Geological Survey of Canada
Commission géologique du Canada

PAPER
ÉTUDE 88-1E

CURRENT RESEARCH PART E
CORDILLERA AND PACIFIC MARGIN

RECHERCHES EN COURS PARTIE E
CORDILLÈRE ET MARGE DU PACIFIQUE

1988

Canada

NOTE TO CONTRIBUTORS

Submissions to the Discussion section of Current Research volumes are welcome from both the staff of the Geological Survey and from the public. Discussions are limited to 6 double-spaced typewritten pages (about 1500 words) and are subject to review by the Chief Scientific Editor. Discussions are restricted to the scientific content of Geological Survey reports. General discussions concerning branch or government policy will not be accepted. Illustrations will be accepted only if, in the opinion of the editor, they are considered essential. In any case no redrafting will be undertaken and reproducible copy must accompany the original submissions. Discussion is limited to recent reports (not more than 2 years old) and may be in either English or French. Every effort is made to include both Discussion and Reply in the same issue. Submissions should be sent to the Chief Scientific Editor, Geological Survey of Canada, 601 Booth Street, Ottawa, Canada, K1A 0E8.

AVIS AUX AUTEURS D'ARTICLES

Nous encourageons tant le personnel de la Commission géologique que le grand public à nous faire parvenir des articles destinés à la section discussion de la publication Recherches en cours. Le texte doit comprendre au plus six pages dactylographiées à double interligne (environ 1500 mots), texte qui peut faire l'objet d'un réexamen par le rédacteur en chef scientifique. Les discussions doivent se limiter au contenu scientifique des rapports de la Commission géologique. Les discussions générales sur la Direction ou les politiques gouvernementales ne seront pas acceptées. Les illustrations ne seront acceptées que dans la mesure où, selon l'opinion du rédacteur, elles seront considérées comme essentielles. Aucune retouche ne sera faite aux textes et dans tous les cas, une copie qui puisse être reproduite doit accompagner les textes originaux. Les discussions en français ou en anglais doivent se limiter aux rapports récents (au plus de 2 ans). On s'efforcera de faire coïncider les articles destinés aux rubriques discussions et réponses dans le même numéro. Les articles doivent être renvoyés au rédacteur en chef scientifique: Commission géologique du Canada, 601, rue Booth, Ottawa, Canada, K1A 0E8.

GEOLOGICAL SURVEY OF CANADA
PAPER 88-1E
COMMISSION GÉOLOGIQUE DU CANADA
ÉTUDE 88-1E

CURRENT RESEARCH PART E
CORDILLERA AND PACIFIC MARGIN

RECHERCHES EN COURS PARTIE E
CORDILLÈRE ET MARGE DU PACIFIQUE

1988

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

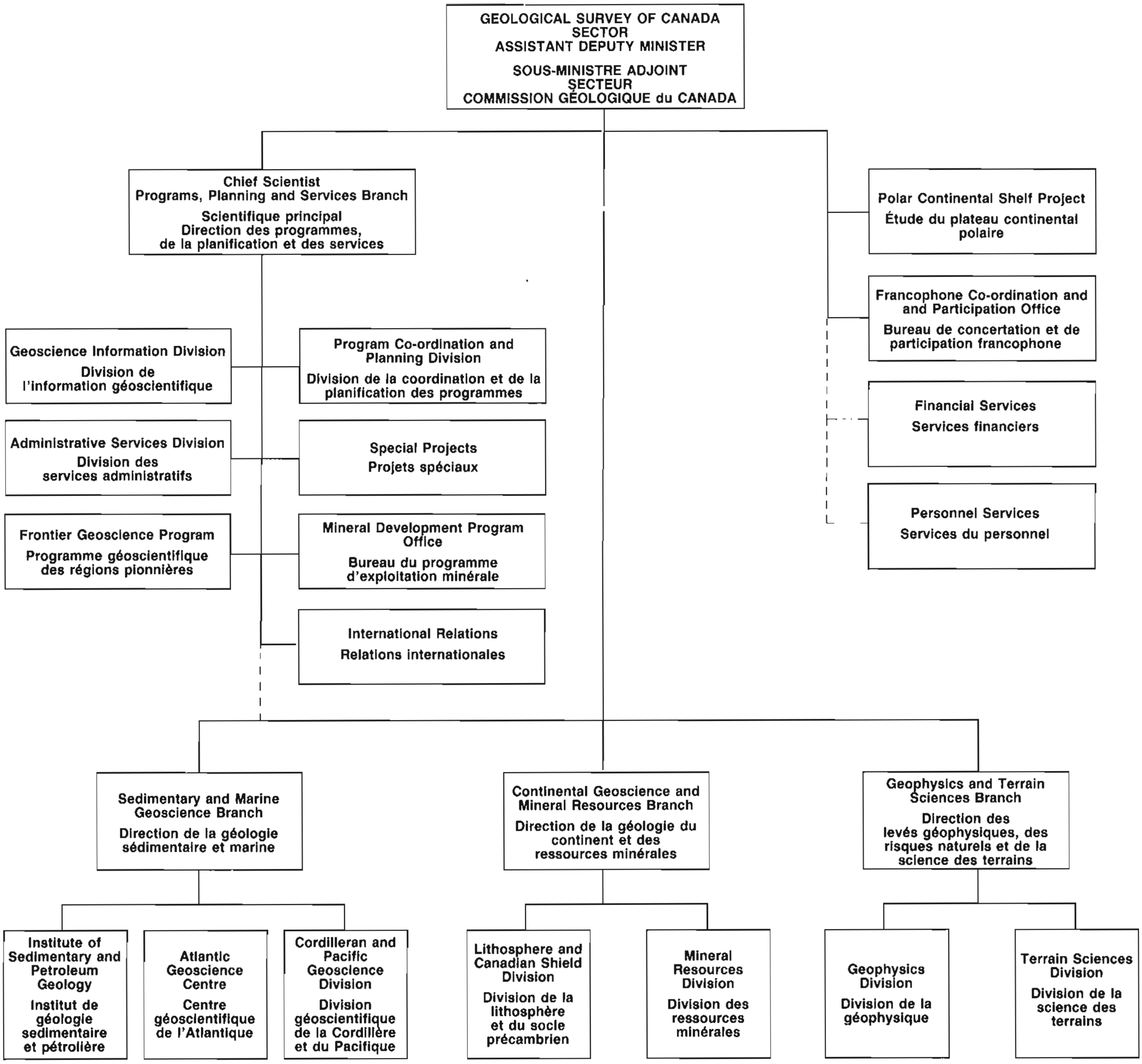
and from

Geological Survey of Canada offices:
601 Booth Street
Ottawa, Canada K1A 0E8
3303-33rd Street N.W
Calgary, Alberta T2L 2A7
100 West Pender Street
Vancouver, British Columbia V6B 1R8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-88/1E	Canada:	$12.00
ISBN 0-660-53900-4	Other countries:	$14.40

Price subject to change without notice


GEOLOGICAL SURVEY OF CANADA SECTOR ASSISTANT DEPUTY MINISTER
SOUS-MINISTRE ADJOINT SECTEUR COMMISSION GÉOLOGIQUE du CANADA
Chief Scientist Programs, Planning and Services Branch
Scientifique principal Direction des programmes, de la planification et des services
Polar Continental Shelf Project
Étude du plateau continental polaire
Francophone Co-ordination and and Participation Office
Bureau de concertation et de participation francophone
Financial Services
Services financiers
Personnel Services
Services du personnel
Geoscience Information Division
Division de l'information géoscientifique
Program Co-ordination and Planning Division
Division de la coordination et de la planification des programmes
Administrative Services Division
Division des services administratifs
Special Projects
Projets spéciaux
Frontier Geoscience Program
Programme géoscientifique des régions pionnières
Mineral Development Program Office
Bureau du programme d'exploitation minérale
International Relations
Relations internationales
Sedimentary and Marine Geoscience Branch
Direction de la géologie sédimentaire et marine
Continental Geoscience and Mineral Resources Branch
Direction de la géologie du continent et des ressources minérales
Geophysics and Terrain Sciences Branch
Direction des levés géophysiques, des risques naturels et de la science des terrains
Institute of Sedimentary and Petroleum Geology
Institut de géologie sédimentaire et pétrolière
Atlantic Geoscience Centre
Centre géoscientifique de l'Atlantique
Cordilleran and Pacific Geoscience Division
Division géoscientifique de la Cordillère et du Pacifique
Lithosphere and Canadian Shield Division
Division de la lithosphère et du socle précambrien
Mineral Resources Division
Division des ressources minérales
Geophysics Division
Division de la géophysique
Terrain Sciences Division
Division de la science des terrains

Separates

A limited number of separates of the papers that appear in this volume are available by direct request to the individual authors. The addresses of the Geological Survey of Canada offices follow:

601 Booth Street,
OTTAWA, Ontario
K1A 0E8

Institute of Sedimentary and Petroleum Geology,
3303-33rd Street N.W.,
CALGARY, Alberta
T2L 2A7

Cordilleran and Pacific Geoscience Division,
100 West Pender Street,
VANCOUVER, B.C.
V6B 1R8

Pacific Geoscience Centre
P.O. Box 6000,
9860 Saanich Road,
SIDNEY, B.C.
V8L 4B2

Atlantic Geoscience Centre,
Bedford Institute of Oceanography,
P.O. Box 1006,
DARTMOUTH, N.S.
B2Y 4A2

When no location accompanies an author's name in the title of a paper, the Ottawa address should be used.

Tirés à part

On peut obtenir un nombre limité de «tirés à part» des articles qui paraissent dans cette publication en s'adressant directement à chaque auteur. Les adresses des différents bureaux de la Commission géologique du Canada sont les suivantes:

601, rue Booth
OTTAWA, Ontario
K1A 0E8

Institut de géologie sédimentaire et pétrolière
3303-33rd St. N.W.,
CALGARY, Alberta
T2L 2A7

Division géoscientifique de la Cordillère
et du Pacifique
100 West Pender Street,
VANCOUVER, Colombie-Britannique
V6B 1R8

Centre géoscientifique du Pacifique
B.P. 6000,
9860 Saanich Road,
SIDNEY, Colombie-Britannique
V8L 4B2

Centre géoscientifique de l'Atlantique
Institut océanographique de Bedford
B.P. 1006,
DARTMOUTH, Nouvelle-Écosse
B2Y 4A2

Lorsque l'adresse de l'auteur ne figure pas sous le titre d'un document, on doit alors utiliser l'adresse d'Ottawa.

CONTENTS

CONTRIBUTIONS TO FRONTIER GEOSCIENCE PROGRAM

INTRODUCTION

In 1987 the Geological Survey of Canada became a Sector within the Department of Energy, Mines and Resources, and was re-organized into the four Branches shown on the accompanying organizational chart. The primary role of the Survey, which was founded in 1842, continues to be to provide an overview of all facets of Canadian geology as a basis for national policy, for planning by government and industry, and for public information.

In order to provide interim results of its program a publication titled "Summary of Research" was initiated in 1963. The title was changed to "Current Research" in 1978 and the report was released three times a year (Part A, B and C). After 1982 Part C was no longer issued and Part B was discontinued in 1987 to encourage greater use of journal publication for short contributions.

Current Research, however, is the one series of GSC publications that gives the public a yearly overview of the range of the Geological Survey of Canada Sector activities. From time to time Current Research has been criticized for its size, as it was necessary for the user to buy a large volume to obtain a few pertinent papers. To introduce greater flexibility, this issue of Current Research is therefore available in six parts that can be purchased separately: four regional volumes, one volume of national and general programs, and a volume that contains abstracts of all the reports. The Parts are:

Part A: Abstracts/Résumés
Part B: Eastern and Atlantic Canada
Part C: Canadian Shield
Part D: Interior Plains and Arctic Canada
Part E: Cordillera and Pacific Margin
Part F: National and General Programs

Identification of the Parts by letters is for convenience only and may be subject to change. Each of Parts B to F includes a paginated Table of Contents for the volume: Table of Contents for the other Parts of this series will be found at the back of each volume.

En 1987 la Commission géologique est devenue un secteur à l'intérieur du ministère de l'Énergie, des Mines et des Ressources et a été réorganisée en quatre directions indiquées sur l'organigramme d'accompagnement. Organisme fondé en 1842, la Commission a comme rôle principal de procurer un cadre d'ensemble de toutes les facettes de la géologie du Canada comme base d'une politique nationale pour la planification du gouvernement et de l'industrie et pour informer le public en général.

