen Rose Limestone in central Texas by Rodgers (1967) may be more relevant to the present study. The Glen Rose serpulids form small "patch reefs" resembling the serpulid mound described in this report. According to Rodgers (ibid.), serpulids in the Glen Rose are associated directly with carbonized wood which is presumed to be the original substrata for the colony. Hoodoo Dome serpulids are associated also with pieces of fossil wood.

Present-day serpulid worm tubes are known to form miniature atolls in Bermuda (Gekker and Ushakov, 1962) and patch reefs and reef fields in Baffin Bay in southeast Texas (Andrews, 1964; Shier, 1969). In Baffin Bay, most patch reefs are less than 30 m (98.4 ft.) in length and only a few tens of centimetres thick. They are initiated on a raised foundation of pelecypod shells and are surrounded now by water 0.5 to 2.5 m (1.6-8.2 ft.) deep. Reef fields, on the other hand, are made up on small reef pinnacles less than a metre (3.3 ft.) in diameter. These project less than a metre (3.3 ft.) above the sandy bottom and are up to 1 m (3.3 ft.) below the present mean sea level. Serpulid worms are filter feeders and therefore are susceptible to siltation; they thrive best in agitated waters. They are geographically wide ranging at the present and occupy a rather wide range of ecological niches. They occur in Arctic as well as tropical regions and may be found either in freshwater or marine environments; in the latter, they occur from near the shore out to the outer continental shelf (Andrews, 1964).

The serpulid reef-rocks of Baffin Bay are cavernous due to the mode of organism growth. Clearly, comparable open spaces once existed in the Hoodoo Dome mounds and these now are filled with lamellar calcite cement.

Relationships of the mounds described in this report to the Hoodoo Dome diapir are little understood because of structural complications but the proximity of mounds to the dome may be of considerable significance. Thorsteinsson (1974) comprehensively reviewed the subject of anhydrite diapirs in the Sverdrup Basin and presented convincing evidence to support the contention that all diapirs on Ellesmere Island and most of those on Axel Heiberg Island were induced by the mid-Cenozoic Eurekan orogeny. Equally convincing stratigraphic evidence is present in the literature to indicate that some diapirs on Ellef Ringnes Island, the area of the present investigation, have been in motion since Late Jurassic or Cretaceous time (Gould and DeMille, 1964; Stott, 1969).

In the Gulf of Mexico, along the Louisiana and Texas coasts, coral and algal reefs grow on topographic highs that overlie salt domes (Forman, 1955). The relief is presumably a result of recent movement of the diapirs and the highs are preferentially colonized by those organisms. If one draws an analogy with the Hoodoo Dome diapir, then the mounds described herein might indicate a topographic high in the Christopher Sea and some diapiric movement during the time of the Christopher deposition.

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REVISED MEGAFOSSIL ZONATION OF MIDDLE AND LOWEST UPPER DEVONIAN STRATA, CENTRAL MACKENZIE VALLEY

Project 680093

A.E.H. Pedder
Institute of Sedimentary and Petroleum Geology, Calgary

During the past few years many Middle Devonian collections from the central Mackenzie Valley have been submitted to the author for identification. These identifications have led to better understanding of the stratigraphic significance of most of the commonly occurring species. They also necessitate some revision, or refinement, of the majority of the previously proposed faunal zones, which is the purpose of the present report.

Several types of faunal zones are used by earth scientists. The zones used here are more properly termed Teilzones and may be defined as a body, or thickness of rock, deposited during the time span of the designated zonal index fossil in the central Mackenzie Valley. The relationship between rock units and the recognized megafaunal zones is shown diagrammatically in Figure 1. None of the zones is known to overlap with any other; indeed, one of the disadvantages of the scheme is that significant gaps occur between some of the zones. This would not be the case if the zonation were based on a succession of orthogenetic taxa. How

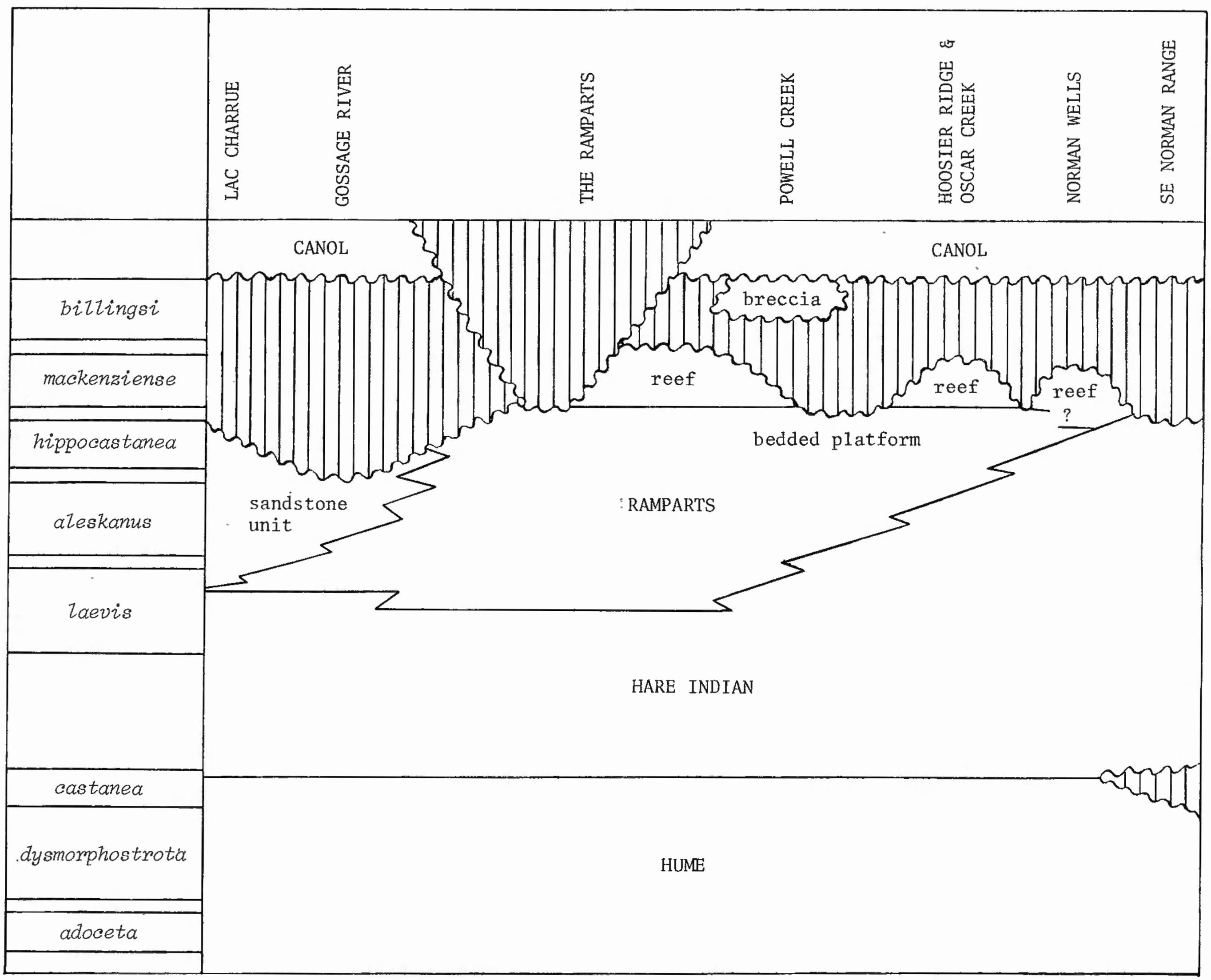

Figure 1. Diagrammatic representation of the relationship between rock units, named and unnamed, and megafossil zones in the central Mackenzie Valley. The figure is not to scale and is simplified. Certain carbonates, such as were encountered between the Ramparts and Hume formations in the Atlantic Col. Car. Manitou Lake L-61 well, are omitted. Megafossils are absent, or so rare in all but the lowest few feet of the lower Hare Indian Formation, that no megafaunal zone can be proposed for this part of the sequence.

ever, it must be remembered that, even if it were possible to erect such a zonation, it would likely be difficult to use, in that large collections normally are required to discriminate species, or subspecies, in evolutionary lineages.

With the exception of *Grypophyllum mackenziense*, which is a rugose coral, the designated index fossils are brachiopods. Each of these brachiopods is well described and illustrated, and is known to have a wide geographic but limited temporal range; moreover, they are readily identified with little or no preparation.

The *adoceta* and *dysmorphostrota* zones are believed now to be Eifelian, that is lower Middle Devonian. The *castanea*, *laevis* and *aleskanus* zones are Givetian, which is the upper stage of the Middle Devonian. The megafossil zones of *hippocastanea* and *mackenziense* correspond to the *hermanni-cristatus* conodont Zone. The long-standing question of whether this should be referred to the Middle (Givetian) or Upper Devonian (Frasnian) is, as yet, unresolved. T.T. Uyeno has identified lowermost *asymmetricus* Zone conodonts in collections from the *billingsi* Zone, which must be regarded, therefore, as early Frasnian.

adoceta Zone

The "*Schuchertella*" *adoceta* Zone was founded by Crickmay (1960, p. 1) and is the lowest of the megafossil zones currently recognized in the Hume Formation. On Anderson River, where the Hume Formation is only 228 feet (69.5 m) thick, it occurs in the basal beds of the formation; in thicker sections in the Franklin and Mackenzie Mountains, the *adoceta* Zone normally occurs 25 to 220 feet (7.9-67.1 m) above the base of the Hume Formation. In northeastern British Columbia and southwestern District of Mackenzie, the index fossil has been found in the Dunedin and Headless formations.

Most of the brachiopods that accompany "*Schuchertella*" *adoceta* extend into overlying zones, but the corals "*Microcyclus*" *multiradiatus* (Meek), *Radiastraea trichomisca* (Crickmay), *R. verrilli* (Meek) strictest sense and *Taimyrophyllum triadorum* Pedder probably are diagnostic of the zone.

In addition to the original description (Crickmay, 1960, p. 18, Pl. 10, figs. 10-17; Pl. 11, fig. 1), illustrations of the index species have been given by Warren and Stelck (1956, Pl. 1, figs. 2, 3) and Caldwell (1971, Pl. 1, figs. 1, 2). The generic name is placed in parentheses because "*S.*" *adoceta* is impunctate, whereas *S. lens*, the type species of *Schuchertella*, is pseudopunctate.

dysmorphostrota Zone

This zone closely approximates the *verrilli* Zone of Crickmay (1960, p. 2) and rocks recognized by Norris (1968, p. 773) and Caldwell (1971) as containing the *Spinulicosta stainbrooki* fauna. *Carinatrypa dysmorphostrota* is preferred as the zonal index as both *Radiastraea verrilli* and "*Spinulicosta*" *stainbrooki* occur with "*Schuchertella*" *adoceta* in the basal Hume beds on Anderson River. Typically, the zone's range spans all but the top few feet of the upper quarter of the Hume Formation, although most of the forms considered diagnostic of the zone, including the index species, are normally restricted to the more argillaceous facies of the formation. Their preference for this facies may explain their absence from purer, more massive, but presumably equivalent limestones occurring near the top of the full Nahanni Formation sections of southwestern District of Mackenzie. Brachiopods, identical with, or very close to *Carinatrypa dysmorphostrota*, are known from the lower beds of the Rogers City Limestone of Michigan (Ehlers and Kesling, 1970, Pl. 12, figs. 50, 51) and the Lake Church Formation of Wisconsin (Griesemer, 1965, Pl. 4, figs. 12-14).

Much of the very rich *dysmorphostrota* fauna remains to be described. At present, the occurrence together of "*Atrypa*" *borealis* Warren and either *Spinatrypa andersonensis* or *S. coriacea* are diagnostic of the zone. The following corals are also diagnostic: *Radiastraea tapetiformis* (Crickmay), *Taimyrophyllum stirps* (Crickmay) strictest sense, *Aphroidophyllum howelli* Lenz, *A. meeki* Pedder and *Mackenziephyllum insolitum* Pedder.