Afin de fournir les résultats préliminaires de son programme de recherche une publication ayant titre « Summary of Research » est apparue en 1963. Une nouvelle publication, ayant les mêmes buts, est apparue en 1978 sous le titre « Recherches en cours »; cet ouvrage était diffusé trois fois par année (parties A, B et C). Après 1982 la partie C a été abandonnée et ce fut de même pour la partie B en 1987. L'arrêt de ces publications avait pour but d'adopter une nouvelle forme d'édition pour satisfaire davantage l'usager.

La publication « Recherches en cours » appartient à part entière à la série des publications de la CGC et apporte à chaque année une vue d'ensemble des activités de la Commission géologique maintenant au niveau de secteur. De temps à autre la publication « Recherches en cours » a été critiquée pour son fort volume, plusieurs ont constaté qu'il était nécessaire d'acheter un gros volume uniquement pour n'avoir accès qu'à un petit nombre d'articles. Maintenant, cette publication est disponible en six parties en vente séparément, ce qui procure une plus grande flexibilité pour l'usager. La publication est répartie comme suit: quatre volumes régionaux, un volume couvrant les programmes nationaux et généraux et un dernier contenant les résumés de tous les articles. On y trouve les parties suivantes:

Partie A: Abstracts/Résumés
Partie B: Est et région atlantique du Canada
Partie C: Bouclier canadien
Partie D: Plaines intérieures et région arctique du Canada
Partie E: Cordillère et marge du Pacifique
Partie F: Programmes nationaux et généraux

L'identification des parties par une lettre a été adoptée uniquement par commodité; on pourra éventuellement utiliser une autre façon. Les parties B à F possèdent une table des matières paginée; il est à noter qu'à chacune des parties de cette série on y trouvera à l'endos une table des matières indiquant le contenu des autres parties.

Tectonics and mineralization of the Kechika Trough, Gataga area, northeastern British Columbia

K.R. McClay, M.W. Insley, N.A. Way, and R. Anderton
Cordilleran and Pacific Geoscience Division, Vancouver and Mineral Resources Division, Ottawa

McClay, K.R., Insley, M.W., Way, N.A., and Anderton, R., Tectonics and mineralization of the Kechika Trough, Gataga area, northeastern British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 1-12, 1988.

Abstract

Hadrynian through Mississippian strata of the Gataga area are involved in a northwest-trending fold and thrust belt. Stratiform barite and barite-sulphide mineralization in the black siliciclastics of the lower part of the Earn Group has been mapped over a stratigraphic interval of 400 m and over a continuous to semicontinuous strike length of 50 km. Five mineralized horizons have been identified, three of which contain significant barite and barite-sulphide accumulations. Intensely deformed sulphide mineralization is found at the Bear and Driftpile deposits. The structure is dominated by large northeastward-verging thrust panels along the western margins of the Gataga area and steeply east-dipping, west-verging thrust faults along the eastern margin. The lower Earn Group siliciclastics are intensely folded and faulted, hence thickness determinations are difficult and correlation of the mineralized intervals is hampered. Structural and stratigraphic analysis indicates that the stratiform barite and barite-sulphide mineralization was deposited in a Late Devonian half graben system that was inverted during Mesozoic contractional deformation.

Résumé

Des couches de l'Hadrynien au Mississippien de la région de Gataga sont associées à une zone de plissement et de charriage de direction nord-ouest. Une minéralisation stratiforme de barytine et de sulfure de barytine dans des roches siliciclastiques noires de la partie inférieure du groupe d'Earn a été cartographiée sur un intervalle stratigraphique de 400 m et sur une longueur en direction continue à semi-continue de 50 km. Cinq horizons minéralisés ont été identifiés, dont trois contiennent des accumulations importantes de barytine et de sulfure de barytine. Une minéralisation sulfurée fortement déformée se trouve dans les gisements de Bear et de Driftpile. La structure est dominée par de grands panneaux de charriage orientés vers le nord-est le long des marges occidentales de la région de Gataga et par des failles de charriage de direction ouest à fort pendage vers l'est le long de la marge est. Les roches siliciclastiques du groupe d'Earn inférieur sont fortement plissées et faillées, de sorte que les mesures d'épaisseur sont difficiles à effectuer, ce qui nuit à la corrélation des intervalles minéralisées. L'analyse structurale et stratigraphique indique que la minéralisation stratiforme de barytine et de sulfure de barytine s'est déposée dans un système de demi graben du Dévonien supérieur qui a été renversé pendant la période de contraction du Mésozoïque.

INTRODUCTION

The Kechika Trough is a linear belt of highly folded and thrust, Ordovician through Mississippian, dominantly fine-grained siliciclastic rocks in the western Rocky Mountains of northeastern British Columbia (Fig. 1). The Kechika Trough is the southern extension of the Selwyn Basin (Fig. 1), and is underlain principally by late Proterozoic (Hadrynian) through Cambro-Ordovician platformal to off-shelf siliciclastics and carbonates deposited on the ancestral North American craton.

Within the Kechika Trough, the "black clastics" of the Devonian lower Earn Group (Gordey et al., 1982, 1987), host significant stratiform barite-zinc-lead deposits —Driftpile Creek, Bear, Cirque, Elf and Fluke (MacIntyre, 1983; Carne and Cathro, 1982; Jefferson et al., 1983). It is the aim of this project to determine the tectonic, sedimentological and stratigraphic setting of this part of the Kechika Trough and to erect models for the deposition and distribution of the stratiform Ba-Zn-Pb deposits.

Previous work in the Gataga area included regional 1:250 000 scale reconnaissance mapping by Taylor and Stott (1973), Gabrielse (1962) and 1:50 000 mapping by MacIntyre (1981, 1983); detailed mapping of the Driftpile Creek Ba-Zn-Pb deposit was carried out by Archer Cathro and Associates (Carne and Cathro, 1982). The present study was initiated in 1985 and the first season's field work concentrated upon the detailed structure and mineralization of the Driftpile deposit (McClay and Insley, 1986).

The 1986 field programme incorporated both 1:10 000 scale and regional mapping at scales 1:20 000 and 1:50 000 (NTS sheets 94E/16, 94F/14, 94K/4, 94L/1,7,8), (McClay et al., 1987) measuring of stratigraphic sections, and logging of drill core from the Driftpile Creek and Bear deposits (MacIntyre, 1983). Attention was focused upon regional structural and stratigraphic analysis and upon the sedimentology and stratigraphy of the lower Earn Group. In particular the stratiform barite and barite-zinc-lead mineralization was mapped and sampled in detail. This paper offers a description of the tectonic and stratigraphic setting of the lower Earn Group siliciclastics and their associated mineralization.

TECTONIC AND STRATIGRAPHIC SETTING

The Gataga area is bounded to the west by the Northern Rocky Mountain Trench-Kechika dextral strike-slip fault system (Gabrielse, 1985), and to the east by folded and thrust Hadrynian age siliciclastics (Taylor and Stott, 1973), (Fig. 2). Strata range from Hadrynian through Mississippian (Fig. 3), and include Hadrynian through Late Cambrian shallow water, platformal siliciclastics and carbonates; Cambro-Ordovician through Silurian shelf to off-shelf fine-grained siliciclastics, carbonates and cherts; and Mid-Devonian to Mississippian dominantly fine grained, black siliciclastics. Rocks of the Gataga area can be divided into four distinct tectonostratigraphic assemblages which are bounded by steep southwest-dipping, northeast-verging thrust faults (Fig. 2). Within each thrust sheet the strata generally young westwards. The easternmost fold and thrust package of this part of the Kechika Trough (IV in Fig. 2), is the focus of this paper. This panel consists of a central core of Road River Group and Lower Earn Group strata (Fig. 4), bounded to the west by a panel of Kechika Group strata and bounded to the east by folded and thrust Hadrynian, Cambrian and Kechika Group rocks (Fig. 4). In the centre of this area the Driftpile "Basin" of lower Earn Group strata hosts significant stratiform barite and barite-zinc-lead mineralization — Driftpile and Saint occurrences (2 and 3 in Fig. 4). Stratiform barite mineralization was mapped as a semi-continuous stratigraphic interval in the lower Earn Group rocks over a strike-length of 50 km (Fig. 4).

STRATIGRAPHY

The geology and structure of the eastern fold and thrust assemblage is shown in Figures 4 and 5. Stratigraphic nomenclature used in this paper follows that of Gabrielse (1962), Taylor and Stott (1973), Fritz (1980), and MacIntyre (1983). Stratigraphic relationships are summarized in Figure 3. The core of the fold and thrust package comprises recessive weathering Devonian shales, siltstones, cherts, thin limestones and lensoidal bodies of chert pebble grits and sandstones (Fig. 4). The siliciclastic rocks are flanked to the west by more

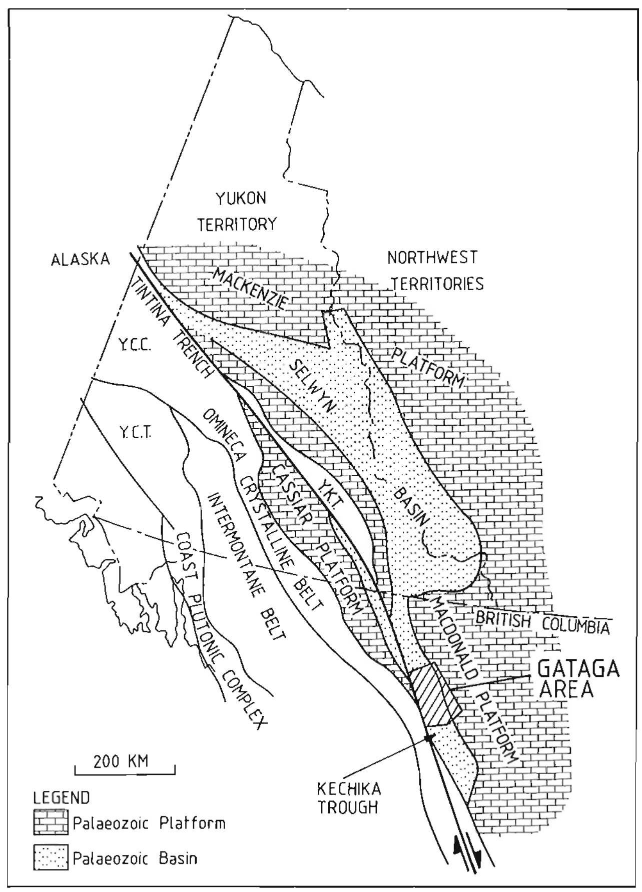


Figure 1. Regional tectonic setting of the Gataga area within the Kechika Trough.
Y.C.C. — Yukon Crystalline Complex
Y.C.T. — Yukon Crystalline Terrane
Y.K.T. — Yukon Cataclastic Terrane

resistant, west-dipping thrust panels of Kechika Group and Road River Group limestones, dolomites, dolomitic siltstones and phyllites (Fig. 4). To the east they are bounded by thick, resistant, steeply dipping panels of folded and thrust Proterozoic argillites, sandstones, and Cambrian quartzites and limestones (Fig. 2, 4). Detailed mapping and carefully measured sections has permitted a more accurate definition of the stratigraphy than that presented in an earlier paper (McClay and Insley, 1986). Accurate thickness determinations within the complexly deformed fold and thrust package are hampered by the intensely deformated and cleaved nature of the rocks.

Late Proterozoic (Hadrynian)

A thick succession of green slates, phyllites, brown sandstones, quartz pebble grits and minor lenses of oolitic limestones of Late Proterozoic (Hadrynian) age (Taylor and Stott, 1973), form the cores of anticlines and the hanging wall panels of thrust sheets at the eastern margin of the map (Fig. 4).

Lower to Middle Cambrian

As yet, no formal name has been proposed for the thick (1.1-2.0 km), sequence of quartzites, dolomitic grits and sandstones and shallow water carbonates that outcrop at the eastern margin of the map area (Fig. 4). Six members — three clastic units and three carbonate units (Fig. 4), can be traced throughout most of the map area.

The lowermost member, the Lower Clastic Unit, consists of 100-150 m of thin- to medium-bedded quartzites and phyllitic siltstones that conformably overlie the Upper Proterozoic phyllite succession (Fig. 4). Above this is a distinctive 20- to 60-m thick, Lower Carbonate Unit of medium-thick bedded grey oolitic limestones and archaeocyathid limestones (Fig. 4). The limestones are overlain by approximately 200 m of medium-thick bedded, crossbedded white quartzites and buff weathering dolomitic grits and sandstones of the Middle Clastic Unit. These lithologies typically exhibit well developed tabular and trough crossbedding. Skolithos trace fossils are common in the quartzites.

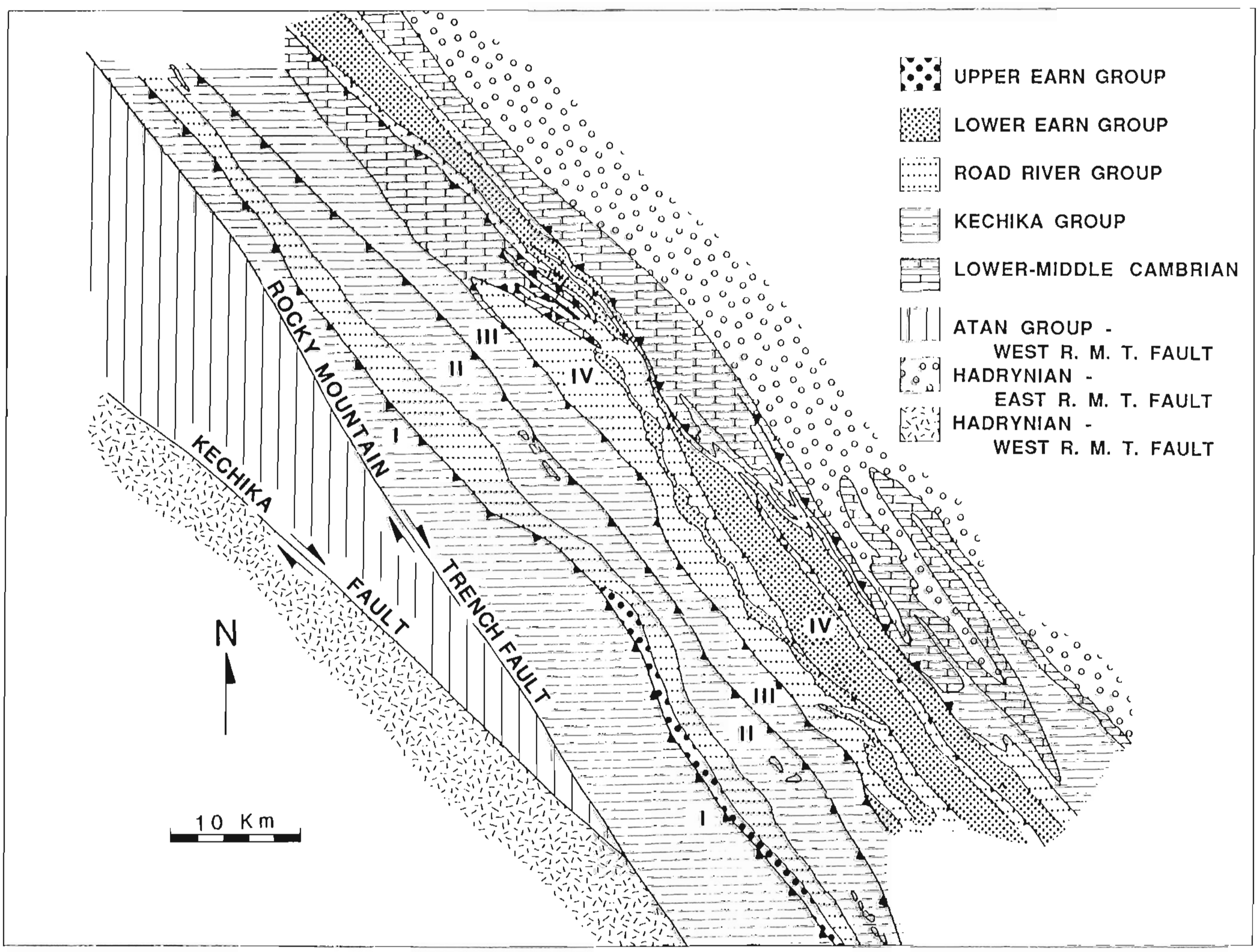


Figure 2. Structural map of the Gataga area showing the major thrust packages I to IV.

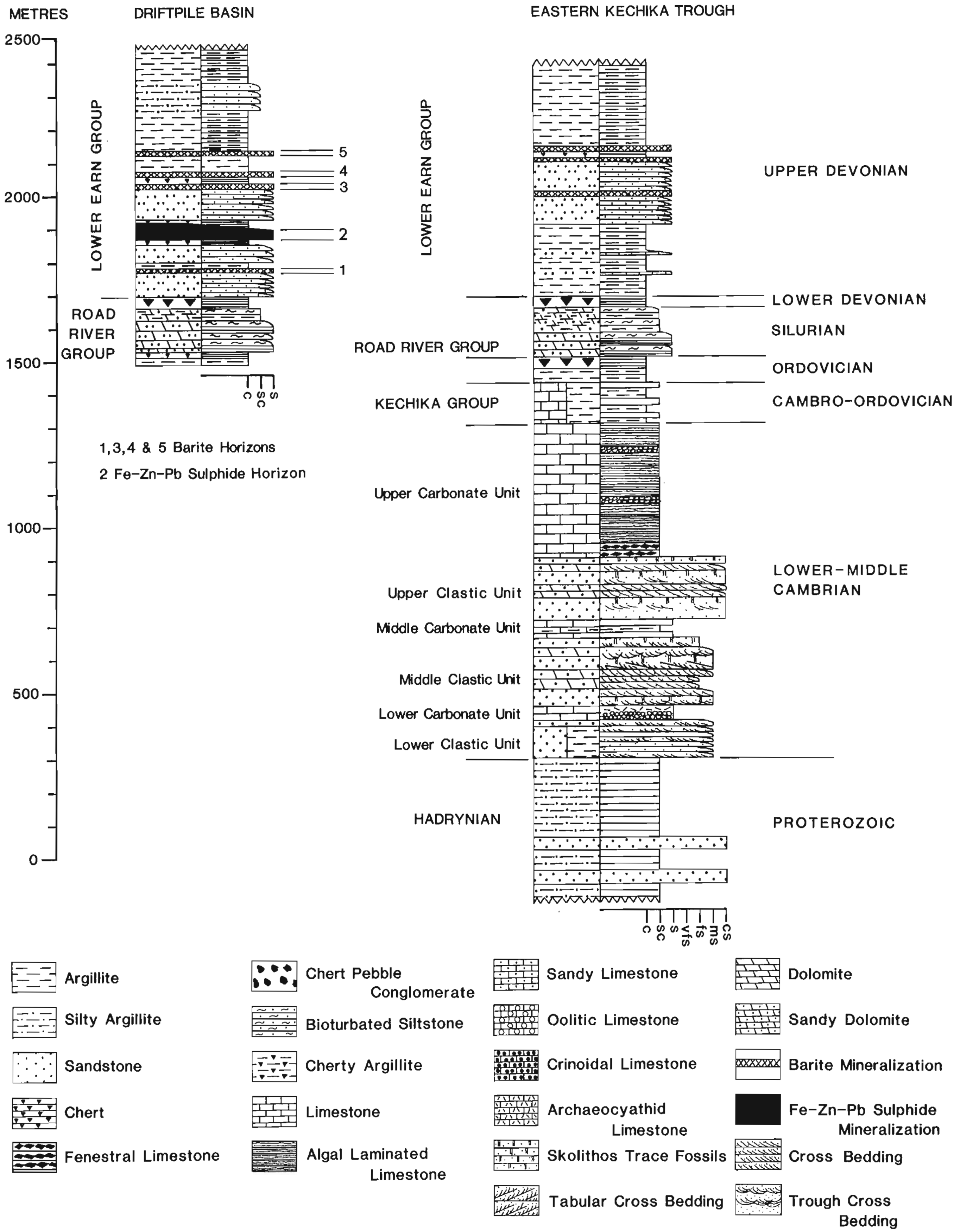


Figure 3. Summary stratigraphic columns showing the general stratigraphy of the eastern Kechika Trough and of the Driftpile "Basin". Left side of column indicates lithology. The right side shows sedimentological features and fossils. C = clay, sc = silty clay, s = silt, ufs = very fine sand, fs = fine sand, ms = medium sand, cs = coarse sand.

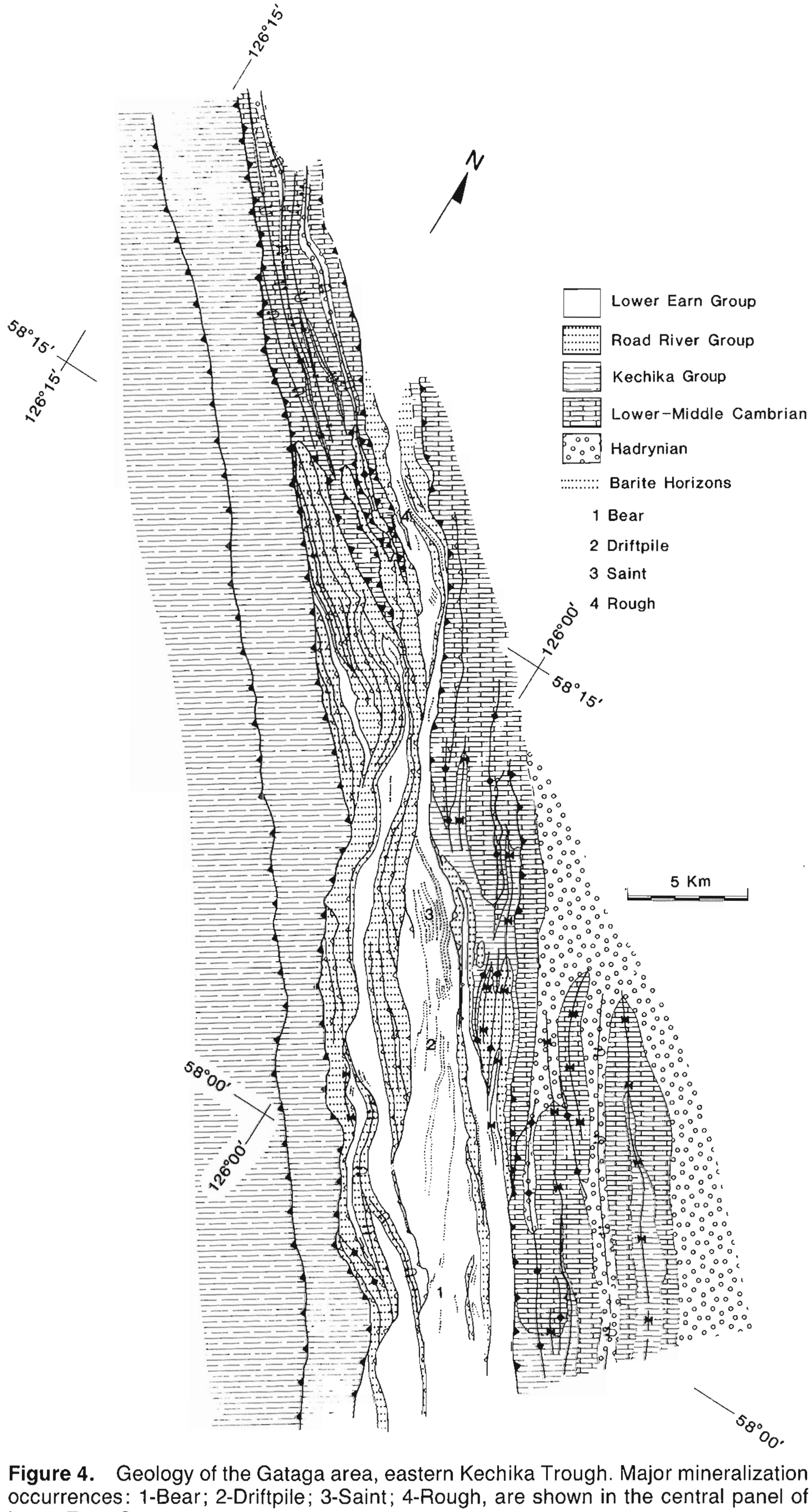


Figure 4. Geology of the Gataga area, eastern Kechika Trough. Major mineralization occurrences: 1-Bear; 2-Driftpile; 3-Saint; 4-Rough, are shown in the central panel of lower Earn Group strata.