The distinctive zone fossil has been described or illustrated in several works: Warren and Stelck (1956, Pl. 2, figs. 14-16); Crickmay (1960, p. 13, 14, Pl. 9, figs. 1-5; 1967, p. 5, Pl. 1, figs. 14, 15); McLaren, Norris and McGregor (1962, Pl. 8, figs. 22-24); Caldwell (1971, Pl. 2, figs. 2a-d); and Copper (1973, p. 496, 497, Pl. 3, figs. 10-13).

castanea Zone

Warren and Stelck (1950, p. 73) were the first to point out that *Leiorhynchus castanea*, in the strict sense, is confined to a narrow stratigraphic inverval in western Canada. They designated this interval the *Leiorhynchus castanea* Zone and referred to the stratum containing it in the lower Mackenzie Valley as the "basal bed of the Fort Creek shale", which, in current terms, is the top few feet (<20) of the Hume Formation, or beds transitional to the overlying Hare Indian Formation. The zone falls within Crickmay's (1960, p. 2, 3, 19) *arctica* Zone, but this zone was ill-founded as it was proposed for the Hare Indian Formation, whereas the name-giving species, *Variatrypa arctica*, occurs commonly in the underlying Hume Formation and only sparingly in the lowermost Hare Indian strata. Beyond the lower and middle Mackenzie Valley region, *Leiorhynchus castanea* is known in the Horn River and Pine Point formations of the Great Slave Lake area, the topmost Nahanni and Dunedin formations of southwest District of Mackenzie and northeast British Columbia, and also in the Woodpecker Limestone of Nevada (Johnson, 1970, Pl. 2, figs. 12-17; 1971, Pl. 43, figs. 27-31).

Leiorhynchus castanea typically occurs in great numbers and commonly dominates the fauna. Other brachiopods that appear to be equally diagnostic of the zone are *Pentamerella*(?) *borealis* (Meek), *Cassidirostrum pedderi* McLaren and *Warrenella kirki* (Merriam), although it must be noted that, in Nevada, *Warrenella* *kirki* apparently underlies *Leiorhynchus castanea* (Johnson, op. cit.).

Numerous figures have been published of Canadian specimens of *L. castanea*: Meek (1867, Pl. 13, figs. 9a-c); Warren (1944, Pl. 1, figs. 6-8); Crickmay (1952, Pl. 70, figs. 6, 7; 1963, Pl. 2, figs. 15-22); Warren and Stelck (1956, Pl. 9, figs. 12-16); McLaren (1962, figs. 24, 25; Pl. 14, figs. 2a-6c; Pl. 15, figs. 1a-11c); McLaren, Norris and McGregor (1962, Pl. 9, figs. 1-3, 16-18); and Caldwell (1971, Pl. 2, figs. 3a-4d).

laevis Zone

Warren (1944, p. 116) was perhaps the first to recognize the stratigraphic importance of *Ectorensselandia laevis*, which was then referred to the genus *Rensselandia*, when he wrote of its occurrence: "Ramparts limestone but in a very definite zone below the *Stringocephalus* horizon". More formal recognition of the zone dates from subsequent works by Warren and Stelck (1950, p. 75; 1956, Pl. 4). In their early works, these authors held that *Ectorensselandia laevis* indexed a zone below the zone of *Stringocephalus*. This is known now to be incorrect, as the earliest known species of *Stringocephalus* in the Mackenzie Valley occur in the upper part of the *laevis* Zone. In fact, the two specimens figured by Warren and Stelck (1956, Pl. 5, figs. 1-4) as *stringocephalus burtini*, and considered by them to have come from their *Stringocephalus* Zone, are specimens of *S. asteius* Crickmay and *S. transversa* Grabau, both of which in the Mackenzie Valley are restricted to the upper part of the *laevis* Zone.

In the Ramparts Gorge section, just upstream from Fort Good Hope, *Ectorensselandia laevis* ranges from 83 feet (22.3 m) below the top of the Hare Indian Formation to approximately 50 feet (15.2 m) above the base of the Ramparts Formation. In the same section, the brachiopod identified by Caldwell (1971, Pl. 2, figs. 9, 10) as *Rhyssochonetes aurora* ranges from 90 to 30 feet (27.4-9.1 m) below the top of the Hare Indian Formation. Thus Caldwell's *aurora* fauna or zone corresponds approximately to the lower half of the *laevis* Zone as used here. The zones of *Hadrorhynchia vallorum* and *Stringocephalus asteius*, proposed by Crickmay (1966, p. 33) for the upper 10 feet (3 m) of the Hare Indian Formation and lower 12 feet (3.7 m) of the Ramparts Formation at Ramparts Gorge, also lie within the *laevis* Zone. Although *Cyrtina panda* occurs commonly in the *laevis* Zone, the zone of that name proposed by Warren and Stelck (1950, p. 73) is far from being synonymous with the *laevis* Zone of this report, as Warren and Stelck's *Cyrtina panda* fauna was based on mixed collections from the Waterways and Upper Ramparts *hippocastanea* Zone (*see* Crickmay, 1968, p. 2).

The typical *Ectorensselandia laevis* fauna has not been recognized south of the Ramparts Gorge or north of Payne Creek (lat. 66°49'30"N, long. 129°54'W), nor is it well known in the Mackenzie Mountain Front, although *E. laevis* itself occurs approximately 15 feet (4.6 m) below the top of the Hare Indian Formation on Gayna River. North of this rather restricted area, the typical fauna is displaced by a more richly stromatoporoidal facies. Southward, it appears to have been replaced by darker, less calcareous shale referred to the Hare Indian Formation.

Other species with known ranges falling within the *laevis* Zone are corals best identified as *Argutastrea* sp. cf. *A. arctica* (Meek) and *Stringophyllum* sp. cf. *S. buechelense* (Schlüter), and the brachiopods *Hadrorhynchia vallorum* Crickmay, *Warrenella franklini* (Meek), *Cyrtina panda* Meek (one only of two species confounded in the original description; the other being a Hume species) and *Stringocephalus asteius* Crickmay, which, unlike *Ectorensselandia laevis*, is normally found only in beds containing abundant species of *Stachyodes*. The Mackenzie form commonly identified as *Rhyssochonetes aurora* (probably better assigned to the subspecies *solox* than to the nominate subspecies) is strongly suggestive of the lower part of the *laevis* Zone as its earliest occurrences only just predate those of *Ectorensselandia laevis*.

Description and illustration of the zone-index fossil may be found in the following works: Meek (1867, p. 108, 109, Pl. 13, figs. 8a-e; Pl. 14, fig. 4); Hall and Clarke (1894, Pl. 78, figs. 17-20); Warren (1944, p. 116, Pl. 1, figs. 12, 13); Warren and Stelck (1956, Pl. 4, figs. 2, 3); McLaren, Norris and McGregor (1962, Pl. 9, figs. 4-6); Johnson (1969, p. 832-834, Text-figs. 1, 2, Pl. 105, figs. 1, 2; 1973, p. 1105-1107, Text-fig. 3).

aleskanus Zone

This zone, based on *Stringocephalus aleskanus*, was established by Crickmay in 1963 (p. 27, Table on p. 28) and 1966 (p. 31, 32). In the reference section at the Ramparts of the Mackenzie, it ranges from 59 to 119 feet (18.0-36.3 m) above the base of the Ramparts Limestone. South and southwest from there, it occurs nearer the base of the limestone. Thus at Powell Creek (lat. 65°16'30"N, long. 128°46'W) and Carcajou Ridge (lat. 65°37'45"N, long. 128°14'30"W), its known range is from 2 to 31 feet (0.6-9.4 m) and from 9 to approximately 55 feet (2.7-116.8 m) above the base of the Ramparts Formation, respectively. Northwest from the Ramparts section, the zone is present in thin limestone within an unnamed sandy unit. Several species that are characteristic, but not necessarily diagnostic of the zone, including an undescribed species of *Moravophyllum* and the gastropods *Mastigospira alata* and *Buechelia tyrrelli*, are known also from the Sulphur Point Formation of Great Slave Lake and the Dawson Bay Formation of Manitoba (McCammon, 1960). Crickmay (1968, p. 11) has suggested that the zone index may be present in the Ramparts Limestone equivalent of the Sentinal Mountain area of British Columbia, but adequate evidence for this has not yet been presented.

Pending further descriptive work on the fauna of the zone, the only fossil absolutely diagnostic of it is *Stringocephalus aleskanus* itself. This has been described and figured by Crickmay (1962, p. 12, 13, Pl. 1, figs. 10, 11; Pl. 6, figs. 1-6, Pl. 8, figs. 4-7; Pl. 9, figs. 1-3; 1968, p. 11, Pl. 10, figs. 1-7); and by

Caldwell (1971, Pl. 3, fig. 2). However, the corals *Temnophyllum decaeni* Pedder and *T. richardsoni* (Meek), which have been described recently (Pedder, 1972), and *Argutastrea arguta* Crickmay (*see* Hill and Jell, 1970, p. 51, 52, Pl. 12, figs. 1a, b) have only very slightly greater ranges than *Stringocephalus aleskanus*. They are not, for example, known to the writer from either the underlying *laevis* or overlying *hippocastanea* zones.

hippocastanea Zone

The *Leiorhynchus hippocastanea* Zone was proposed by Crickmay in 1960 (p. 3) and was said to be present in a well-bedded limestone known as Beavertail, which was believed to overlie the Ramparts Limestone, or to be "merely equivalent to the uppermost beds of Ramparts reef of places where bioherm makes up most of that formation". The fauna listed as representative of the zone contained essentially the same mixture of Ramparts and Waterways fossils that previously had constituted Warren and Stelck's (1950, p. 73; 1956, Pls. 8, 9) *Cyrtina panda* Zone. These errors were corrected eventually by Crickmay himself (1968, 1970), who was the first to demonstrate the true position of the *Leiorhynchus hippocastanea* fauna above the last occurrences of *Stringocephalus* in the Mackenzie Valley and below the Rampart reefs, which he assigned to the Beavertail Formation. Crickmay, however, remained mistaken on one important point, and that was his belief that the reefs are separated by a significant unconformity from the underlying platform beds. Any sedimentary break that may exist between the reefs and platform beds is certainly of minor significance, since conodonts, indicative of the *hermanni-cristatus* Zone, have been recovered from both the *hippocastanea* and *mackenziense* zones (T.T. Uyeno *in* Lenz and Pedder, 1972, p. 36, 37).

Leiorhynchus hippocastanea occurs in the Ramparts Limestone from Oscar Creek (lat. 65°30'N, long. 127°21'W) to the Ramparts of the Mackenzie. At the latter locality, the zone ranges from approximately 122 to 164 feet (37.2-50.0 m) above the base of the Ramparts Limestone. Northwest of Fort Good Hope, the zone fossil and some of its usual associates have been found near the top of the unnamed sandy unit, mentioned above. At many of the outcrops of this unit, the facies is so arenaceous that fossil shell material has been leached completely away, resulting in cast and mould preservation. The *hippocastanea* Zone has been recognized in the Denay Limestone of Nevada (Johnson, 1970) and is reported also in the Great Slave Lake area of southern District of Mackenzie (Crickmay, 1966, p. 16), where it occurs 70 to 90 feet (21.0-27.4 m) below *Ladogioides kakwaensis* (=*billingsi* Zone), and on Whistler Mountain (lat. 56°26'N, long. 123°32'W), British Columbia, where it is said (Crickmay, 1967, p. 8) to occur 350 feet (106.7 m) above *Stringocephalus axius* (possibly equivalent to the *laevis* Zone) and 700 to 800 feet (213.4-243.9 m) below *Eleutherokomma killeri* (younger than the *billingsi* Zone shown in Fig. 1).

Typically, the *Leiorhynchus hippocastanea* fauna is dominated by brachiopods, many of which have been described. Those that appear to be diagnostic of the zone include: *Schizophoria mcfarlanei* (Meek), *Helaspis caurina* Crickmay, *Productella gulosi* Crickmay, *Stelckia galearius* Crickmay, *Hadrorhynchia sandersoni* (Warren), *Ladogioides mollicomus* Crickmay, *Leiorhynchus optimum* Crickmay, *L. rhabdotum* Crickmay, "*Atrypa*" *percrassa* Crickmay and *Warrenella occidentalis timetea* Crickmay.

Descriptions and figures of the zonal index have been provided by Warren and Stelck (1956, Pl. 8, figs. 29-31); Crickmay (1960, p. 13, Pl. 9, figs. 10-17; 1963, p. 9, Pl. 2, figs. 1-14); Johnson (1970, p. 2099, 2100, Pl. 3, figs. 6-17); and Caldwell (1971, Pl. 3, figs. 5a-6).

mackenziense Zone

Although the zone of *Grypophyllum mackenziense* was proposed first by the present writer (*in* Lenz and Pedder, 1972, p. 36, 37), the stratigraphic importance of the zone marker had been made known previously by Crickmay (1968, p. 1-3; 1970). The zone has been recognized (Pedder, 1973) over a wide area in western Canada extending from the platform of the Swan Hills Formation of west-central Alberta, to the Slave Point Formation of northern Alberta and southern District of Mackenzie, and to reefs of the Ramparts Formation (broad sense), as far north as the south end of the Ramparts of the Mackenzie. In the reference section at the Ramparts of the Mackenzie, the zone fossil ranges from 170 to 220 feet (51.8-67.1 m) above the base of the Ramparts Limestone. North of this section, rocks of this age were not deposited, or were removed by either pre-Canol or pre-Cretaceous erosion.