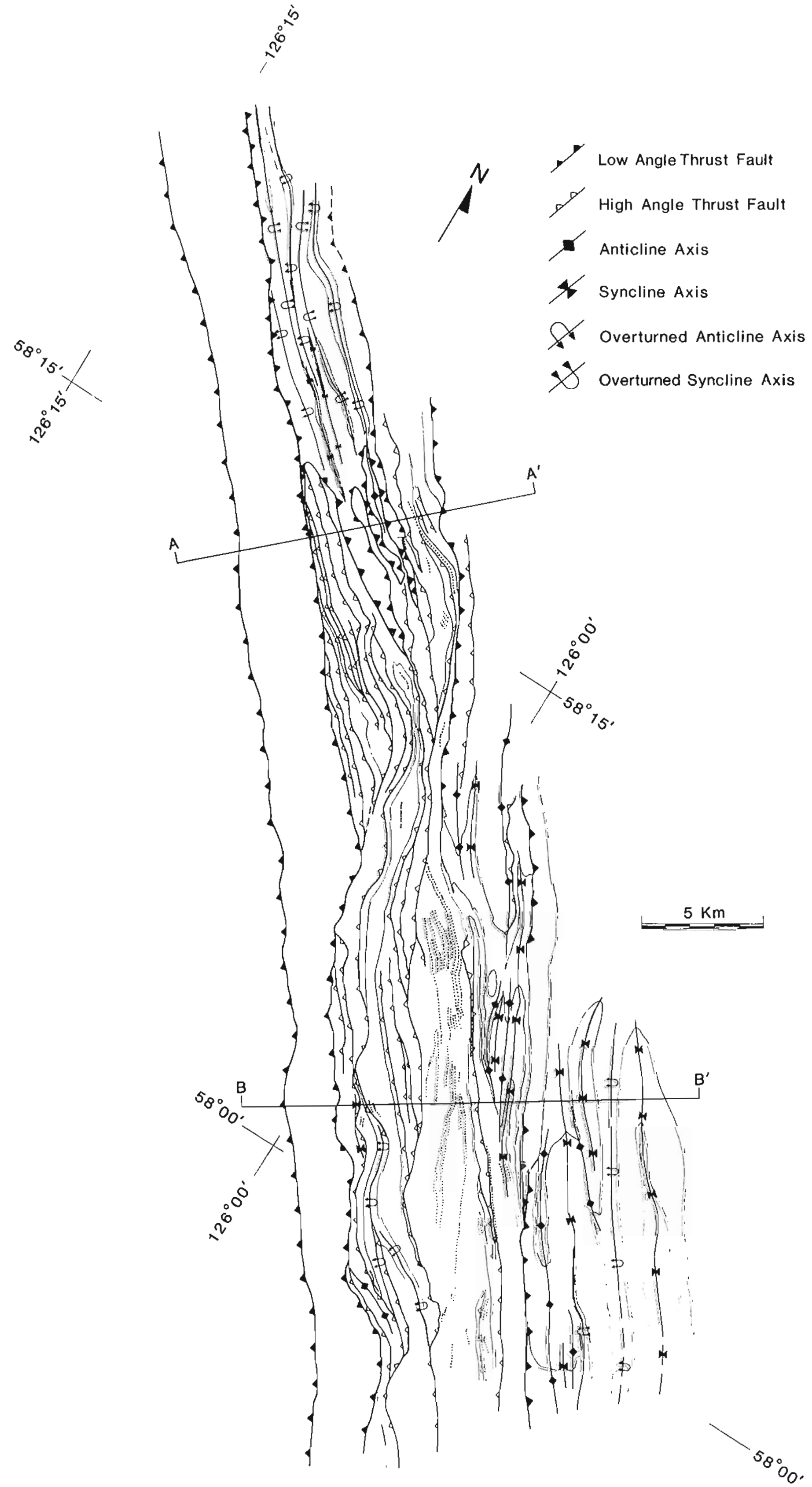


Figure 5. Structural map showing the major faults and folds of the Gataga area, eastern Kechika Trough.

Sixty metres of distinctive purple-grey weathering medium-bedded limestones with interbedded calcareous and noncalcareous shales constitute the Middle Carbonate Unit. This forms a regional marker in most of the map area. Above is approximately 200 m of thick-bedded white orthoquartzites and buff weathering dolomitic grits and sandstones form the Upper Clastic Unit. The orthoquartzite beds, in places, contain abundant Skolithos trace fossils. This unit grades upwards into a medium-thin bedded distinctive, buff weathering fenestral dolomite. The dolomite is overlain by medium to massively bedded grey, fine-grained micritic, oolitic and algal laminated limestones. These shallow water limestones and dolomites of the Upper Carbonate Unit are in places approximately 1 km thick and form very resistant and rugged outcrops in the eastern and northern parts of the map area.

In the north of the map area (Fig. 4) most of the underlying units thin out and only the Upper Carbonate member is well developed.

Kechika Group (Upper Cambrian-Ordovician)

Kechika Group rocks conformably overlie the Cambrian carbonates. At the base, is a distinctive orange weathering unit (up to 30 m thick), of thinly interbedded dolomitic siltstones, dolomites and grey-black phyllites. This is followed by approximately 150 m of grey-brown weathering calcareous phyllites intercalated with characteristically 1-3 cm thick limestone beds. Trace fossils are rare from this part of the Kechika Group and to date no conodonts have been recovered.

Road River Group (Ordovician-Lower Devonian)

Ordovician through Lower Devonian Road River Group rocks conformably overlie the Kechika Group. In the map area the basal Road River rocks are a thin (approximately 30-60 m thick), succession of recessive, graptolitic carbonaceous black argillites, cherts and thin limestones. Poorly preserved biserial graptolites are commonly found in the black carbonaceous shales. These strata are overlain by approximately 130-170 m of more resistant, distinctive orange weathering dolomitic, plane-laminated micaceous siltstones and heavily bioturbated orange siltstones that contain typical monoserial Silurian graptolites and abundant burrow- and grazing-trail trace fossils. Two distinctive, 1-2 m thick, grey weathering limestone beds are found in the siltstone sequence. Preliminary conodont dating has revealed that in places the limestones are of Early Devonian age (M.J. Orchard, pers. comm., 1986). The "Silurian" siltstone is a unique map unit in the Gataga area and it is overlain by a thin sequence of recessive, silver-grey weathering black argillites, black cherts and minor limestones of Early Devonian age.

Lower Earn Group (Middle to Upper Devonian)

The Road River Group is succeeded by a strongly folded and thrusted sequence of the lower part of the Earn Group (sensu lato after Gordey et al., 1982) "black clastics". The base of the lower Earn Group is characterized by "tongues" of resistant, thick-bedded, chert pebble conglomerates and chert grits which are interpreted as proximal submarine fan and submarine canyon deposits. These units interdigitate with more distal thin bedded laminated siltstones and silt banded argillites. The basal succession is overlain by a minimum of 400 m of recessive, unlaminated to thinly laminated silver-grey weathering black argillites, cherty argillites and cherts. The fine-grained black clastics range in age from Frasnian to Fammenian with Fammenian dates being more common (M.J. Orchard, pers. comm., 1985). This Upper Devonian unit (informally called the Gunsteel Formation further to the south at the Cirque deposit (Jefferson et al., 1983)), contains from three to five stratiform layers of barite and barite-zinc-lead mineralization (Fig. 4). In the Driftpile Creek-Saint area (Fig. 4), the three most important mineralized intervals, although complexly folded and faulted, have been mapped over a strike length of 12 km. Regionally, the zone of barite and barite-zinc-lead stratiform mineralization is semi-continuous for a strike length of 50 km (Fig. 4).

TECTONICS OF THE GATAGA AREA

The fold and thrust belt that hosts the stratiform mineralization is bounded to the west by a large thrust sheet of Kechika Group and older rocks and to the east by complexly folded and faulted Lower to Middle Cambrian strata (Fig. 4, 5). The dominant vergence of all the major thrust sheets is to the northeast (McClay and Insley, 1986). At the eastern edge of the thrust belt steep southwest verging folds and thrusts are found — perhaps back thrusts or reactivated early extensional faults. Complicated smaller scale deformation patterns are found within the thrust sheets indicating at least local early tectonic transport to the northwest possibly associated with lateral and oblique ramps in the dominantly northeasterly-verging thrust system.

The western thrust sheet is underlain by steeply dipping, northwest-trending duplex systems of imbricated Road River Group and lower Earn Group strata (Fig. 4, 5). The fault pattern indicates the existence of several duplex systems along the strike of this part of the thrust belt (Fig. 4, 5). East of these duplexes the main lower Earn Group outcrop comprises tight to chevron folded and thrust cherty black argillites, siltstones and occasional thin sandstone and grit beds (Fig. 7a). North of the Rough claims (4 on Fig. 4) carbonates of the Lower to Middle Cambrian are thrust over the Road River and lower Earn Group strata (Fig. 6). This thrust sheet appears to have been thrust towards the west and folded after emplacement by movement on underlying younger thrusts that verge to the northeast (Fig. 6, 7b).

The eastern boundary of the lower Earn Group outcrop is a complex system of steeply-east-dipping, west-verging fold and thrust faults that bring the Lower to Middle Cambrian Middle Clastic through Upper Carbonate units over the Earn Group rocks (Fig. 4). Fold geometries vary from open to tight and are controlled by the thick clastic and carbonate packages of the Lower to Middle Cambrian.

Within the central core of highly folded lower Earn Group strata, the stratiform barite horizons are repeated by folds and thrust faults that produce a complex outcrop pattern (Fig. 4).

The siliciclastic rocks of the Kechika, Road River and lower Earn groups are all strongly cleaved (Fig. 8) with intense pressure solution in places generating incipient transposition fabrics (Fig. 8a). Cleavage refraction is common in the Lower Earn Group siliciclastics (Fig. 8b). The intense and ubiquitous cleavage development prevents accurate measurements of stratigraphic thicknesses in these siliciclastic units.

MINERALIZATION

Five mineralized units have been identified in the lower part of the Earn Group of the Gataga area (Fig. 10). Of these the three units at the base of the sequence are the most persistent and contain the thickest accumulations of stratiform barite and barite with sulphides (Fig. 10). The barite varies from medium- to coarse-grained, massive unlaminated beds, laminated barite intercalated with thin black argillites (Fig. 11a), and disseminated to blebby barite within argillites and cherts. The barite beds are typically thicker (up to 50 cm), and more massive at the base of mineralized intervals but thin and become more laminated to blebby higher up in the sequence (Fig. 10).

The thickest accumulations of sulphide mineralization are centred around the Driftpile Creek deposit (Locality 2, Fig. 4). Drill intersections of up to 45 m of massive fine-grained laminated pyrite, nodular to bedded carbonate, with subordinate sphalerite and galena (with up to 12 % combined metals over thin intervals), have been obtained. The sulphides are found mainly in unit 2 — Figure 9. The mineralization is strongly cleaved with transposition of fabrics (Fig. 11b). Outboard from the central sulphide accumulation at Driftpile Creek the mineralization is typically bedded massive-laminated barite (Fig. 11a), intercalated with black argillites

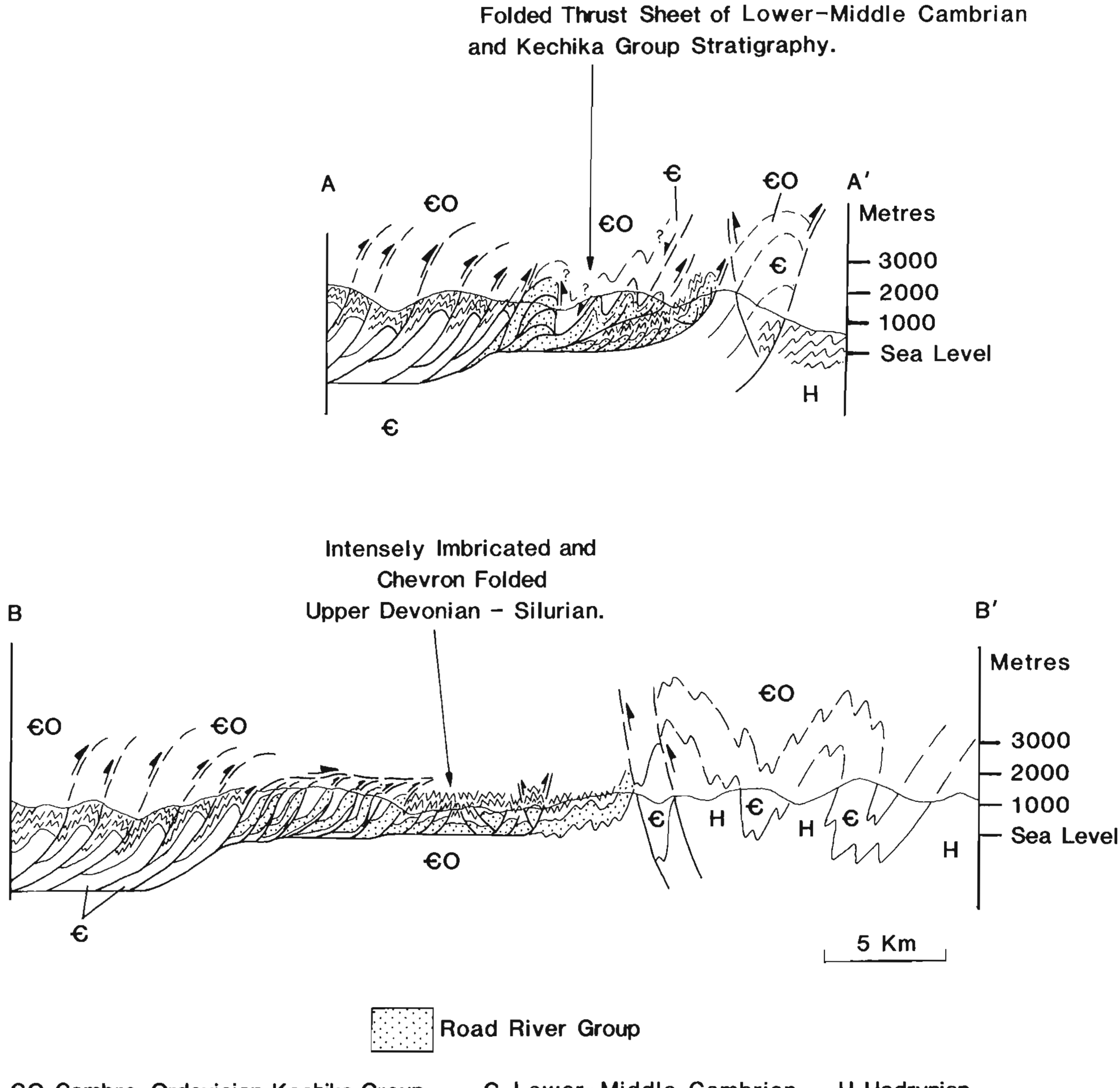


Figure 6. Cross-sections through the Gataga area (locations shown on Fig. 5).

Figure 7a. Tightly folded and cleaved Road River and lower Earn Group siltstones and shales, Rough claims (locality 4 — Fig. 4).

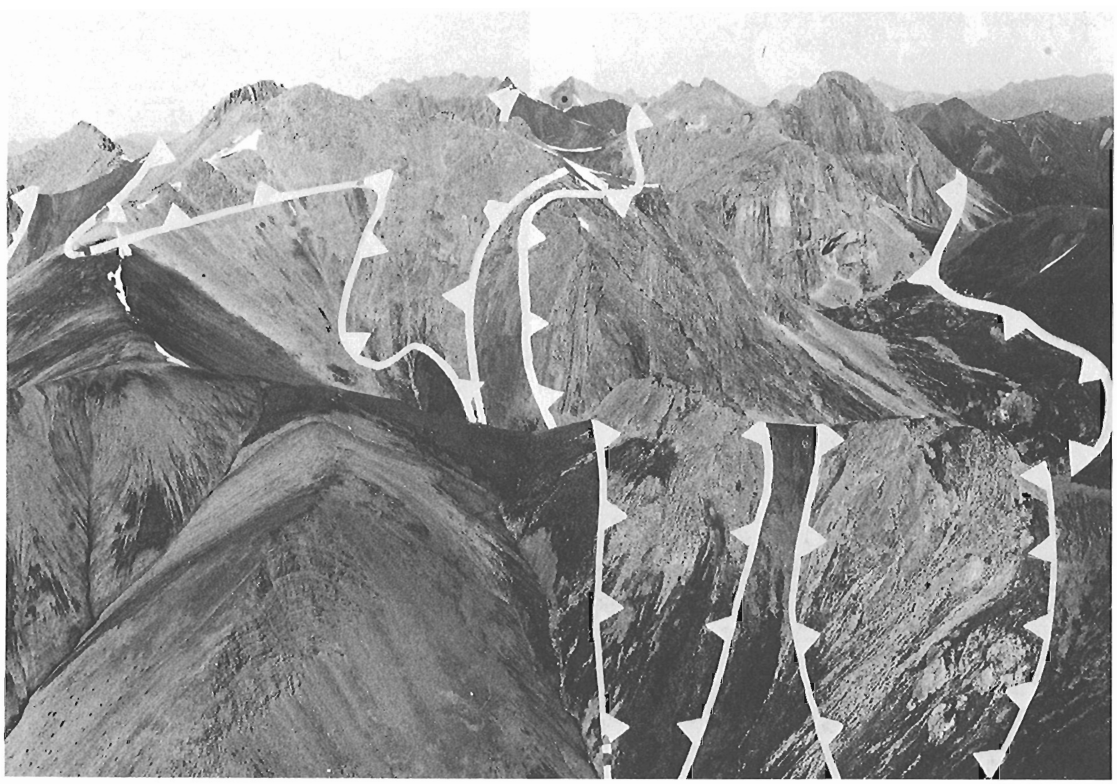


Figure 7b. Tightly folded thrust sheet of Early and Middle Cambrian age carbonates overlying imbricated Road River Group siltstones and shales. Northern part of thrust package IV — Fig. 2).

and cherty argillites (Fig. 10). Mineralized units 1, 3, 4 and 5 vary from massive bedded barite to laminated and blebby barite; units 4 and 5 are generally less than 20 m thick and are laterally impersistent. The structural complexity of the folds and thrust faults make correlation of mineralized intervals and drill intersections extremely difficult and further detailed mineralogical and geochemical studies are being carried out in an attempt to characterize the individual mineralized units.

DISCUSSION AND CONCLUSIONS

Detailed and regional mapping of the Gataga area has established the stratigraphic and structural framework of the stratiform barite and barite-sulphide mineralization. Four major thrust panels have been identified (Fig. 2). The barite mineralization occurs almost exclusively in the lower Earn Group siliciclastics (minor nodular barite is found in the Ordovician Road River Group black argillites), of thrust unit 4 (Fig. 2). Barite mineralization has been identified over a stratigraphic thickness of 400 m and along strike for 50 km as a semicontinuous interval. Economic to subeconomic sulphides (pyrite-barite-sphalerite-galena), are concentrated at the Bear (locality 1, Fig. 4), and Driftpile deposits (locality 2, Fig. 4), but other as yet undiscovered areas of barite-sphalerite and barite-galena mineralization may occur elsewhere in the belt. Further research will concentrate on the detailed structure of the Driftpile deposit and upon the mineralogy, textures and geochemistry of the deposit.

The structure of the Gataga area is dominated by large northeast-verging thrust sheets (Fig. 6), dominated by the thick competent clastic and carbonate units of Early and Middle Cambrian age. Major detachments occur in the thinly bedded Kechika Group and in the lower Earn Group siliciclastics (Fig. 6). Internal deformation within these two units is intense with strong cleavage development and local transposition. The eastern boundary of the Gataga area is characterized by steeply east-dipping, southwest-verging thrust faults that may be major backthrusts along reactivated early extensional fault systems. To date stratigraphic and structural mapping suggests that the lower Earn Group strata were deposited in a half graben system (in part of the "Driftpile Basin"), with the siliciclastic units thickening to the southwest towards major growth faults (e.g. MacIntyre, 1983). The half graben system was subsequently inverted during the Mesozoic contractional tectonics. Further detailed analysis of measured sections and of the fault tectonics is being undertaken in order to determine the geometry of the original Driftpile Basin.

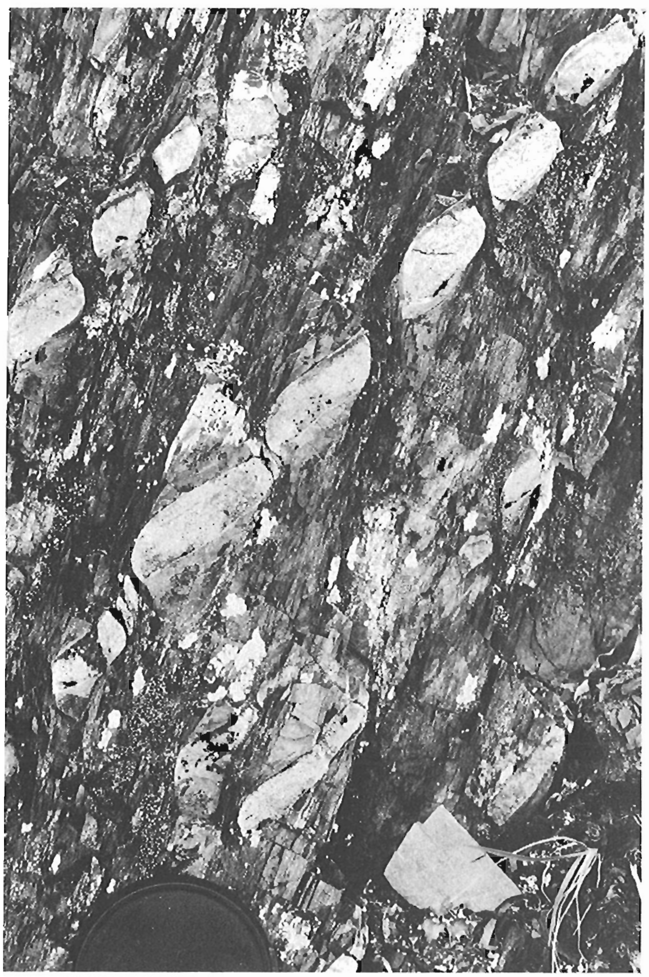


Figure 8a. Intense pressure solution cleavage in Kechika Group siltstones with thin limestone beds.

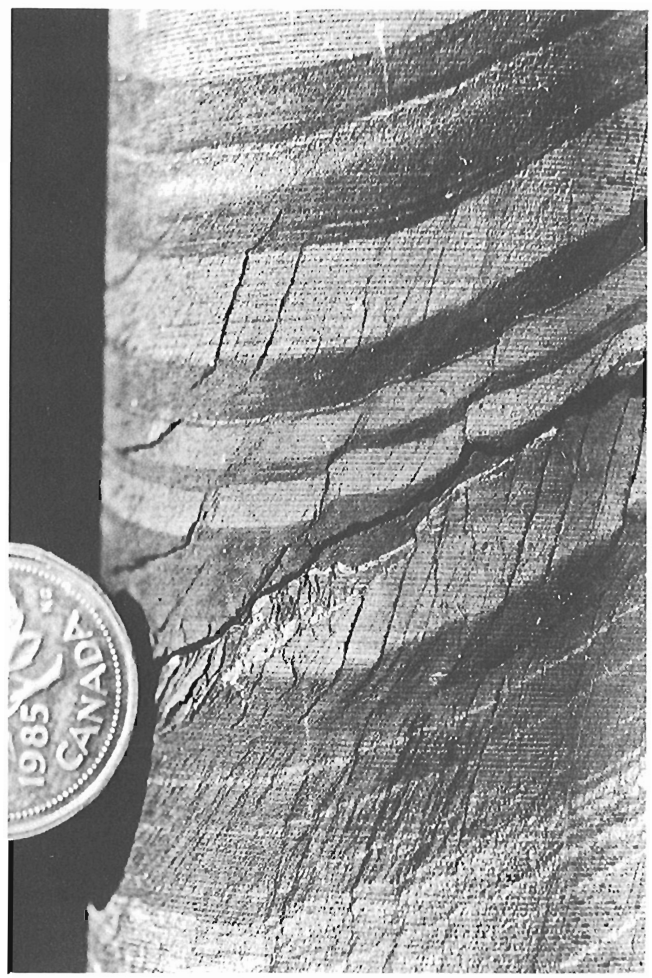


Figure 8b. Cleavage refraction in thin siltstone beds within black shales of the lower Earn Group.

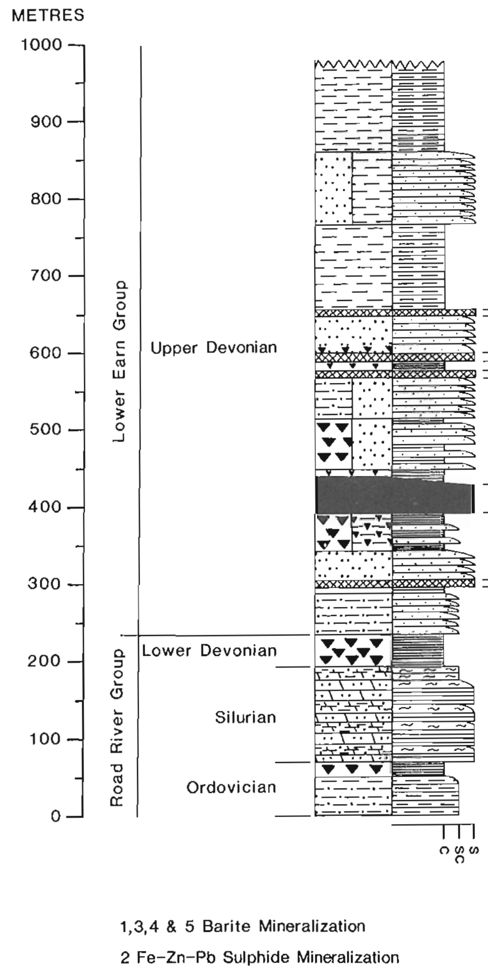


Figure 9. Detailed stratigraphy of the Driftpile-Saint area (localities 2 and 3, Fig. 4). For symbols refer to Figure 3. Left side of column indicates lithology. The right side shows sedimentologic features. C = clay, sc = silty clay, s = sand.