The zone is confined to beds containing abundant tabulate corals and stromatoporoids which greatly outnumber the more stratigraphically important rugose corals and brachiopods. Described species, which, for the present at least, may be regarded as co-markers of the *Grypophyllum mackenziense* Zone are *Temnophyllum lenzi* Pedder, *T. macconnelli* Pedder, *Emanuella vernilis* Crickmay and *Ladjia landesi* Crickmay.

Description and figures of the zonal index were published by the writer in 1963 (p. 133, 134, Pl. 19, figs. 1-6) and 1973 (p. 107-111, Text-figs. 48-58, Pl. 13, figs. 7-12; Pl. 14, figs. 1-8; Pl. 15, figs. 1-3, ?4, 5-10).

billingsi Zone

This zone, which was used first by the writer (*in* Lenz and Pedder, 1972, p. 37), corresponds closely to Warren and Stelck's (1950, p. 72; 1956, Pls. 10-12) zone of *Allanaria allani*, to McLaren's (1954, p. 168, 169; 1962, p. 15) zone of *Ladogioides kakwaensis*, and to Crickmay's (1957, p. 11; 1966, p. 13, 15-17, 20, 21) zone of *Eleutherokomma impennis*. The zonal index was changed because of the very considerable geographic range of *Tecnocyrtina billingsi* and also because of the extreme ease with which it may be identified. Each of the earlier authors mentioned above appears to have considered it to be an important index to the stratigraphic interval in question.

In the lower and middle Mackenzie Valley, the time of the zone was essentially one of non-deposition or active erosion. The only locality known at present where the existence of the zone can be demonstrated is in the allochthonous beds on Powell Creek (lat. 65°16' 30"N, long. 128°46'W). These are labelled as breccia in Figure 1.

Excellent description and figures, and a carefully documented account of the distribution of *Tecnocyrtina billingsi* and related forms, have been given by Johnson and Norris (1972, p. 566-571, Pl. 1, figs. 19-24; Pl. 2, figs. 1-19).

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FACIES CHANGES, BRECCIAS, AND MINERALIZATION IN DEVONIAN ROCKS OF ROCKY MOUNTAINS, NORTHEASTERN BRITISH COLUMBIA (94 B, G, K, N)

Project 630017

G.C. Taylor, R.W. Macqueen and R.I. Thompson
Institute of Sedimentary and Petroleum Geology, Calgary

A major objective of this project is a better understanding of the locus and nature of platform carbonates to basinal shale facies changes within the Devonian of northeastern British Columbia (*see* Macqueen and Taylor, 1974). These facies changes are receiving special attention by mineral exploration companies in the light of recent diagenetic models for the origin of strata-bound zinc-lead mineralization, and the discovery of presumably related zinc-lead mineralization in platform carbonates of the Devonian Stone Formation near Robb Lake (northwestern Halfway River area, 94B; Sangster, 1973).

Stratigraphy and Facies Changes

Major carbonate to shale facies changes have been identified in Silurian to Middle Devonian rocks of northeastern British Columbia (Fig. 1). Macqueen and Taylor (1974) discussed briefly the upper part of the Middle Devonian succession (Pine Point, Sulphur Point, Watt Mountain, and Slave Point formations); and Taylor and MacKenzie (1970) and Taylor and Stott (1973) reported on the older part of the succession (Muncho-McConnell, Wokkpash, Stone, and Dunedin formations). In northwestern Halfway River (94B) and southwestern Trutch (94G) map-areas, two major facies changes or carbonate fronts were examined in 1974. These are the Middle Devonian "Pine Point" (actually Pine Point plus Sulphur Point) front and the Lower and Middle Devonian Stone Formation carbonate front (Fig. 1).

The zone of Middle Devonian facies change extends along a sinuous trace east of Robb Lake, between Mount Helen and Mount Bertha, and to the southwest of Redfern Lake (Fig. 1). In the Mount Helen area, which is located on the basinal side of the facies change, lateral facies equivalents of the Pine Point Formation include dark grey, thin-bedded limestone and dolomite of the Dunedin Formation (Taylor and MacKenzie, 1970), and overlying shale of the Besa River Formation. Exposures northeast of Redfern Lake are located on the platform side of the Middle Devonian facies change. There, strata of the Pine Point Formation, about 240 m (≃787 ft.) thick, are exposed, the lower 85 m (278 ft.) of which consist of indistinctly to very thickly bedding dolomite; some dolomitic beds are rich in large bulbous stromatoporoids, characteristic of high energy, bank margin facies. The upper 155 m (≃508 ft.) are made up of a variety of light grey lime-mudstones and lime-packstones typical of bank interior environments. The indistinct to very thick bedding of the lower 85 m (279 ft.) of the Pine Point at Redfern Lake differs from the well-bedded, biostromal character of much of the Pine Point at sections studied by Macqueen and Taylor (1974) in the southwestern Halfway River area, and probably is confined to the highest energy zone or barrier facies at the facies front. If so, the barrier facies of the Pine Point is not more than a few kilometres or miles in width at any given stratigraphic level, and much of the Pine Point in the region consists of relatively lower energy sediments which accumulated in a shallow subtidal environment behind the main barrier of the facies front.

The underlying Lower and Middle Devonian zone of facies change involves the Stone Formation, which is the host for zinc-lead mineralization at Robb Lake. On a regional scale, the Stone Formation is a platform carbonate unit that extends northward to the northern end of the Caribou Range in Toad River map-area (94N), where it grades abruptly into basinal shale of the Besa River Formation (Taylor and MacKenzie, 1970, p. 16). This facies change occurs basinward of the Pine Point facies front (Fig. 1). Reconnaissance work by Taylor in 1974 indicates that dolomitic siltstone and shale of basinal aspect and laterally equivalent to the Stone are present between Robb and Lady Laurier lakes. These basinal rocks appear to be part of a sharp, southeast-trending re-entrant of basinal facies into the Stone carbonate platform (Fig. 1). Thus zinc-lead mineralization present within the upper part of the Stone at Robb Lake (discussed below) and in the lower part of the Stone at Mount McCusker may be located near a previously undetected carbonate-shale facies change. Between Mount McCusker and the Caribou Hills, the zone of facies change must have had an arcuate trace (Fig. 1), but rocks of this zone have been removed by Cenozoic erosion and are now missing over most of the area.

On a regional scale, dolomites of the Stone Formation are very uniform, and appear to represent deposition in low-energy, very shallow water or intertidal and supratidal environments. The only obvious variables are the amount of breccias, cyclical nature, and overall thickness of the unit (Taylor and MacKenzie, 1970, p. 11).

At Robb Lake, which is close to the facies change noted above, Stone dolomite (at least within the upper part of the formation) contains some evidence for higher energy conditions (?bank margin). This evidence includes phaceloid colonial corals, ?*Amphipora* sp., large brachiopods (possibly pentamerids), a single massive stromatoporoid or blue-green alga, rare echinoderm ossicle pseudomorphs within dolomite, and a relatively common macrodolomite texture suggestive of an original limestone-sand sediment. White Presqu'ile-type dolomite (*see* Macqueen and Taylor, 1974), in part forming "zebra" textures, is more common throughout the Stone Formation at Robb Lake than elsewhere. Black pyrobitumen, although

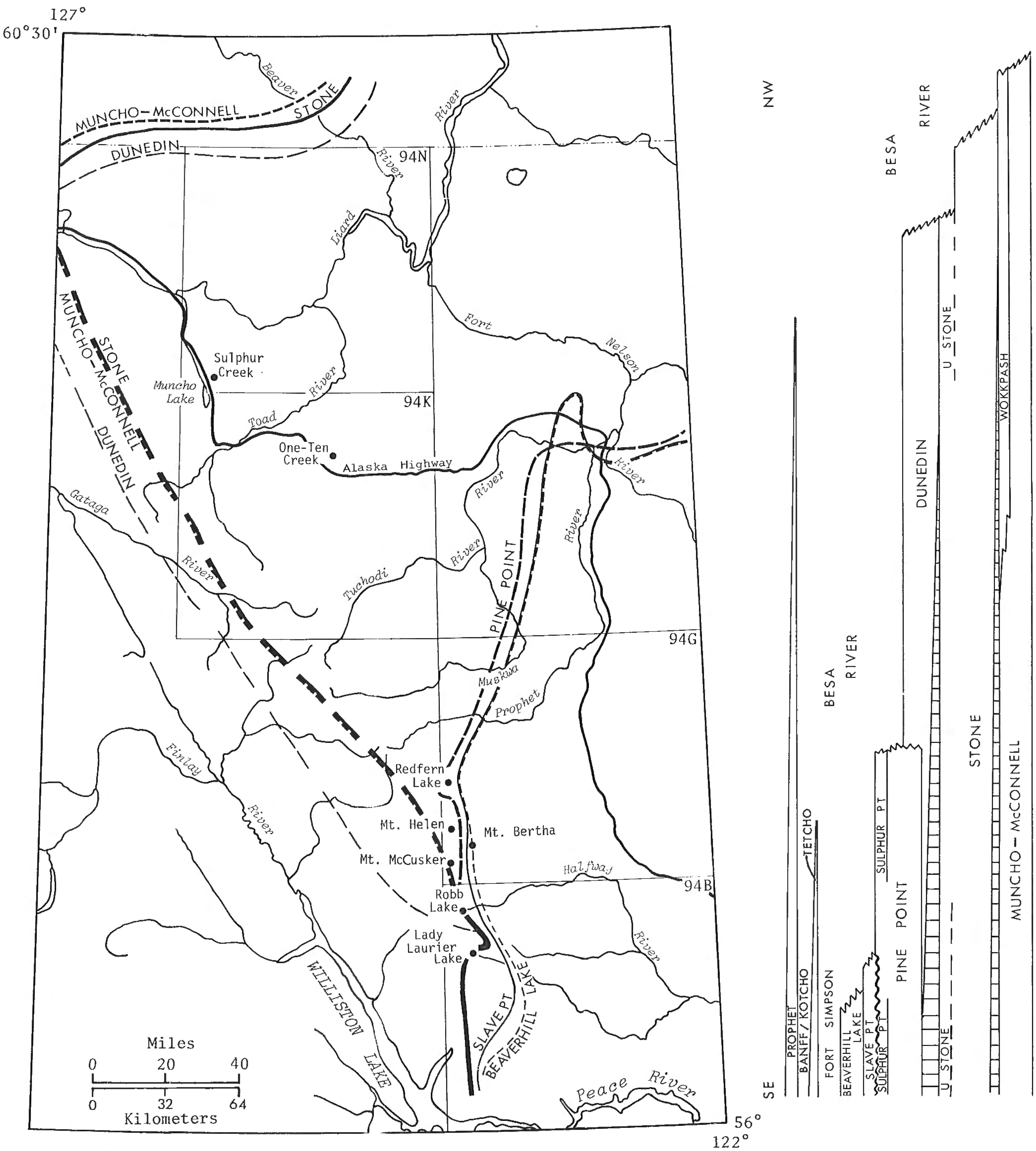

FIGURE 1: Map of northeastern British Columbia and adjacent Northwest Territories showing locations of Devonian facies changes: Muncho-McConnell (Lower Devonian), Stone (Lower and Middle Devonian), Pine Point (Pine Point and Sulphur Point combined, Middle Devonian), Slave Point (Middle Devonian), Beaverhill Lake (Upper Devonian). Basinal facies Besa River Formation shales occur north and/or west of facies fronts shown; platform carbonates occur to the south and/or east. Diagrammatic cross-section at right is generalized from Peace River (southeast) to Beaver River (northwest), and also shows Upper Devonian Fort Simpson and Tetcho formations, Devonian and Lower Carboniferous Banff/Kotcho formations, and Lower Carboniferous Prophet Formation.

rare, is also more common within the Stone at Robb Lake than elsewhere.