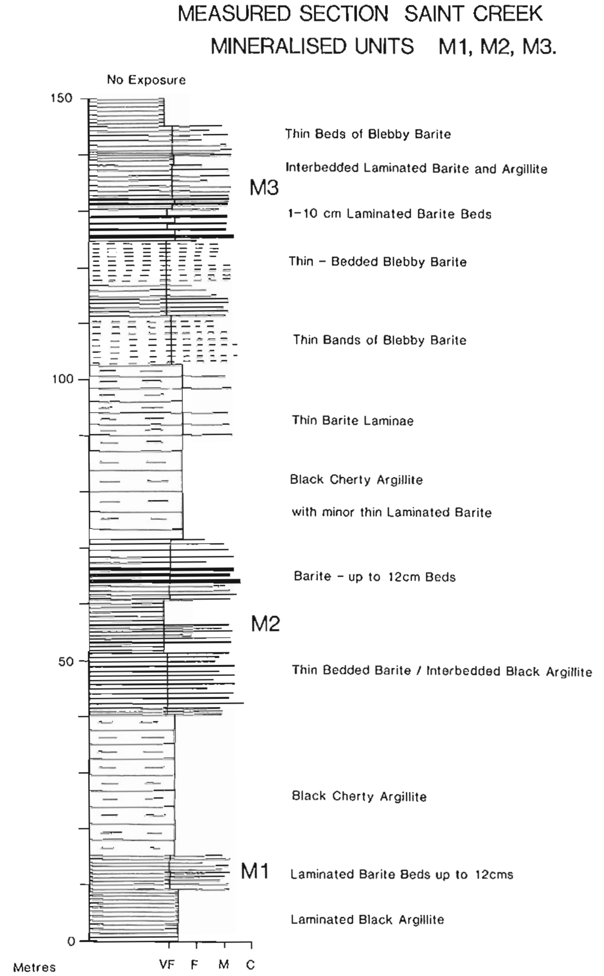


Figure 10. Measured section through the mineralized interval on Saint Creek (locality 3, Fig. 4). For symbols refer to Figure 3. Uf = very fine, f = fine, m = medium, c = coarse.

Figure 11a. Highly sheared and transposed pyrite-sphalerite and nodular carbonate mineralization — unit 2, Driftpile deposit.

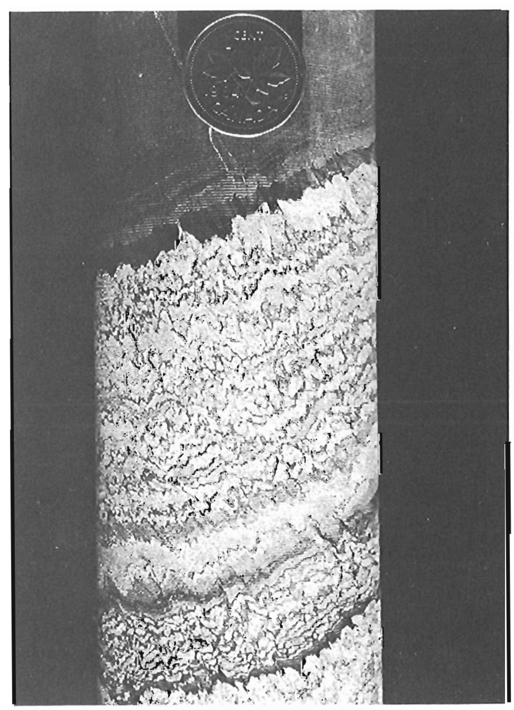


Figure 11b. Laminated barite mineralization with thin black shale laminae. Unit 3 — Driftpile deposit.

ACKNOWLEDGMENTS

This project is supported by a Natural Environment Research Council Grant to Dr. K.R. McClay. Logistic assistance was provided through the Geological Survey of Canada (H. Gabrielse, R.B. Campbell, D. Sangster, C. Findlay), and through the B.C. Ministry of Energy, Mines and Petroleum Resources (W. McMillan, D. MacIntyre). H. Beeley and A.C. Scott gave valuable assistance in the field and Okanagan Helicopters (R. Kernaham and T. Grant) gave excellent service.

REFERENCES

Carne, R.C. and Cathro, R.J.
1982: Sedimentary exhalative (Sedex) zinc-silver-lead deposits, northern Canadian Cordillera; Canadian Institute of Mining and Metallurgy Bulletin, v. 75, p. 66-78.

Fritz, W.H.
1980: Two Cambrian stratigraphic sections near Gataga River, Northern Rocky Mountains, British Columbia; *in* Current Research, Part C, Geological Survey of Canada, Paper 80-1C, p. 113-119.

Gabrielse, H.
1962: Kechika, British Columbia; Geological Survey of Canada, Map 42-1962.
1985: Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia; Geological Society of America Bulletin, v. 96, no. 1, p. 1-14.

Gordey, S.P., Abbott, J.G., and Orchard, M.J.
1982: Devono-Mississippian (Earn Group) and younger strata in east-central Yukon; *in* Current Research, Part B, Geological Survey of Canada, Paper 82-1B, p. 92-100.

Gordey, S.P., Abbott, J.G., Tempelman-Kluit, D.J., and Gabrielse, H.
1987: Antler clastics in the Canadian Cordillera; Geology, v. 15, p. 103-107.

Jefferson, C.W., Kilby, D.B., Pigage, L.C., and Roberts, W.J.
1983: The cirque barite-lead-zinc deposits, northeastern British Columbia; *in* Sediment Hosted Stratiform Lead-Zinc Deposits, Sangster, D.F. (ed.), Mineralogical Association of Canada, Short Course Notes, v. 9, p. 121-140.

McClay, K.R. and Insley, M.W.
1986: Structure and mineralization of the Driftpile Creek area, northeastern British Columbia (94E/16, 94F/14, 94K/4, 94L/1); B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 86-1, p. 343-350.

McClay, K.R., Insley, M.W., Way, N.A., and Anderton, R.
1987: Stratigraphy and tectonics of the Gataga area northeastern British Columbia, (94E/16, 94F/14, 94K/4, 94L/1, 94L/7, 94L/8); B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1986, Paper 87-1, p. 193-200.

MacIntyre, D.G.
1981: Geology of the Akie River Ba-Pb-Zn mineral district; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 44.
1983: Geology and stratiform barite sulphide deposits in northeastern British Columbia; *in* Sediment Hosted Stratiform Lead-Zinc Deposits, Sangster, D.F. (ed.), Mineralogical Association of Canada, Short Course Notes, v. 9, p. 85-120.

Taylor, G.C. and Stott, D.F.
1973: Tuchodi Lakes map-area, British Columbia; Geological Survey of Canada, Memoir 373.

The South Fork Volcanics: mid-Cretaceous caldera fill tuffs in east-central Yukon

Steven P. Gordey
Cordilleran and Pacific Geoscience Division, Vancouver

Gordey, S.P., The South Fork Volcanics: mid-Cretaceous caldera fill tuffs in east-central Yukon; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 13-18, 1988.

Abstract

The South Fork Volcanics comprise quartz — biotite — feldspar ± hornblende crystal and crystal lithic tuff. Their distribution, faulted contacts with country rocks, massive character, dense welding and great thickness indicate formation by the ponding of hot pyroclastic ejecta in discrete calderas ranging from 6 km to as much as 38 km across. Crosscutting relationships and the occurrence of granite clasts in the tuffs show the South Fork to be cogenetic with mid-Cretaceous granitic rocks. Although this plutonic suite occurs the length of the Canadian Cordillera, the South Fork Volcanics are its only known volcanic equivalent.

Résumé

Les roches volcaniques de South Fork comprennent des cristaux de quartz, de biotite, de feldspath et de ± hornblende, ainsi qu'un tuf volcanique cristallin. Leur distribution, leur contact faillé avec les roches encaissantes, leur caractère massif, le réseau dense de soudures et leur grande épaisseur indiquent qu'elles proviennent de la formation de lacs de projections volcaniques pyroclastiques chaudes dans des caldeiras bien définis de 6 à 38 km de diamètre. Les relations entre coupes transversales et la présence de fragments de granite détritique dans les tufs montrent que la formation de South Fork est de même origine que les roches granitiques du Crétacé moyen. Même si cette série plutonique se trouve le long de la Cordillière canadienne, les roches volcaniques de South Fork constituent son seul équivalent volcanique connu.

REGIONAL SETTING AND PREVIOUS WORK

The geology of east-central Yukon is dominated by unmetamorphosed sediments and local volcanics of late Precambrian to Triassic age that were deposited along the western margin of the North American craton. In Jura-Cretaceous time the collision and suturing of the North American craton with an island arc terrane (Tempelman-Kluit, 1979) resulted in northeastward imbrication and folding of autochthonous strata and the obduction of allochthons of mylonite, ophiolite and granite. The subsequent emplacement of post-tectonic, mid-Cretaceous granitic rocks and local volcanics presumably was related to heating and thickening of continental crust during collision. At least 450 km of right lateral slip occurred on Tintina Fault Zone between the Late Cretaceous and mid-Eocene time and later (Tempelman-Kluit, 1979). The post-collision mid-Cretaceous plutonic rocks occur the length of the Cordillera. However, their only known volcanic equivalents are the South Fork Volcanics of east-central Yukon.

The South Fork Volcanics were first mapped in their entirety by Roddick and Green (1961a,b), who described them as a series of gently dipping massive dark andesite, dacite and basalt flows unconformably overlying deformed Paleozoic strata. They considered them Paleocene, but subsequent radiometric dating (Green, 1962) and Roddick (1966) hinted at a broadly mid-Cretaceous age. Wood (1981) and Wood and Armstrong (1982), described a small area of the volcanics (area B, Fig. 1) as calk-alkaline andesite and dacite ashflow tuffs, and also portrayed their contact with country rocks as unconformable. Potassium-argon dating by these

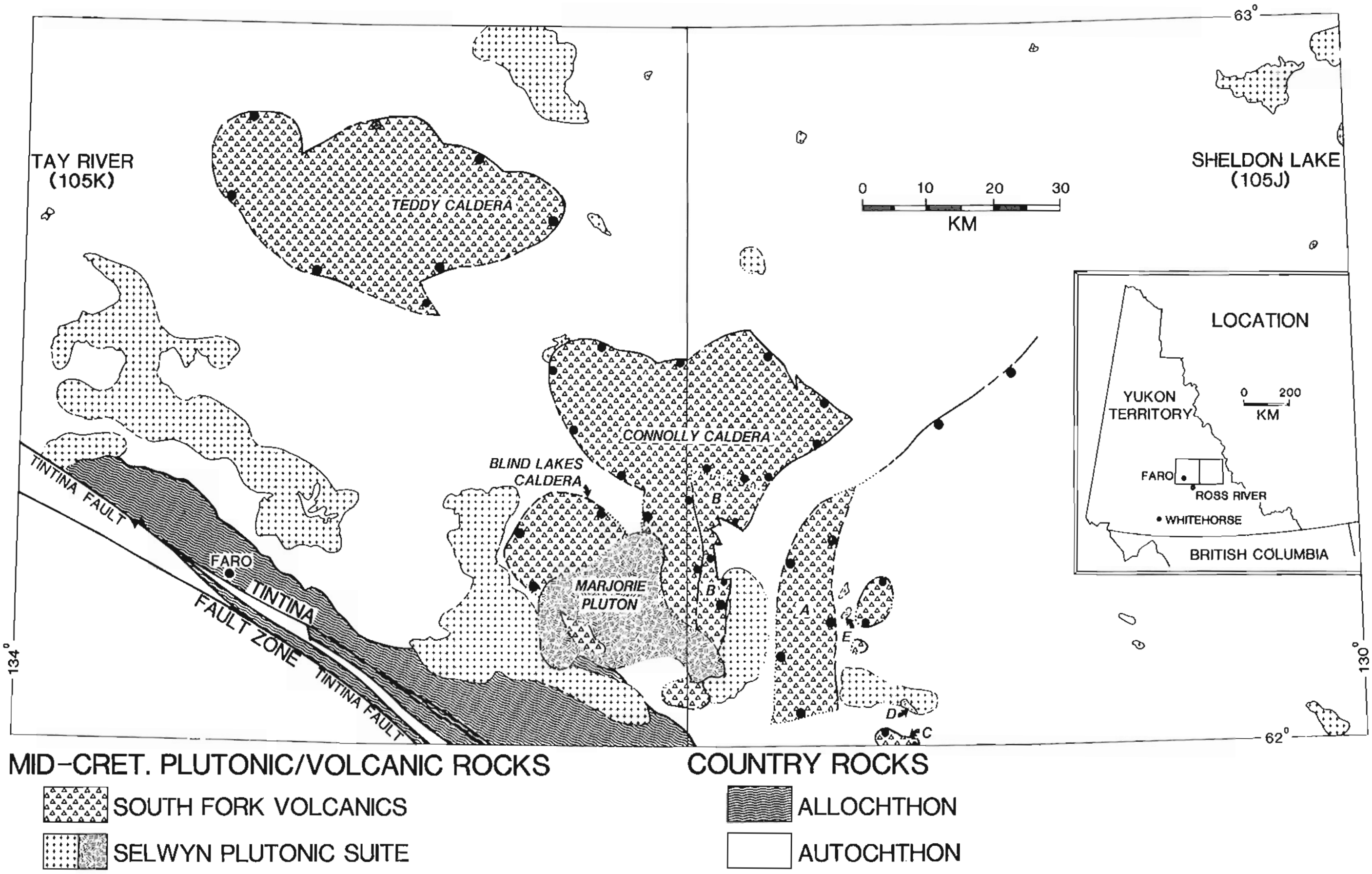


Figure 1. Regional setting and location of mid-Cretaceous South Fork Volcanics and coeval plutonic rocks of the Selwyn Plutonic Suite with reference to Sheldon Lake (105J) and Tay River (105K) map areas. The autochthon (unpatterned) represents mostly late Precambrian to Upper Triassic sediments and minor volcanics deposited along the western margin of North America. The allochthon includes mylonite, greenstone, limestone, and chert accreted to North America in the Jura-Cretaceous, simultaneous with thrust faulting and folding of the autochthon. Tintina Fault Zone is a dextral strike-slip fault system with at least 450 km of displacement, most of this along the main strand, the Tintina Fault. All known occurrences of the South Fork Volcanics are in the Sheldon Lake and Tay River map areas. The volcanics are preserved within several calderas, the largest of which are here termed the Teddy (after Teddy Creek), Connolly (after Mount Connolly), and Blind Lakes (after Blind Lakes) calderas (for location of these physiographic features see NTS sheets 105K/10, K/9, and K/8 respectively). The bulk of the Selwyn Plutonic Suite is shown in cross pattern, the Marjorie pluton in complex cross-hatch. For descriptions see text. Satellitic stocks of Marjorie-like granite occur in areas D and E. Areas A,B and C are referenced in text. Solid lines indicate well defined contacts, dashed lines indicate approximate contacts, dotted lines indicate assumed contacts. Black dots indicate downthrown side of dip-slip faults. Note that the volcanics of area A are not indicated on the slightly earlier geological map of Gordey and Irwin (in press).

authors indicated ages of between 94.4 and 102 Ma for the volcanics, and confirmed their time equivalence to regionally extensive mid-Cretaceous plutonic rocks.

The Geological Survey of Canada recently completed updating of geological mapping for the Sheldon Lake (105J) and Tay River (105K) map areas (Gordey and Irwin, in press), during which many exposures of the South Fork Formation were examined. Figure 1 shows the distribution of the volcanics and equivalent plutonic rocks relative to elements of the regional setting outlined above. On close inspection the volcanic-country rock contact is not an unconformity, but is everywhere faulted. The distribution of the volcanics and their fault-bounded nature show they are preserved within several discrete calderas. Field relations are consistent with a cogenetic relationship for the volcanics and some of the mid-Cretaceous granitic rocks, in this region referred to the Selwyn Plutonic Suite (Gordey and Irwin, in press; Pigage and Anderson, 1985; see also Anderson, 1982).

SOUTH FORK VOLCANICS

The volcanics are preserved within at least eight calderas, ranging from 2.5 km to up to 38 km in diameter. The bounding contacts are not exposed for any of the calderas, but in many places they can be located to within 100-200 m. The intersection of the contact with topography shows them to be near vertical (e.g. north half of the Teddy caldera (Fig. 1), and much of the eastern and northern margins of the Connolly caldera). In areas of poorer exposure the proximity of flat-lying volcanics to adjacent country rocks of equal or higher topographic elevation indicates a fault contact of at least moderate dip. The caldera-margin curvilinear faults were discrete localized surfaces of failure. Related shearing or intense fracturing were not noted within adjacent country rock. The sense of displacement on faults bounding the west and north sides of area B (Fig. 1) is not certain. The interpretation preferred is that these somewhat different tuffs (see below) represent volcanics low in the sequence, and comprise a slightly upthrown block. The origin of the north-trending panel of volcanics of area A (Fig. 1) is also uncertain. Its bounding faults may in part be post-volcanic and younger (perhaps Eocene?).

There are few differences between the tuffs from caldera to caldera. Rocks of the Teddy and most of the Connolly calderas are virtually indistinguishable in grain size, degree of welding, mineralogical composition and colour. Both contain densely welded crystal or crystal lithic tuff that weathers from dark brown to dark grey and on fresh surfaces ranges from light grey-green to dark grey. Many outcrops resemble granitic rock in their resistance to erosion, massive character, medium grain size and induration. Yet, thin section examination proves the rock to be pyroclastic (Fig. 2a). Crystals, typically about 1 mm across but ranging up to 4 mm, are commonly broken or bent and consist of quartz (10-25 %), biotite (0-5 %), hornblende (0-3 %), plagioclase (15-40 %) and rare orthopyroxene. These are set in a very finely microcrystalline felsic matrix that forms the remainder (40-75 %) of the rock. Lithic clasts are uncommon and range typically from pebble to cobble size. They are all of identifiable country rock and constitute chert, argillite and locally granite. At one locality in Connolly caldera a house-sized clast of bedded chert is enveloped in tuff (Fig. 2b). Within area B (Fig. 1) the tuffs are distinguished from those elsewhere by their dark grey-green weathering colour, lower mafic crystal content and well-displayed bedding (see below). The Blind Lakes caldera (Fig. 1) includes crystal lithic tuffs with quartz (15 %), feldspar (40 % ?), biotite (1 %) and are typified by up to 30 % lithic fragments ranging up to 0.6 m across. The clasts range from rounded to angular and are commonly chert, argillite, and rarely limestone, chert pebble conglomerate and granite porphyry. Volcanics of the pendant within Marjorie pluton (see Fig. 1) locally resemble the lithic-rich tuff and may be related. Tuffs within area A (Fig. 1) and the smaller calderas generally resemble those of the Teddy and main Connolly calderas. In area C (Fig. 1), however, the rock is compositionally different. It typically lacks quartz and contains hornblende, pyroxene, and feldspar crystals densely welded in a finely microcrystalline felsic(?) matrix.

Bedding is rarely seen in the volcanics and is well developed only in southeast Connolly caldera (area B, Fig. 1; Fig. 2c; Fig. 2d; Wood and Armstrong, 1982; Wood, 1981). There it is defined within crystal tuff by faint colour lamination that is parallel to millimetre scale mineral segregation and alignment. On a larger scale the rock has well developed parting parallel with the lamination which lends outcrops a well bedded appearance. In other parts of the Connolly caldera and elsewhere, the rocks are massive, and bedding orientation is reflected in local subvertical columnar jointing, rare visible flattened fiammae, or at one locality the plane of apparent flattening of elliptical gas cavities.

The most impressive feature of the volcanics in the Teddy and Connolly calderas is their massive nature and great thickness (Fig. 2e). In the Connolly caldera, the volcanics are at least 950 m thick. Their flat-lying attitude is indicated by generally well-developed subvertical columnar joints (Fig. 2f). From a short distance, tiers of columnar joints intersected by flat-lying master joint sets give a false impression of individual flows. On detailed inspection the rocks are massive and show no variation in composition or degree of welding across these apparent boundaries. The thickness of the volcanics in Teddy caldera is probably as great as that of Connolly caldera. These rocks are also massive and the combination of columnar jointing and subhorizontal joints also gives a false impression of individual flows. For area A (Fig. 1) and the other smaller calderas exposed in areas of low relief, the thickness of tuff is uncertain. In these areas too, the rocks locally display columnar jointing and are typically massive.

RELATIONS OF SOUTH FORK VOLCANICS TO SELWYN PLUTONIC SUITE

Mid-Cretaceous plutonic rocks within the same region as the South Fork Volcanics consist mostly of unfoliated, grey weathering, resistant, medium- to coarse-grained granite, quartz monzonite and granodiorite. Mafic minerals commonly include biotite and hornblende. The plutons are clearly post-tectonic, their boundaries cleanly crosscut folded and faulted country rocks. The disribution of felsenmeer exposures

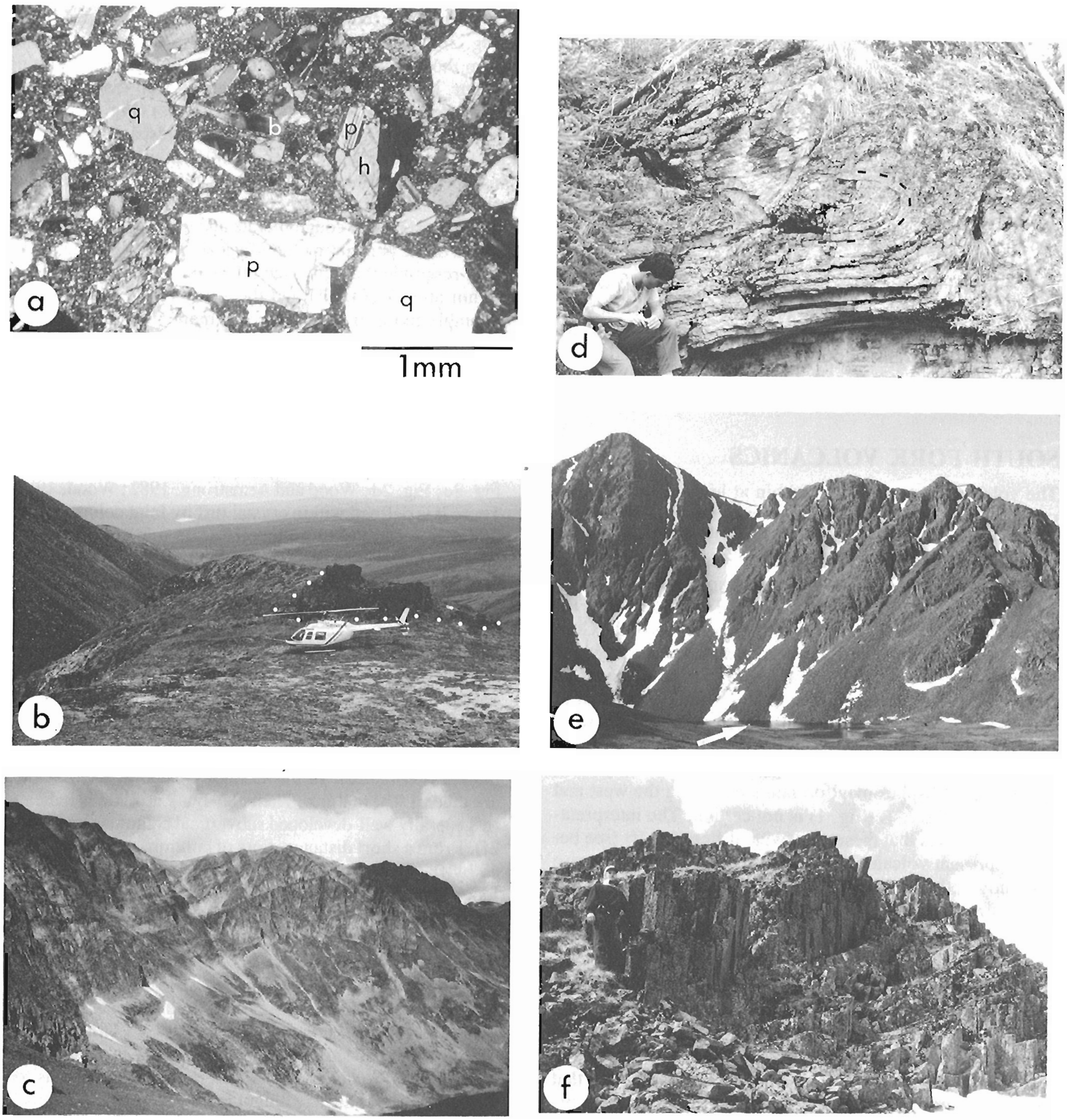


Figure 2. Some features of the South Fork Volcanics
(a) Typical texture of crystal tuff as seen in thin section (crossed polarizers). q = quartz, p = plagioclase, h = hornblende, b = biotite. Matrix is very finely crystalline, low birefringent felsic(?) material. Rock is from northwest Connolly caldera from section pictured in photo (e).
(b) A large block of bedded chert (white dots) within crystal tuff of the Connolly Caldera. All rock in foreground is crystal and crystal lithic tuff. Low area in middle distance is country rock outside the caldera.
(c) Well bedded crystal tuffs of southeast Connolly caldera, area B (Fig. 1). Bedding dips gently to left of photo.
(d) Bedding-parallel parting in crystal tuff outlining tight slump(?) fold with horizontal axial plane. Tuff is from area A (Fig. 1). Most tuffs in this area are massive.
(e) Massive, thick densely welded crystal tuff at the northwest end of Connolly caldera. Relief is about 440 m (1450 ft). Arrow points to a tent (small pin-sized dot). On the basis of local vertical columnar joints, the bedding is presumed flat-lying. The tuffs form a single cooling unit. Composition and degree of welding is uniform throughout this entire well exposed section.
(f) Local vertical columnar joints in crystal tuff of the Connolly caldera.

shows that the northwest end of Connolly caldera truncates one of the plutons, indicating the caldera formed after consolidation of the granitic body.