Stone Formation Breccias

Breccias composed of sharp angular fragments of dolomite cemented predominantly by coarse white calcite or dolomite occur at widely spaced localities and at various stratigraphic levels within the Stone Formation (Figs. 2-9). The association of sphalerite and galena with this type of breccia at Robb Lake has led to increased interest in the nature and origin of the breccias. Table 1 summarizes some of the important characteristics of these breccias at three widely separated localities along the mountain front (Fig. 1); for comparison, the general characteristics of syn-depositional transported breccias, and post-lithification non-transported breccias also are included.

Three other types of breccias occur in the Stone, but are only mentioned briefly here. These are:
a) scattered penecontemporaneous breccias associated with "tee-pee" structures and disturbed laminae;
b) very rare, poorly lithified sink-hole(?) fillings which postdate tectonic emplacement of Stone Formation rocks, and include much fine-matrix material - these are believed to be of Cenozoic origin; and c) rare buttress structures tens of metres wide, hundreds of metres high, and a kilometre or more long, made up of chaotic blocks of all shapes and sizes, strongly cross-cutting bedding. These buttress structures appear to be pre-tectonic in origin (fold structures terminate against buttresses) and may be pre-Laramide collapse structures. They clearly are different in origin from the breccias discussed herein. The best-known example is located in the Sentinel Range, about 10 km (≃6 miles) southeast of Muncho Lake (94N).

Stone Formation breccias discussed here (Table 1) are true breccias consisting of angular rock fragments cemented in a secondary matrix that is clearly distinguished from the fragments. Thus these breccias are unlike the Pine Point Formation pseudo-breccias described from the southwestern Halfway River area (Macqueen and Taylor, 1974), in which replacement of pre-existing macrodolomite by white Presqu'ile dolomite appears to have occurred on a significant scale. The only evidence for replacement within the Stone breccias (Table 1) is the presence of uncommon odd-shaped fragments surrounded by coarse-matrix carbonate. Elsewhere within the Stone, Presqu'ile-type dolomite is present, as noted above; at least some Presqu'ile-type dolomite has replaced pre-existing micro- and macrodolomite of the Stone.

Internal and external morphology of the breccias place some constraints on the possible mode(s) of origin, as shown in Table 1. The angular nature of the fragments, lack of sedimentary structures or penecontemporaneous deformational fabrics, and common presence of crackle and mosaic fabrics (Figs. 2, 3, 4) indicate that brecciation occurred after lithification and dolomitization of the original sediment, and argue strongly against a syn-depositional origin. Origin of the breccias within a karst erosion surface and subjacent channelway and cavern system also appears unlikely on several grounds. The matrix consists mostly of medium to coarsely crystalline minerals, white in colour and clearly secondary, and lacks any appreciable fine matrix "trash" (Fig. 8). There is no evidence of near-surface channelway or cavern development, collapse of overlying beds, exotic blocks, or solution thinning of lateral beds. Other near-surface features such as vadose silt or vadose pisolites have not been seen in any Stone Formation outcrops. A third possibility, that the breccias resulted from collapse into space provided by the solution of evaporite beds, is difficult to support, although anhydrite is known at the level of the Stone Formation within the adjacent subsurface of northeastern British Columbia (Pan American Sheep Creek C-86-D well, 94J, approximately Lat. 58°35'N, Long. 123°55'W). Breccias may be traced laterally into non-brecciated carbonate beds (Fig. 7); fine-matrix "trash" typical of evaporite solution zones (Sando, 1974; and others) is rare; and pseudomorphs after evaporite minerals have not been found in or near the breccia zones.

Breccias at One Ten Creek and Sulphur Creek: Although Stone Formation breccias from the three localities described in Table 1 differ from one another in many aspects, those present at One Ten Creek and at the head of Sulphur Creek have more in common with one another than the main breccia zone at Robb Lake (Table 1). The characteristics of the One Ten Creek and Sulphur Creek breccias (Table 1) are reasonably consistent with an origin resulting from subsurface, post-dolomitization carbonate solution along channelways or conduits (Fig. 2) which may have been, in part, fracture-controlled, but were controlled mainly by stratigraphy. In this interpretation, solution must have taken place at a depth sufficiently far below the surface to have escaped formation of typical near-surface, vadose-zone features. Such solution could have been accomplished in pre-Dunedin time by circulating formation waters, connate and/or meteoric, that were undersaturated with respect to dolomite. Solution may have created space within which blocks of all sizes and shapes settled. Pre-Dunedin time for the formation of the breccias is suggested because of the lack of breccia or solution features in limestone of the overlying Dunedin Formation. According to Parizek *et al.* (1971), solution of carbonate rocks within deep groundwater systems, although little known, must take place.

At least two problems remain with a subsurface solution hypothesis, however. The first of these is the development of solution cavities in dolomite rather than limestone. Rauch and White (1970) have found that most present-day solution porosity in Paleozoic carbonate aquifers of Pennsylvania are developed in limestone; development in dolomite is extremely rare. Solution of dolomite by groundwater apparently does occur, however, within Tertiary carbonate aquifers of the Yucatan Peninsula (Back and Hanshaw, 1970). A second problem is the apparent lack of a well-developed conduit or channelway system related to

	LOCATION	STRATI-GRAPHIC LEVEL	INDIVIDUAL BRECCIA BODIES OR ZONES								
			NUMBER	TYPE(S)[1]	FORM	STRATI-GRAPHIC CONTINUITY	THICKNESS	IN SITU TECTONIC FEATURES	CLASTS	MATRIX FINE[2]	MATRIX COARSE[2]
STONE FORMATION	Type Stone, One-Ten Creek (94K)	upper 1/3 of formation	at least 7[4]	mainly mosaic; locally crackle	tabular or sheet-like conformable	probably hundreds of metres or or more	< 1/2 m-? ± 2 m	none seen	< 1 cm-?1/2 m, angular	v.minor	calcite>>[3] barite>> fluorite
STONE FORMATION	Robb Lake (94B)	" [5]	one main zone	mainly rubble; v. minor crackle to mosaic	main zone lenticular; all zones cross-cut bedding in part	main zone + 1 km thinner zones? hundreds of metres	main zone ±50m, tapering NW to ±10m	main zone shows rare macroscopic folds, possibly tectonic	main zone < 1 cm- ?± 10 m, angular, subangular	minor, heterogeneous	dolomite> quartz>> sphalerite> galena
STONE FORMATION	Head Sulphur Ck. (94N)	≃15-30 m above base of formation	2 or more	mainly crackle, minor mosaic	tabular or sheet-like; conformable	hundreds of metres or more	1/2 m- ?1 1/2 m	none seen	< 1 cm- 1 1/2 m, angular	v.minor homogeneous	calcite>> barite
BRECCIAS OF KNOWN OR INTERPRETED ORIGIN											
SYN-DEPOSITIONAL BRECCIAS, TRANSPORTED	Edgewise[6] conglomerates or breccias	-	-	"rubble"; may show sedimentary imbrication	tabular or sheet-like; conformable	variable; may be kms; typically tens of m or less	variable; generally < 1 m	none expected	pebbles-boulders; subangular-subrounded	commonly abundant	minor to absent
SYN-DEPOSITIONAL BRECCIAS, TRANSPORTED	Subaqueous[7] debris flows (slope breccias)	-	-	"rubble", exotic blocks. Imbrication and overfolds common	sheet-like or lenticular; conformable	variable; may be tens of m to kms	variable; commonly < 1 m, may reach ±10 m or more	none expected	cm-m, angular to rounded	commonly graded, fining upward	absent
POST-LITHIFICATION BRECCIAS, NON-TRANSPORTED	Evaporite[8] solution breccias	-	-	commonly rubble, lesser mosaic or crackle	variable, may be sheet-like or prismatic; commonly cross-cuts bedding	variable; dependent on distribution of original evaporite and solution fronts	highly variable	none expected	cm-m, angular	very abundant as "trash"	commonly calcite; pore-filling
POST-LITHIFICATION BRECCIAS, NON-TRANSPORTED	Tectonic[9] (fault, fold, crush) breccias	-	-	rubble; crackle or mosaic very minor	highly variable; commonly cross-cuts bedding	highly variable; commonly limited	highly variable	commonly exhibits impressed fabric	?cm to tens of m; highly variable	abundant	rare to abundant; commonly carbonate

[1]Crackle breccia - little displacement of fragments; mosaic breccia - fragments largely but not wholly displaced; rubble breccia - no fragments match. Used in a descriptive sense only. See AGI Glossary (1972), and Ridge (1968).

[2]See Ridge, 1968.

[3]> greater than; >> much greater than.

[4]See Taylor and MacKenzie (1970, p. 38, 39).

[5]Similar mineralized breccias to those of the main zone at Robb Lake occur within ≃ 75 metres of the base of the Stone near Mt. McCusker (94G).

[6]Hatch, Rastall, and Black (1965), and others.

[7]Mountjoy and others (1972), Wilson (1974).

[8]De Mille and others, 1964; Roberts (1966); Sando (1974).

[9]Hills (1972), AGI Glossary (1972) and others.

TABLE 1. Attributes of Stone Fm breccias at One Ten Ck, Robb Lk, and Sulphur Ck; attributes of other breccias included for comparison.

zones of brecciation within the Stone. Possibly this reflects presently inadequate knowledge of the lateral extent and attributes of the breccias. Despite these reservations, subsurface solution appears, at present, to explain more of the breccia attributes than any other process of origin.

The second part of the breccia problem, the origin and time of formation of the interfragment coarse-matrix minerals (Table 1), perhaps is related to diagenetic activities associated with deep (?"deeper") burial. Whether the above interpretation is valid or not, it is likely that both the brecciation process and precipitation of the coarse-matrix filling occurred before emplacement of Stone Formation dolomites into their present tectonic setting, at least for the One Ten Creek and Sulphur Creek breccias.

Breccias at Robb Lake: The main breccia zone at Robb Lake is well exposed on the west limb of a broad anticlinal structure as a northward-tapering wedge thinning from about 50 m to less than 10 m (≈33-164 ft.) in stratigraphic thickness (Figs. 5-7, 9). This breccia zone apparently is broadly conformable with bedding, and is thicker and probably more continuous than similar breccias at One Ten and Sulphur creeks. Interpretation of internal and external relationships of the Robb Lake breccia is controversial at present.

Viewed from a distance (≈ km, or 1¼ miles), the main breccia zone comprises a gently warped elongate mass without internal layering, and lies on well-bedded planar dolomite typical of the Stone Formation (Fig. 5). The top of the zone is located about 100 m (328 ft.) below the top of the Stone Formation. Lack of internal organization typifies cliff-face exposures where blocks up to 10 m (≈3 ft.) in maximum dimension are mixed randomly with fragments that range down to "pea" size (Fig. 6). Rubble fabric is most common, but crackle and mosaic breccia occur in most exposures. Within the breccia zone, fractures occur that have symmetrical sides and may be partly filled with small fragments derived from an overlying bed (Fig. 9).

Angular fragments with sharp boundaries set in a matrix of white, coarsely crystalline cement are similar to breccias observed at One Ten and Sulphur creeks (Table 1). The Robb Lake breccias also contain sharp crosscutting contacts between breccias and dolomite beds (Fig. 7), and thin, unbrecciated beds within the upper part of the main breccia zone, some of which are deformed into small-scale folds that may or may not be confined to the breccia zone.

Several origins have been considered for the Robb Lake breccias. Thompson (in press) suggests fracturing caused by extension along a specific stratigraphic interval. Others have considered that the breccias are of evaporite solution origin, or of near-surface karst origin. On the basis of the data presented in Table 1, it appears that a syn-depositional origin (edgewise conglomerates, slope deposits) may be ruled out, and both evaporite solution and a surface or near-surface karst origin are unlikely. Carbonate solution and collapse at depth, perhaps with later tectonic modification of the breccia fabric, is a possibility. It has yet to be determined whether the space between the fragments in the breccia is the result of removal of carbonate rock by solution, or was created by physical expansion, or represents a combination of both processes. Any definitive statement on origin awaits new data.

Zinc-lead Mineralization

Mineralization at Robb Lake consists of sphalerite, galena and pyrite in decreasing order of abundance. The sphalerite and galena occur along clast boundaries within the breccias - commonly on only one side of a fragment - and as blebs and knots of fractured crystals in the white dolomite cement (Fig. 10). Neither euhedral crystal form nor colloform texture has been observed. Pyrite is rare, although locally it occurs as a fine-grained partial replacement of dolomite clasts; paragenetically, pyrite predates sphalerite in specimens collected (Fig. 10).

Several important differences are apparent between the mineralized breccias at Robb Lake and the classic Mississippi Valley-type zinc-lead deposits. A regional unconformity with well-developed solution features of probable karst origin occurs at the top of the zinc- and lead-bearing Lower Ordovician Mascot Formation in the United States, but there is no analogue recognized in the Stone Formation of the northern Rocky Mountains. The presence of limestone in the Kingsport (Lower Ordovician) and Mascot formations appears to be an important controlling factor in the distribution of the breccias which are the hosts of Mississippi Valley mineralization (Harris, 1971). As noted above, at Robb Lake dolomitization was complete before brecciation and mineralization occurred; beds of limestone are very rare in the Stone throughout northeastern British Columbia (Taylor and MacKenzie, 1970). The only area known to the writers in which limestone beds within the Stone have been mineralized is located in the southwestern Halfway River area on the north flank of Mount Burden, where galena and smithsonite occur within limestone of the uppermost Stone Formation (Macqueen and Taylor, 1974, Sec. 4). Another feature apparently typical of breccias of the Kingsport and Mascot formations is a coarsening upward size-distribution of fragments from a fine-fragment "trash" zone at the base of breccia zones (Harris, 1971). As noted above, this is not the case at Robb Lake, where fine-matrix "trash" is rare and at least the main breccia zone contains little internal stratification or widespread evidence that fragments settled in response to gravity. The tabular and conformable nature of the Robb Lake breccia is typical of Stone Formation breccias in general, and contrasts strongly with the variety of shapes of breccia zones, many of which are linked by channelways, within the Mississippi Valley-East Tennessee deposits (Harris, 1971). Colloform sphalerite textures, common within Mississippi Valley-type ore deposits and abundantly developed within probable solution cavities in the Pine Point ore field on the south shore of Great Slave Lake (Skall *in* Irvine and Gondi, 1972, p. 7-14), have not been found within mineralized Middle Devonian out-

Figure 2. Rubble and mosaic breccia partly filling ?conduit, coarse matrix fill calcite. Stone Fm., ≈100 m (328 ft.) above base, type section, One Ten Creek (94K).

Figure 3. Crackle breccia, coarse matrix fill calcite, note sag (?) of central bed. Circled 25¢ piece gives scale. Stone Fm., as Figure 2.

Figure 4. Large-scale crackle breccia crosscutting bedding, coarse matrix fill calcite with local (?) barite. Stone Fm., ≈25 m (82 ft.) above base, Head of Sulphur Creek (94N).

Figure 5. View upslope to northwest of main rubble breccia zone in upper Stone Fm., Robb Lake. Stratigraphic thickness of breccia zone in foreground ≈50 m (164 ft.) (94B).

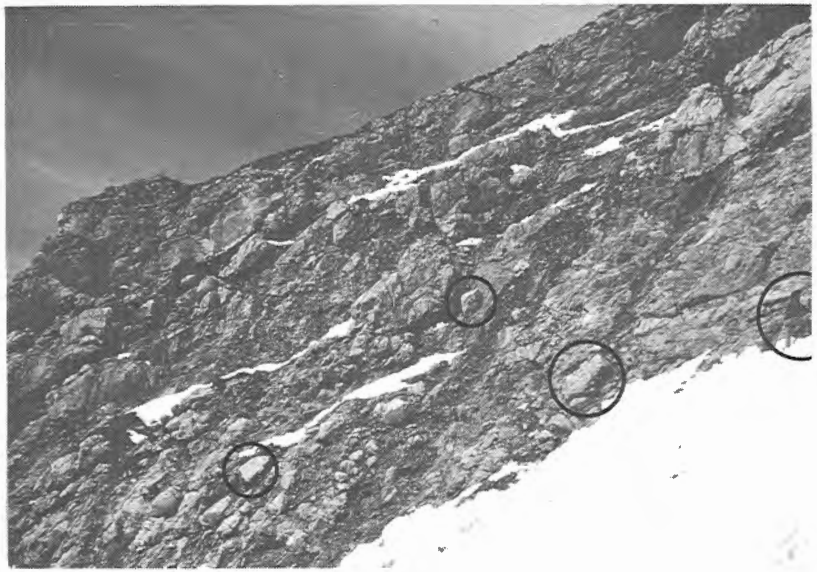

Figure 6. Close view of part of main rubble breccia zone at Robb Lake, as seen in Figure 5. Several large fragments circled. Figure circled at right gives scale.

Figure 7. Sharp contact between breccia and unbrecciated sandy dolomite beds, Robb Lake. Location as Figures 5, 6.

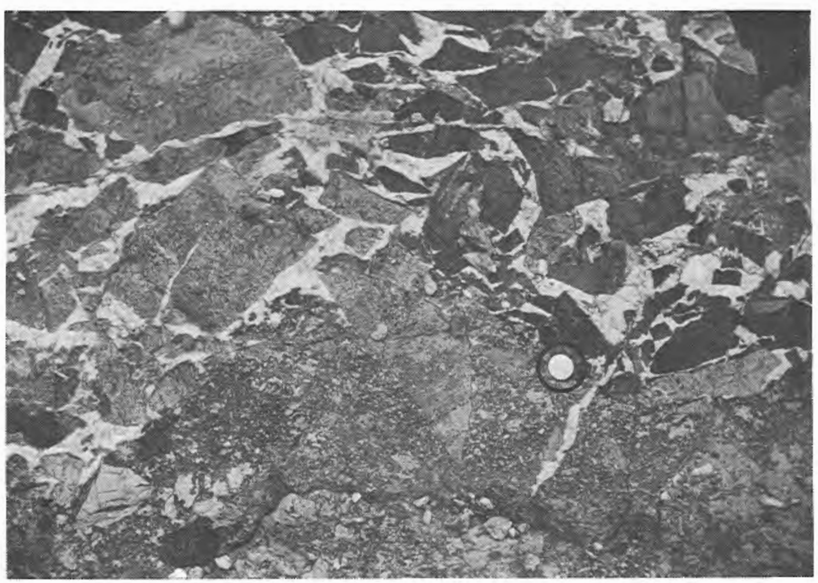

Figure 8. Rubble breccia with "trash" zone at base, coarse matrix fill calcite. Circled 25¢ piece gives scale. Stone Fm., ≃75 m (164 ft.) above base, Head of Sulphur Creek (94N).

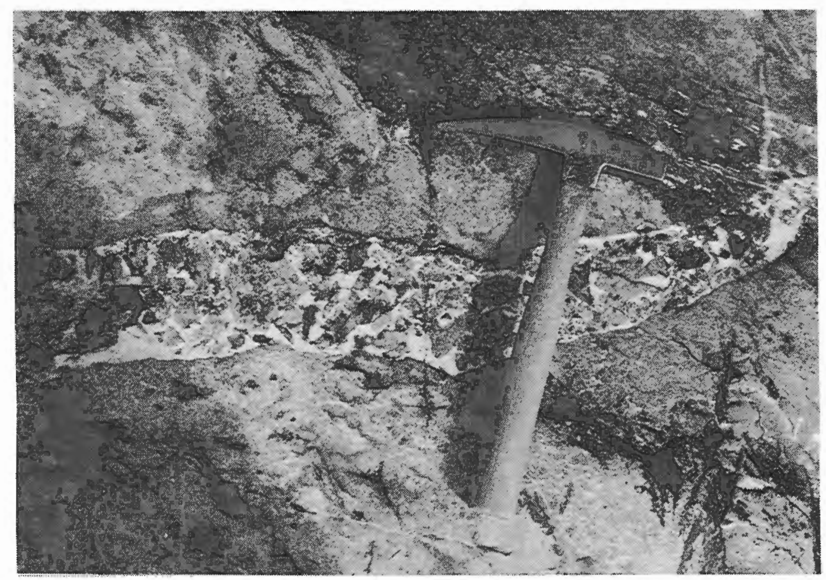

Figure 9. Bedding plane exposure of fractured dolomite bed; note symmetrical sides of fracture. Coarse matrix fill around fragments is white dolomite. Creek exposure of main breccia zone, Robb Lake.

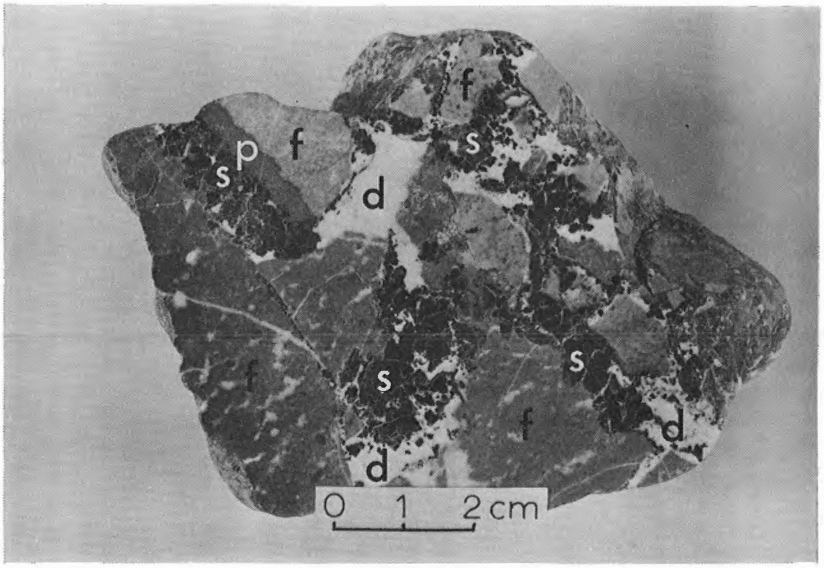

Figure 10.

Polished specimen from Robb Lake main breccia zone, showing dolomite fragments (f), white dolomite (d), pyrite (p), and sphalerite (s).

crops studied by the writers in northeastern British Columbia.

Barite and Fluorite Mineralization

Barite occurs: as a lag deposit at the unconformity overlying the Lower Devonian Wokkpash Formation, as a bedded deposit at the base of the Stone Formation, and as both a pseudo-breccia and a coarse-matrix breccia filling within the Stone Formation. Fluorite occurs within pseudo-breccias in the Stone, and also may occur with coarse-matrix breccia fillings. Fluorite also occurs alone as vug linings within the Dunedin Formation. No assessment has been made of the amounts of barite and fluorite present within the pseudo-breccia or coarse-matrix breccia fillings; however, barite appears to be much more abundant than fluorite. Neither of these minerals is known to be associated with galena and/or sphalerite. Although the breccias at all localities may have many features in common, it seems likely that base metal mineralization is genetically separate from the development of barite and fluorite.

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154. RECONNAISSANCE OF PETITOT RIVER (94P), FONTAS RIVER (94I) AND BEATTON RIVER (94H) MAP-AREAS, DISTRICT OF MACKENZIE

Project 630017

R. I. Thompson
Institute of Sedimentary and Petroleum Geology, Calgary

Helicopter reconnaissance mapping of Petitot River (94P), Fontas River (94I) and Beatton River (94H) map-areas was conducted in June and part of July. Outcrop is sparse except in parts of the Beatton River sheet where the Dunvegan escarpment is a prominent topographic feature.

The few exposures in 94P and 94I comprise dark grey and black shale and siltstone of the Fort St. John Group (undivided); fish scales found in some exposures may correlate with the "fish scale" marker, a radioactive shale marker recognized in the subsurface. Contact between the shales and siltstones of the Fort St. John Group and overlying conglomerate and coarse sandstone of the Dunvegan Formation extends obliquely from southwest to northeast across the northern half of 94H. A change in topography and soil colour may indicate presence of Smoky Group shale along the western extremity of 94H, however no outcrop was found in this area.

Subsurface well information will aid in preparation of surface geology maps.

155. MEMORIALS TO SIR WILLIAM LOGAN

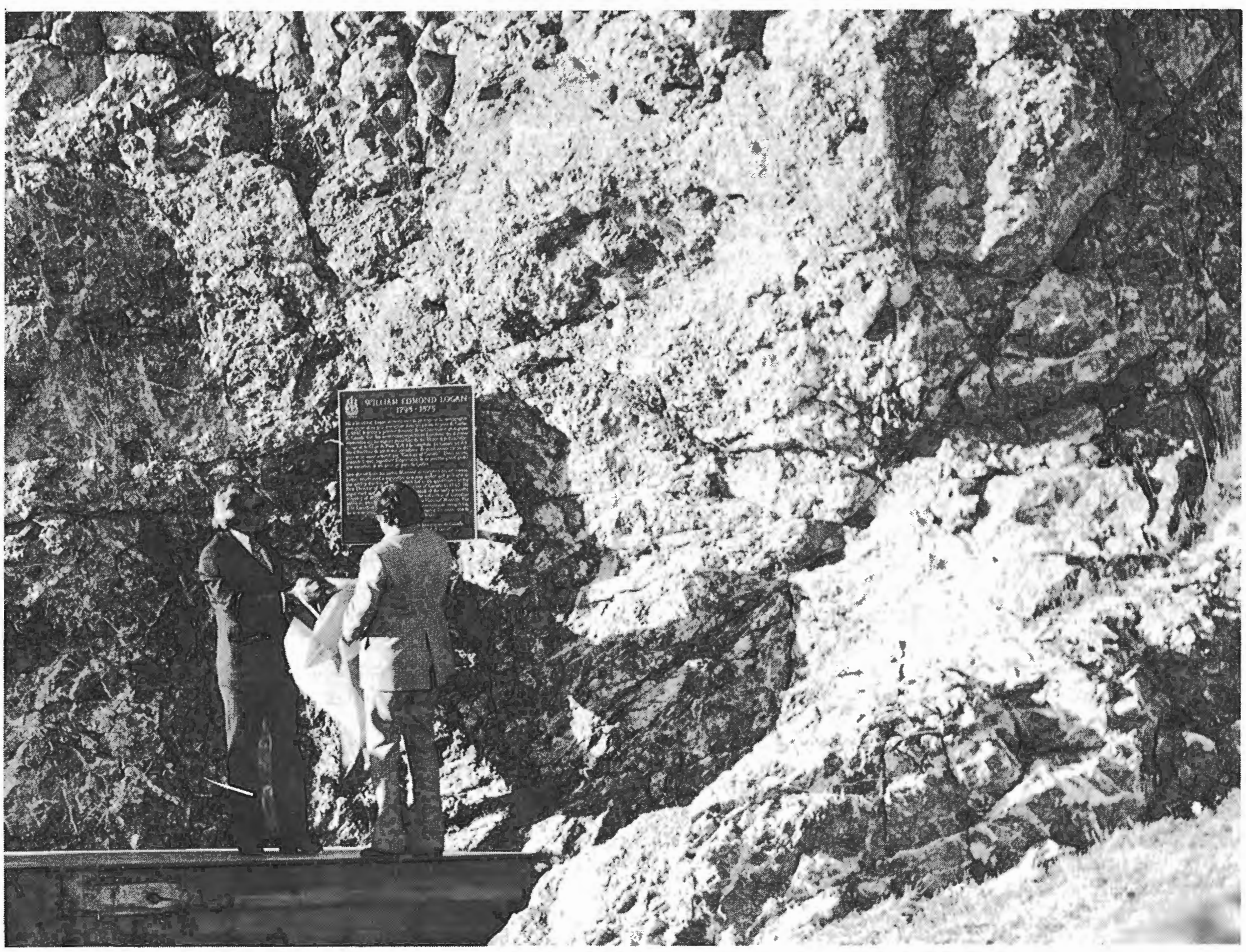
Peter Harker
Geological Information Division

Sixty-one years ago a bronze plaque in honour of Sir William Logan was erected at Percé by the 12th International Geological Congress and was dedicated before a large gathering of geologists participating in the Gaspé field trip. On September 10 of this year, a somewhat similar ceremony took place with the unveiling of a plaque honouring Sir William, erected at the same site by Parks Canada as part of a continuing program honouring great Canadians. On this occasion the guests of honour were again from an important international organization — the Tenth Commonwealth Mining and Metallurgical Congress.

M. Marc Laterreur, Chairman of the Historic Sites and Monuments Board of Canada, was chairman of the proceedings and M.J.-Jacques Séguin, Director, Parks Canada Québec Region, represented the Hon. Judd Buchanan, P.C., Minister, Department of Indian and Northern Affairs. After an offical welcome by Dr. Yvon Gaudreault, Mayor of Percé, Dr. John Convey, Secretary-General of the Congress, spoke on behalf of the Congress.

I represented the Director of the Geological Survey and gave a short address on the life and works of Logan and the significance of the Gaspé region in Logan's contribution to Canadian geology and continuing in French, some aspects of the 1913 occasion were recalled from a contemporary account. The plaque was dedicated by Abbé Jules Bélanger, President of the Gaspé Historical Society.

The original bronze plaque, which was cast from the same mould as the one on the Logan Boulder in front of the Geological Survey Building, Ottawa, is on the north side of the outcrop at Percé. It is still in very good condition and has not been defaced in any way.



M. Séguin and M. Laterreur at the unveiling of the memorial.

The new plaque — also in bronze — has a short biographic note on Logan and is on the south side. The outcrop also has a bronze war memorial tablet for the 1914-1918 war. The rock and the immediate land around it has been fenced and landscaped as a small park and is maintained by Parks Canada. It has a magnificent situation, almost in the centre of Percé, surrounded by spectacular geological features and with views of Roche à Percé and the small fishing harbour.

A few days earlier in South Wales, there was another Logan commemoration. A special service was held in the parish church of St. Llawddog, Cilgerran, on Sunday, September 8th, followed by the dedication of a memorial plaque on the grave of Sir William Logan in the churchyard. The plaque was given by the Geological Association of Canada. Dr. C. Gordon Winder represented the Association and Dr. W. T. Dean was present on behalf of the Director of the Geological Survey.

St. Llawddog - - - Cilgerran

A

SERVICE

TO COMMEMORATE

THE LIFE AND WORK

OF

Sir William Edmond Logan, Kt.

LL.D., F.R.S., F.G.S.

FIRST DIRECTOR
OF THE
GEOLOGICAL SURVEY OF CANADA

ON

Sunday, September 8th, 1974

at 11.00 a.m.

BORN:
April 20th, 1798, at Montreal.

DIED:
June 22nd, 1875, at Castell Malgwyn, Llechryd.

BURIED:
At Cilgerran, Pembrokeshire, Dyfed, Wales.

The Graveside Plaque has been given by
THE GEOLOGICAL ASSOCIATION OF CANADA

Project 490038

S.F. Leaming
Regional and Economic Geology Division, Vancouver

During the 1974 field season, one month was spent in the field visiting jade (nephrite) deposits in Washington State, British Columbia and Yukon Territory. In addition, new localities for rocks and minerals of interest to collectors were visited with a view to revising Geological Survey Paper 72-53.

Jade occurs in a great number of localities as alluvial boulders, and in situ deposits associated with alpine-type ultramafic bodies in the North American Cordillera from California to Alaska. Recent discoveries, particularly in British Columbia, have been directly the result of incentive provided by a wholesale price ranging from \$1.00 to \$3.00 per pound. Small quantities of superior quality jade in small blocks with six sawn faces may sell for as much as \$30.00 per pound. Production of large quantities of jade in 1973-74 came mainly from three sources: the Cassiar Asbestos mine at Cassiar, B.C.; New World jade on Mount Ogden; and Far North jade from an area east of Letain Lake (*see* Fig. 1). About 1,600 tons of crude jade were produced of which probably only a small percentage is saleable.

The writer was shown a deposit on Mount Higgins in Skagit County, Washington, by Mr. Lanny Ream of Mount Vernon, Washington. The locality is accessible by a logging road which leaves Highway 50 between Oso and Darrington. The property is privately owned and a fee is charged for collecting jade from the claim. When visited in July no active exploitation was in progress and the only jade seen was in the colluvium from the steep slope along the Darrington phyllite - serpentine contact which presumably was the locality from which the jade was derived. Blocks and slabs of soft talcy serpentine, jade and 'white rock' marks the zone but no contact metasomatic zone between the principal rocks was seen. Judging from some better quality specimens donated by Mr. Ream, the jade seems typical of most Cordilleran jade. It is obviously nephrite with the usual defects of fracturing and mottling due to impurities such as chlorite, talc and magnetite. A fine specimen of botryoidal jade from Cultus Mountain was donated by Mr. Ream, but the deposit, which is alluvial, was not visited.

An attempt was made to locate the source of the jade mentioned by Kindle (1953) east of Klukshu Lake near the Haines Road in Yukon Territory, but no jade was discovered. Apparently this occurrence is atypical of Cordilleran deposits because no serpentinite is present. The occurrence may be analogous to the Wyoming jade in which actinolite with nephritic texture occurs in amphibolite.

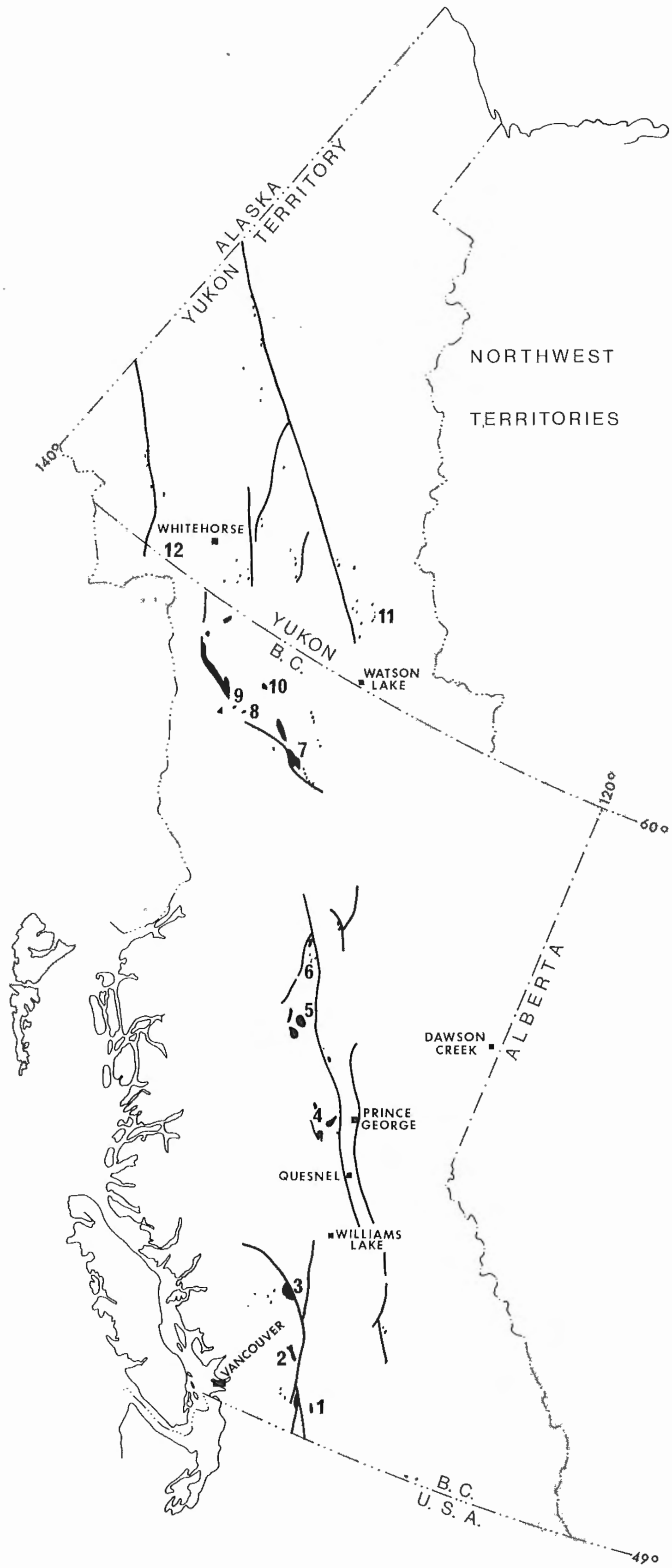
The King Jade property north of Watson Lake, Yukon Territory, and owned by Mr. Karl Ebner of Fort St. John, B.C., was visited for the first time. The property lies 4 miles west of Mile 84 on the Campbell Highway north of Watson Lake. There, contact reaction zones have developed between serpentine and sediments of Devono-Mississippian age. Locally, jade is present in irregular lenses and pods. Most of the production has come from alluvial blocks in the creek below the outcrop. The material is typical nephrite jade with the usual variations in quality due to discoloration and fracturing. The best material is as good as any found elsewhere in the Cordillera. Enough was seen of the deposit to establish that the property does have good potential for continued production of high quality jade. Five separate serpentinite bands are known in the local area (Blusson, 1966), and seem to offer good prospecting potential for jade.

The Seywerd deposit at the north end of Dease Lake was mapped in detail. There a small pit has been excavated on an outcrop of jade lying along a fault contact between serpentinite and cherty schist. The jade zone, including sheared talcose material, appears to wrap around a small 'nose' of serpentinite along a major northwest-striking fault. The zone is as much as 10 or 12 feet wide and has a curving strike length of from 40 to 50 feet. Geological relationships are somewhat obscured but the body apparently plunges westward along a major fault. Potential for development is considered good but estimates of tonnage are speculative. Possibly this lens contains between 50 and 100 tons. Many blocks of jade have been found in the general area and probably other in situ occurrences exist nearby.

Jade occurs in the Cassiar Asbestos Mine in northern British Columbia. Much of the material was formerly disregarded by the company but due to the efforts of Mr. Clancy Hubbell, it is now recovered and used by Mr. Hubbell in a joint venture with the company. At present about 300 tons are stockpiled on the mine property and in the next phase of the mining, more jade will undoubtedly be recovered.

The jade occurs along a fault zone between serpentinite and a long band of rodingite alteration developed between serpentinite and argillite hanging-wall rocks. Cassiar jade is somewhat atypical in that it has a high percentage of uvarovite (chrome-bearing) garnet. The garnet imparts an emerald green colour contrasting with the darker green of the nephrite matrix.

A visit to Delure Creek confirmed the reported occurrence of jade boulders there. Delure Creek flows into Thibert Creek about 2 miles west of the north end of Dease Lake. Two boulders each weighing about 400 pounds were noted. Serpentinite occurs in the lower reaches of the creek and quartz-carbonate mariposite and rodingite zones were seen. No in situ jade was found but insufficient time was available for a thorough examination.



ULTRAMAFIC BODIES AND FAULTS IN PART OF THE WESTERN CORDILLERA SHOWING JADE LOCALITIES

Fault ....

Ultramafic Body ....

1	Coquihalla	unconfirmed reports of in situ jade, boulders known
2	Nahatlatch	unconfirmed repors of alluvial jade
3	Shulaps Range	in situ deposits on Hell, Brett, Hog and Jim Creeks; alluvial boulders in Marshall Creek, Bridge and Yalakon Rivers
4	Prince George Area	alteration zones, faults suggest possibilities for discovery of jade, none reported to date
5	Mt. Sidney Williams	Jade Queen property, inactive, in situ jade and alluvial blocks, presumably little left
6	Mt. Ogden	(New World Jade) (Far North Jade) active mining and recovery of alluvial and in situ jade; 1974 reserves of 1000 tons proven but of various grades Far North-inactive
7	Wheaton Creek Area	production mainly from alluvial boulders; in situ deposits confirmed on Wheaton Creek; reported south of Letain Lake. 125 tons removed spring 1974 from Kutcho Creek
8	Dease Lake	Sawmill Pt. small annual production from in situ deposit
9	Delure Creek	boulders confirmed, no in situ deposits found but alteration zone seen
10	Cassiar Asbestos Mine	1300 tons stockpiled on mine property
11	King Jade	in situ deposits confirmed
12	Klukshu Lake	reported jade not found. Atypical geological environment

MILES 0 — 200

0 — 300 KILOMETERS

Two days were spent checking jade potential in Prince George map-area (Tipper, 1961). A number of ultramafic bodies there lie within a major belt joining the jade occurrences in southern British Columbia with those in the central and northern part of the province. The ultramafic bodies on sinkut, Bobtail, and the Baldy Hughes areas are not known to contain jade. However, one small piece of jade was found in a gravel pit north of Sinkut Mountain by Mr. H.F. Hewitt of Colleymount, B.C. In addition, the development of talc, rodingite and quartz-carbonate alteration zones near major faults (especially the Baldy Hughes body), suggests that the rocks may contain undiscovered jade.

The Sinkut Mountain ultramafic body offers little encouragement for jade prospecting. A few small patches of talc were the only alteration seen and the rock is largely unserpentinized peridotite and pyroxenite. Of more interest was the alteration zone in serpentinite exposed along a logging road which runs across the south end of the serpentinite body west of Baldy Hughes Mountain. There, an apparent contact reaction zone is present. The rock may be rodingite but study of thin-sections are required for confirmation. Only a small part of the ultramafic body was seen and the possibilities of finding jade cannot be dismissed.

Activities in the Bridge River area has been reduced to the exploration of the head of Jim Creek north of Marshall Lake by Mr. C. McEwen and partners. On this property, in situ jade is being worked. The main deposit at present is an elliptical lens of jade lying with serpentinite near a chert-serpentinite contact. It has exposed length of about 10 feet and a width of about 5-6 feet. The lens could not be moved by available equipment and presumably the long dimension at least is much greater than the exposed length. Minimum weight is considered to exceed 20 tons.

The last examination of the field season was made at the New World jade property on Mount Ogden, northwest of Germanson Landing. The original discovery area has been largely depleted of near surface jade along the serpentinite - metasedimentary contact. There is now about 800 tons of jade of all grades in rough blocks, and cut blocks weighing from a few hundred pounds to 50 tons.

The new showing found in 1972 lies 1,500 feet southwest of the original discovery, and lies presumably near the western margin of the serpentinite body. The jade zone as outlined by surface observation and drill holes is from 1 to 10 feet wide. Only a small quantity has been produced from the New Showing. About 60 tons is currently being removed from the property for shipment mainly to Hong Kong.

This property is the principal jade producer in British Columbia. It is nephrite variety and much of the rock is of bright green premium quality. Like other occurrences it has a high percentage of fractured and poorly coloured material so that large quantities of low quality material are present.

In summary it is apparent that jade is much more common than was once thought. The occurrence of jade in the North American Cordillera provides many examples of the metasomatic processes by which jade talc, vesuvianite, hydrogrossular, and other minerals are produced in contact reaction zones between serpentinite and wall-rocks or tectonic inclusions. There can be no doubt that many more deposits remain to be found. Very large bodies cannot be expected but the number of undiscovered bodies is probably great. Areas with extensive bodies of serpentinite such as the Cry Lake map-area (Gabrielse, 1962) should be considered favourable for further jade exploration.

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157. NATIONAL MINERAL COLLECTION

Project 550101

H.R. Steacy and H.G. Ansell
Central Laboratories and Administrative Services Division

H.G. Ansell and H.R. Steacy, assisted by J. Lemieux, collected mineral specimens from 23 localities in Newfoundland, Quebec and Ontario for the research portion of the National Mineral Collection. Collecting was directed mainly toward the rarer minerals, which will be used in part for exchange to improve the content of the collection, and thus its research capacity. Samples collected specifically for mineralogical study will be examined and, where warranted, described in the appropriate literature.

Operating mines and quarries are prime sources of mineral specimens for research and for display. We, therefore, encourage operators to report occurrences of unusual or well-formed minerals encountered during mining operations. Such reports will be followed up wherever possible and can contribute greatly to the development of the National Mineral Collection.

Figure 1

Fresh road-cuts often provide useful material for the National Mineral Collection and are always carefully examined. Here H.R. Steacy and J. Lemieux are collecting purple scapolite from a road-cut in Eastern Ontario. GSC 202659-C.

Figure 2

Weloganite, associated with calcite, quartz and cryolite, from a silico-carbonate sill at the Francon quarry, St. Michel, Montreal Island, Quebec. A rare hydrated carbonate of strontium and zirconium, weloganite is named in honour of Sir William Logan, founder and first Director of the Geological Survey of Canada. GSC 202659-A.

ZIRCON TESTING KIT

Project 730046

R.K. Wanless
Regional and Economic Geology Division

In order to obtain sufficient zircon for isotopic age determinations it is often necessary to collect, transport and process large quantities (75-100 lb) of rock. To ensure that the sample selected does contain sufficient zircon before expending the time and energy required for collection, a portable field testing kit is used. The testing technique was first employed during the summer of 1972 to help select suitable samples of rhyolite (Wanless and Stevens, 1973) and has been further successfully employed during the two subsequent field seasons. Fourteen Geological Survey field parties were supplied with kits for use during the 1974 season and reports from field officers indicate that they found them useful.

Several enquiries have been received as to the make up of the kits and the mode of field operation which is herewith briefly described.

The kit comprises a small stainless steel mortar in which a few grams of rock may be pulverized using a geologist's hammer, a plastic sieve set fitted with a 100 mesh nylon screen, a small (125 ml) plastic separatory funnel, a 30 ml plastic beaker, a miniature portable microscope, and miscellaneous minor items listed below.

The procedure carried out on the outcrop is as follows: A few grams of rock are crushed and passed through the nylon screen. The powder is placed on top of 2 to 3 cc of methylene iodide (specific gravity = 3.3) in the separatory funnel. After vigourously shaking the powder-liquid mixture the funnel is allowed to stand for 2 to 3 minutes while the heavies settle to the bottom. The liquid containing the heavy fraction is discharged into a pre-folded filter paper placed in the plastic beaker by quickly rotating the stopcock. The filter paper is washed with carbon tetrachloride and allowed to dry. If magnetite is present it may be removed by passing a small magnet over the dried sample on the filter paper. The optical arrangement of the microscope is such that the slide must be inserted upside down and hence the grains must be firmly attached. This is accomplished by placing a little nail polish on the slide and then pressing the tacky surface lightly to the filter paper. This system of mounting has been found satisfactory on all but the most humid days when some difficulty was experienced in getting the polish to adhere firmly to the glass. The slide is scanned for zircon grains and the decision to collect or not is based on the results obtained. Experience has shown that the presence of one or two zircon grains in a sufficient indication that a useful concentrate may be prepared from a 75-pound sample of rock (i.e. one 5 gal. pail). Usually it is possible to carry out the test, select a sample, clean and store the kit, and be ready to take off for the next sampling site within 45 to 60 minutes.

Reference

Wanless, R.K. and Stevens, R.D.
1973: Collection of samples from the Kaminak Group for zircon age, determination; *in* Report of Activities, April to October 1972, Geol. Surv. Can., Paper 73-1, Pt. A, p. 65-66.

Contents of Zircon Kit

1 - stainless steel mortar

1 - screen set with 100 mesh nylon screen — available from: - Spex Industries Inc., Metuchen, N.J., U.S.A.

1 - bottle methylene iodide (S.G. - 3.3) - 250 ml

2 - bottles carbon tetrachloride - 250 ml

1 - separatory funnel - 125 ml plastic

1 - microscope - McArthur - available from: - Air Flow Development Canada Ltd., 244 Newkirk Road, Richmond Hill, Ontario. Cost: approx. $60.00

24 - microscope slides 25 mm x 75 mm

24 - filter papers, 9 cm diameter

1 - beaker, plastic 30 ml

1 - magnet, hand

1 - bottle clear nail polish

1 - spatula

1 - small artists paint brush

2 - batteries for microscope

ADDENDUM

(The following reports were submitted after October 23, the date on which editing of this publication began)

159. SUMMARY OF RESEARCH ON THE PROJECT - GEOCHEMISTRY OF METALLOGENESIS

Project 730001

R.W. Boyle
Resource Geophysics and Geochemistry Division

This project involves the geochemistry of metallogenesis from the Precambrian to the Recent. Part of the project also includes a study of the zonal geochemistry of metallogenesis with respect to igneous (granitic-gabbroic) and metamorphic centres and/or zones. Field work has consisted in recent years of detailed geochemical work in the Canadian Shield (Yellowknife, Kirkland Lake-Timmins area, Red Lake area, Cobalt area), in the Canadian Cordillera (Keno Hill, Whitehorse, Slocan) and in the Appalachians (Bathurst, New Brunswick; Dorchester, New Brunswick; Walton, Nova Scotia; Cape Breton Island). In recent years visits have also been made to the Sudbury area, Ontario; the Michigan copper belt in the Keweenawan Peninsula; the Colorado mineral belts; the Mississippi Valley lead-zinc belt, and the mineralized parts of the Appalachians in the United States (Maine, Ore Knob, Ducktown, etc.). In past years and during the recent summer attention has been paid to many of the classical mineralized areas of Europe including Cornwall, England; Mendips, England; the Welsh lead-zinc-copper-gold belts; the lead-barite-fluorite deposits of Derbyshire; the massive sulphide orebodies of Eire; the lead-zinc-silver belts of Southern Scotland (Leadhills, Gatehouse of Fleet); the lead and copper ores in the Triassic sandstones of Alderley Edge in England and at Commern and Mechernich (Aachen) Germany; the lead-zinc ores of Moresnet (Belgium and Luxembourg), the classic deposits of the Bohemian massif in Czechoslovakia including those containing lead, zinc, silver, uranium, tin, tungsten, etc.; the classic deposits in the Tertiary of the eastern part of Czechoslovakia including lead, zinc, copper, silver, gold, barium, etc. deposits; the classic lead-zinc and other deposits at Laurium in Greece, and a number of deposits associated with recent hot spring phenomena in Italy.

An extensive literature review of most of the western European deposits has been made while in England during the past summer, and visits were made to check certain critical features in the field mostly in England. In addition the writer attended the field trips sponsored by the International Association on the Geneses of Ore Deposits (IAGOD) in Bulgaria in September and the field trip sponsored by the International Geological Correlation Programme and the Bureau de Recherches Geologiques et Minieres (Metallization associated with acid magmatism (MAWAM) symposium) in the Massif Central of France in October. During the former field trips, lead, zinc, copper, etc. deposits ranging in age from Precambrian to Tertiary were visited and examined; during the field trip to the Massif Central deposits of Li, Be, Sn, W, and U were examined and their relationships to granites of Hercynian age were carefully noted.

Particular problems for which answers are sought in this project include the following:

1. The validity of geochemical (mineralogical) zoning about granite or metamorphic (granitization) centres. Is the zoning single stage or multistage, essentially a single event or is the mineralization spread over a long geological time interval? Many districts visited suggest multistage phenomena in which structural conditions play a large part.
2. What is the reason for the apparent preponderance of certain elements in rocks of certain ages: e.g., gold in Archean rocks; uranium in Proterozoic and Tertiary rocks; tin in Carboniferous rocks, etc.? As yet there are no satisfactory answers to this problem.
3. Do granitic rock suites that are enriched in such elements as Be, Sn, Li, U, etc. represent remobilization (or granitization) of previously existing granitic or gneissic terranes, e.g., remobilization of Precambrian granitic or gneissic zones to yield Paleozoic or younger granitic rocks. This certainly appears to be the case with Hercynian granites in Europe (e.g. Massif Central; Bohemia). It may also apply to certain areas of New Brunswick (e.g., Mount Pleasant). The case for Cornwall is uncertain.
4. Is there any relationship of mineralization to plate tectonics? Only a vague answer can be given: There is a definite relationship of mineralization to geosynclinal development which has been known for many years, but how this ties in with plate tectonics is certainly not clear and any hypothesis is speculative in the extreme.

Correlation work is now in progress in an attempt to discover elemental patterns with respect to both igneous and metamorphic centres and geological periods of sedimentation, metamorphism, igneous activity, diastrophism, etc.

One publication concerned with this project is now in press:

Boyle, R.W.
Some thoughts on mineralization processes in Archean greenstone and sedimentary belts; Golden Jubilee Volume of the Geological Mining and Metallurgical Society of India, 1974. (in press).

A STUDY OF STRATIFORM COPPER DEPOSITS IN CARBONIFEROUS STRATA OF NEW BRUNSWICK AND NOVA SCOTIA

A.C. Brown[1]
Regional and Economic Geology Division

Red-bed copper occurrences in Carboniferous strata of New Brunswick and Nova Scotia were examined and sampled during three weeks of field work. Mineragraphic and chemical analyses will be carried out during the winter.

Particular attention was given to the Dorchester area, near Sackville, N.B., where copper sulphides occur as replacements of fossil plant debris, pyrite, and carbonate cement in basal portions of the Shepody Formation (Pennsylvanian/Mississippian). This investigation benefits from prior information gathered during mining of near-surface, oxidized ore (between 1881 and 1917), and from additional data realized during earlier evaluations by mining concerns, government agencies and academic institutions, especially during post-war years. Recent exploration (1972-74) involving diamond drilling to depths of several hundreds of feet on down-dip extensions of the gently-inclined Shepody strata, has outlined primary sulphide mineralization of possible economic importance.

Cupriferous beds in the Shepody Formation at the Dorchester property are generally limited to a 5- to 20-foot basal section composed primarily of fine- to coarse-grained, grey fluviatile sandstones. The Shepody also includes some conglomerates and dark grey shaly horizons. Organic debris occurs chiefly as fine particle and small fragments within bedding (Fig. 1), and as larger, rather erratically distributed fragments in the form of coalified bark of tree trunks and limbs.

Copper values, accompanied by traces of silver, are highly variable both laterally and vertically within the mineralized zone, but commonly average 0.2 to 2% copper over the mineralized section. Selected short sections may assay several per cent in copper. Copper distribution is clearly related to organic debris, which in turn is related to facies of the host sandstone. Analysis of flood plain and stream channel facies may determine further extensions of high-grade zones.

Chalcocite, the principal copper sulphide of unoxidized mineralization, is intimately related to plant debris and to pyrite which is localized in and around organic matter. Textural evidence indicates that chalcocite was formed at least in part by replacement of pyrite which had previously filled uncollapsed plant cells. Pyrite also occurs in beds overlying the mineralized strata, especially as very fine grained disseminations in dark grey shales higher in the Shepody section. Small amounts of galena and sphalerite have also been reported in beds above the usual cupriferous zone. In oxidized zones, covellite, malachite and iron oxides indicate alteration of primary chalcocite and pyrite.

The Dorchester sulphide mineralization in greyish beds is complemented by native copper mineralization in underlying brick-red sediments of the Maringouin Formation (Mississippian, probably equivalent to upper Windsor Group marine strata), which are excellently exposed along Cape Dorchester. This facies of red-bed copper mineralization is especially characterized by mineralized reduction spheres (Fig. 2), and has no obvious economic importance. However, a close genetic relation may exist between this mineralization and the copper occurring as chalcocite in basal Shepody beds on the Dorchester property. Professor W. Van de Poll has begun studies of copper and its associated metals in the Maringouin at the University of New Brunswick.

The above-mentioned copper occurrences represent the most abundant and readily accessible copper showings of the red-bed type at the Upper Mississippian/Pennsylvanian contact. A large number of similar but relatively minor copper and pyrite showings have been noted at the same or approximately equivalent stratigraphic level at widely scattered localities

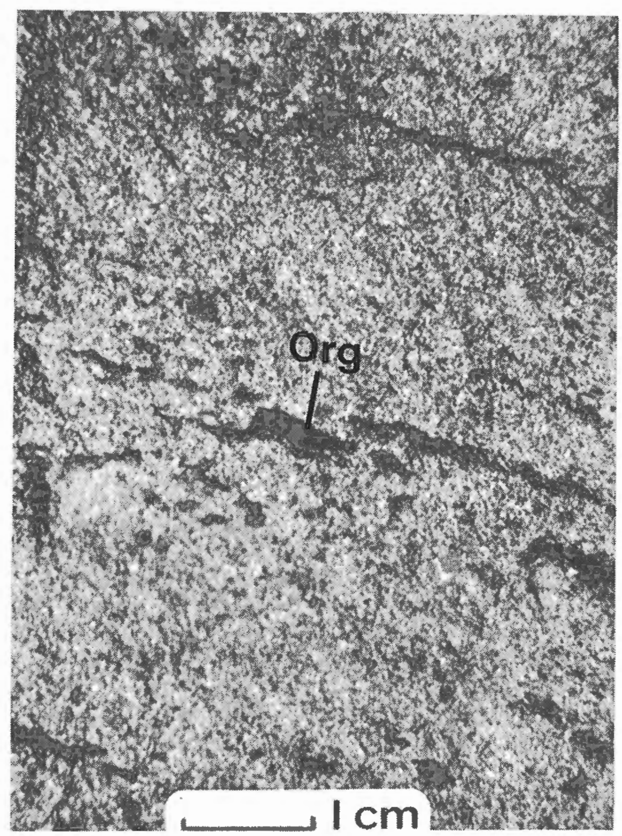

Figure 1. Sandstone facies of the Shepody Formation showing organic matter (Org) with which sulphides are associated.

[1]Ecole Polytechnique, University of Montreal; Contract No. OSU4-0129.

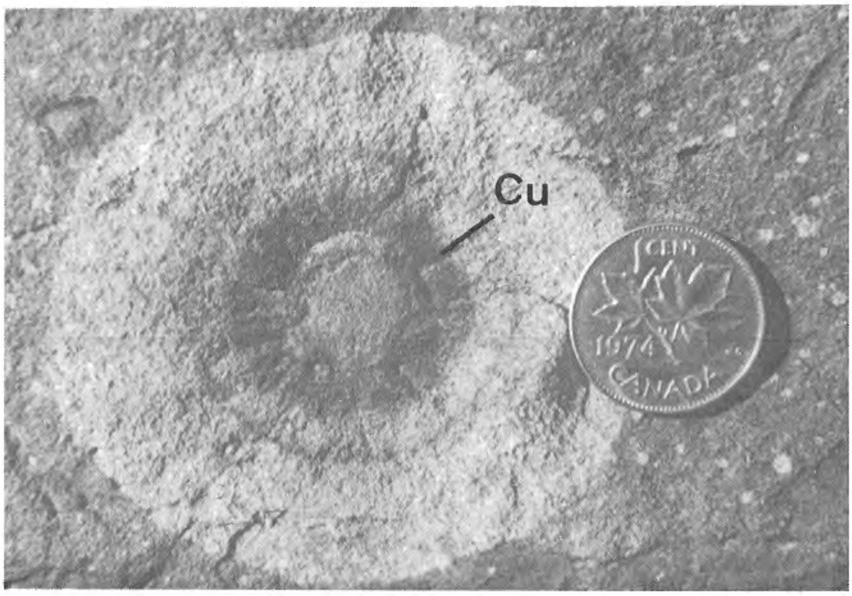

Figure 2

A large greenish reduction sphere in red sandstone of the Maringouin Formation. The presence of copper (Cu) is indicated by malachite stains in central portions. A large number of tiny reduction spheres occur in the adjacent sandstone.

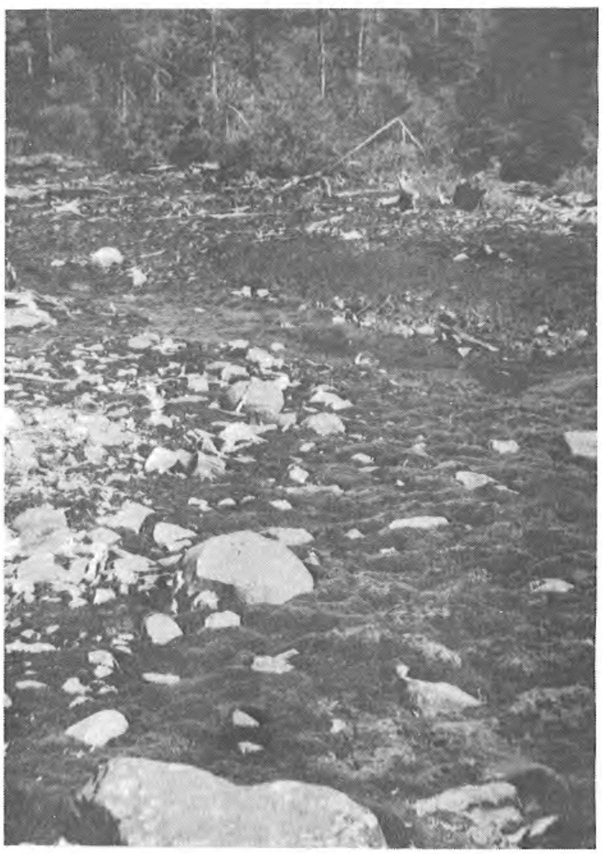

Figure 3. View across open swampy portions of the Tantramar copper bog.

in southern New Brunswick and adjacent Nova Scotia (Papenfus, 1931; Brummar, 1958; Van de Poll, 1974; Kirkham, 1974). These occurrences are stratigraphically distinct from abundant stratiform copper showings at the Windsor-Horton contact (Lower Mississippian) presently under study by W. P. Binney of Queen's University and R. V. Kirkham of the Geological Survey (*see* this publication, report 72).

A third facies of copper mineralization is found in postglacial peat bogs about 7 miles northeast of the Dorchester property, and about 50 feet in elevation above the present Tantramar tidal swamps of the Sackville area. The principal bog is estimated to contain about 300 tons of copper beneath $2\frac{1}{2}$ acres of swamp and forest (Fig. 3). Although analyses of peat reveal concentrations up to 10% copper, dry weight, no copper-bearing mineral has yet been found, and it seems that the copper has been fixed by organic sequestration (Frazer, 1961). The source of this copper may be Shepody or Maringouin-type mineralization concealed beneath the Tantramar glacial plain. Groundwater in the area contains 70 to 250 ppb copper.

Field examination and sampling of the above types of mineralization was carried out both individually and jointly with mining, government and university-based personnel working on related problems in the Maritime Provinces. Appreciation is particularly extended to the Amax Exploration Inc. - Canerpa Ltd. Joint Venture (1972-74) for access to their drill core and related information on copper occurrences at Dorchester and other locations.

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