The Marjorie pluton of southeastern Tay River map area (Fig. 1) is atypical of the mid-Cretaceous suite. It consists of porphyritic biotite ± hornblende granite characterized by large smokey grey quartz phenocrysts and locally K-feldspar phenocrysts. It appears to crosscut the Connolly and Blind Lakes calderas, and therefore to be younger, although lithic clasts within tuff of the Blind Lakes caldera are identical to Marjorie granite indicating the granite to be older. This contradiction is accommodated if formation of the Blind Lake tuffs and Marjorie intrusion were synchronous. Earlier-cooled portions of the high-level Marjorie pluton could be incorporated as clasts within cogenetic Blind Lakes tuff, which could then be invaded by later intrusion of the same, or pulses of very similar magma.

Age-dates (see Pigage and Anderson, 1985; Wood and Armstrong, 1982) and the above field relations show that the South Fork Volcanics and the mid-Cretaceous plutonic suite are synchronous and that the Marjorie pluton and Blind Lakes tuff are likely cogenetic. In mineral composition the volcanic and granitic rocks are also similar. Why the mid-Cretaceous plutons have eruptive equivalents only in Sheldon Lake and Tay River areas, and not elsewhere in the Cordillera, is unknown.

MODEL OF FORMATION

The suggested mode of formation of the South Fork Volcanics is patterned after a model proposed by Lipman (1984) to explain features of many well studied ash-flow calderas in the western United States. Numbers in the following description refer to Figure 3. Volcanism began when a shallow magma chamber (for the Blind Lakes caldera possibly early components of the Marjorie pluton) vented to the surface resulting in a pyroclastic eruption. As the eruption proceeded the magma chamber evacuated, and the overlying ground subsided to form a caldera. Caldera formation is superposed on folded and faulted country rock (1) and in places on early intrusive phases of broadly coeval plutonic rock (2). The crystal and ash ejecta fell back to the ground, much of it still hot, to accumulate within the subsiding caldera to form very thick massive densely welded tuff (3). The caldera walls formed as normal fault scarps (4) and large blocks of country rock (5) locally fell into the caldera and mixed with the ash. Younger phases of mid-Cretaceous plutonic rock (6) (Marjorie pluton) locally intruded across the caldera margins. Ejecta fell far from the the vent(s) originally covered the landscape (7) but post-volcanic erosion (8) stripped off these deposits leaving behind only the fault-bounded caldera fill (3). Whether ejecta related to one caldera fell into another, or whether the larger calderas formed from single or multiple eruptions is unknown. In diameter, the Teddy (35 km) and Connolly (28 km) calderas are large when compared to other North American examples (eg. Lipman, 1984, Table 1). Even if produced by more than one event, the eruption(s) that led to their formation were likely cataclysmic.

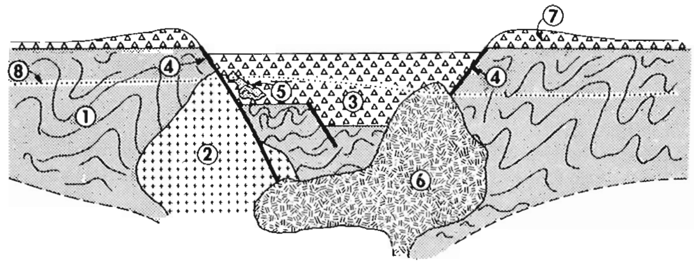


Figure 3. Diagrammatic cross-section summarizing extrusive relations of the South Fork Volcanics and relations with the coeval intrusive Selwyn Plutonic Suite. Relationships from several South Fork calderas are depicted. Numbers 1 to 8 are referenced in text.

MINERAL EXPLORATION POTENTIAL

The South Fork Volcanics have received relatively little attention as an exploration target. Their massive, fresh character, lack of gossans, and paucity of known occurrences is discouraging. No new occurrences were discovered during this work. Heat and faulting, implicit in the caldera model, suggest the volcanics may have been a favourable host to high-level gold- and silver-rich hydrothermal systems. However, later erosion sufficient to remove all of the "extracaldera" deposits has also likely eroded any shallow vein systems. Exploration targets of the South Fork Volcanics would therefore be aimed at deeper mesothermal veins which may perhaps be enhanced in sulphides at the expense of precious metals and therefore currently less attractive. Exploration and prospecting should probably concentrate around the caldera-bounding faults.

ACKNOWLEDGMENTS

Excellent assistance in the field was provided at various times by S. Gareau, B. Thomas, S. Irwin, and D. Reese. Much appreciated was the superb flying ability of John Witham, helicopter pilot, Ross River. C. Evenchick and R.B. Campbell suggested improvements to the manuscript. Christine Davis drafted Figure 3.

REFERENCES

Anderson, R.G.
1982: Geology of the Mactung pluton in Niddery lake map area and some of the plutons in Nahanni map area, Yukon Territory and District of Mackenzie; *in* Current Research, Part A, Geological Survey of Canada, Paper 82-1A, p. 299-304.

Gabrielse, H.
1985: Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia; Geological Society of America Bulletin, v. 96, p. 1-14.

Green, L.H.
1962: K-Ar dates for the Tay Formation, Yukon Territory; *in* Age determinations and geological studies — report 3, Geological Survey of Canada, Paper 62-17, p. 17.

Gordey, S.P. and Irwin, S.E.B.
— Geology of Sheldon Lake (105J) and Tay River (105K) map areas, east-central Yukon; Geological Survey of Canada, Map 19-1987 (in press).

Lipman, P.W.
1984: The roots of ash flow calderas in western North America: windows into the tops of granitic batholiths; Journal of Geophysical Research, v. 89, no. B10, p. 8801-8841.

Pigage, L.C. and Anderson, R.G.
1985: The Anvil plutonic suite, Faro, Yukon Territory; Canadian Journal of Earth Sciences, v. 22, p. 1204-1216.

Roddick, J.A. and Green, L.H.
1961a: Sheldon Lake map area, Yukon Territory; Geological Survey of Canada Map 12-1961.
1961b: Tay River map area, Yukon Territory; Geological Survey of Canada Map 13-1961.

Roddick, J.A.
1966: K-Ar date for the Tay Formation, Yukon Territory; *in* Age determinations and geological studies, K-Ar ages — report 7, Geological Survey of Canada, Paper 66-17, p. 42-43.

Tempelman-Kluit, D.J.
1979: Transported cataclasite, ophiolite, and granodiorite in Yukon: evidence of arc-continent collision; Geological Survey of Canada Paper 79-14, 27 p.

Wood, D.H.
1981: Stratigraphy and geochronology of the Cretaceous South Fork Volcanics, southeastern Yukon Territory; unpublished B.Sc. thesis, University of British Columbia, 56 p.

Wood, D.H. and Armstrong, R.L.
1982: Geology, chemistry and geochronometry of the Cretaceous South Fork Volcanics, Yukon Territory; *in* Current Research, Part A, Geological Survey of Canada Paper 82-1A, p. 309-316.

Stratigraphy and structure of the Monashee complex and overlying rocks adjacent to the Trans-Canada Highway, west of Revelstoke, B.C.

Robert Bosdachin[1] and Robin M. Harrap[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Bosdachin, R. and Harrap, R.M., Stratigraphy and structure of the Monashee complex and overlying rocks adjacent to the Trans-Canada Highway, west of Revelstoke, B.C.; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 19-23, 1988.

Abstract

The Monashee décollement, a westerly rooted shear zone that displaced Selkirk Allochthon rocks eastwards in the Middle Jurassic and Late Cretaceous, intersects the Trans-Canada Highway 16 km west of Revelstoke at Victor Creek. The shear zone separates underlying Monashee complex mantling gneisses from overlying higher grade Selkirk Allochthon gneisses. Kinematic studies indicate a northeastward sense of shear of the allochthon relative to the Monashee complex. Structures in the footwall are truncated by the décollement.

Footwall stratigraphy comprises upper amphibolite facies carbonate, clastic and minor volcanic rocks. Metapelites are kyanite- and sillimanite-bearing; kyanite is partially replaced by sillimanite. Hanging wall stratigraphy consists of calc-silicate and psammitic gneiss with abundant amphibolite boudins, and impure marble and quartzite horizons. Sillimanite is the only aluminosilicate in the hanging wall, and leucogranitic pods are common. The décollement thus juxtaposed higher grade hanging wall rocks of the Selkirk Allochthon against lower grade footwall rocks of the Monashee complex.

Résumé

Le décollement de Monashee, une zone de cisaillement enracinée vers l'ouest qui a déplacé les roches de l'allochtone de Selkirk vers l'est au milieu du Jurassique et à la fin du Crétacé, traverse la trans-canadienne à 16 km à l'ouest de Revelstoke, à la hauteur du ruisseau Victor. La zone de cisaillement sépare les gneiss de couverture du complexe de Monashee sous-jacents des gneiss à teneur plus élevée sous-jacents de l'allocthone de Selkirk. Des études cinématiques indiquent que le cisaillement de l'allocthone a une direction nord-ouest par rapport au complexe de Monashee. Les structures de l'éponte inférieure sont tronquées par le décollement.

La stratigraphie de l'éponte inférieure comprend des roches carbonatées, clastiques et, par endroits, volcaniques du faciès supérieur des amphibolites. Des métapélites contiennent de la kyanite et de la sillimanite; la kyanite est partiellement remplacée par la sillimanite. La stratigraphie de l'éponte supérieure comprend du calc-silicate et du gneiss psammitique avec de nombreux boudins d'amphibolite, ainsi que des horizons de quartzite et de marbre impurs. La sillimanite est le seul aluminosilicate dans l'éponte supérieure, et on trouve de nombreuses masses leucogranitiques allongées. Le décollement a donc juxtaposé des roches de l'éponte supérieure à teneur élevée de l'allocthone de Selkirk aux roches de l'éponte inférieure à faible teneur du complexe de Monashee.

[1] Ottawa-Carleton Geoscience Centre and Department of Earth Sciences, Carleton University, Ottawa, K1S 5B6

INTRODUCTION

The Monashee décollement, a westerly rooted and easterly verging ductile shear zone, carried Proterozoic and Paleozoic rocks of the Selkirk Allochthon eastward across Proterozoic core and mantling gneisses of the Monashee complex (Read and Brown, 1981; Brown and Read, 1983; Journeay, 1986; Brown and Journeay, 1987). Displacement on the Monashee decollement is thought to have occurred initially in the Middle Jurassic with major reactivation in Late Cretaceous time (Brown and Journeay, 1987, Journeay, 1986). The décollement is exposed along the western flank and northern and southern limits of the Monashee complex, but is truncated to the east by the Eocene Columbia River fault (Lane, 1984, Lane and Brown, 1987). The location at which the décollement cuts the Trans-Canada Highway has recently been revised (Journeay and Brown, 1986; Brown and Journeay, 1987). Two Master's theses projects in progress at Carleton University are dedicated to locating and tracing the décollement north and south of the highway, to establishing the relations between footwall and hanging wall structure and stratigraphy, and to documenting the metamorphic change across the break. Two months were spent in the field by each of the authors: Bosdachin worked north of the highway and Harrap to the south.

The field area lies within the structural depression between two structural culminations in the complex, Frenchman's Cap dome to the north and Thor-Odin nappe to the south. Read and Klepacki (1981) inferred continuous stratigraphy up into the highest exposed units, effectively positioning the décollement farther to the west, near Sicamous, as originally suggested by Read and Brown (1981). This study confirms with local modifications the revised location (Fig. 1) proposed by Journeay and Brown (1986), and documents the geology of the footwall and hanging wall rocks in this region.

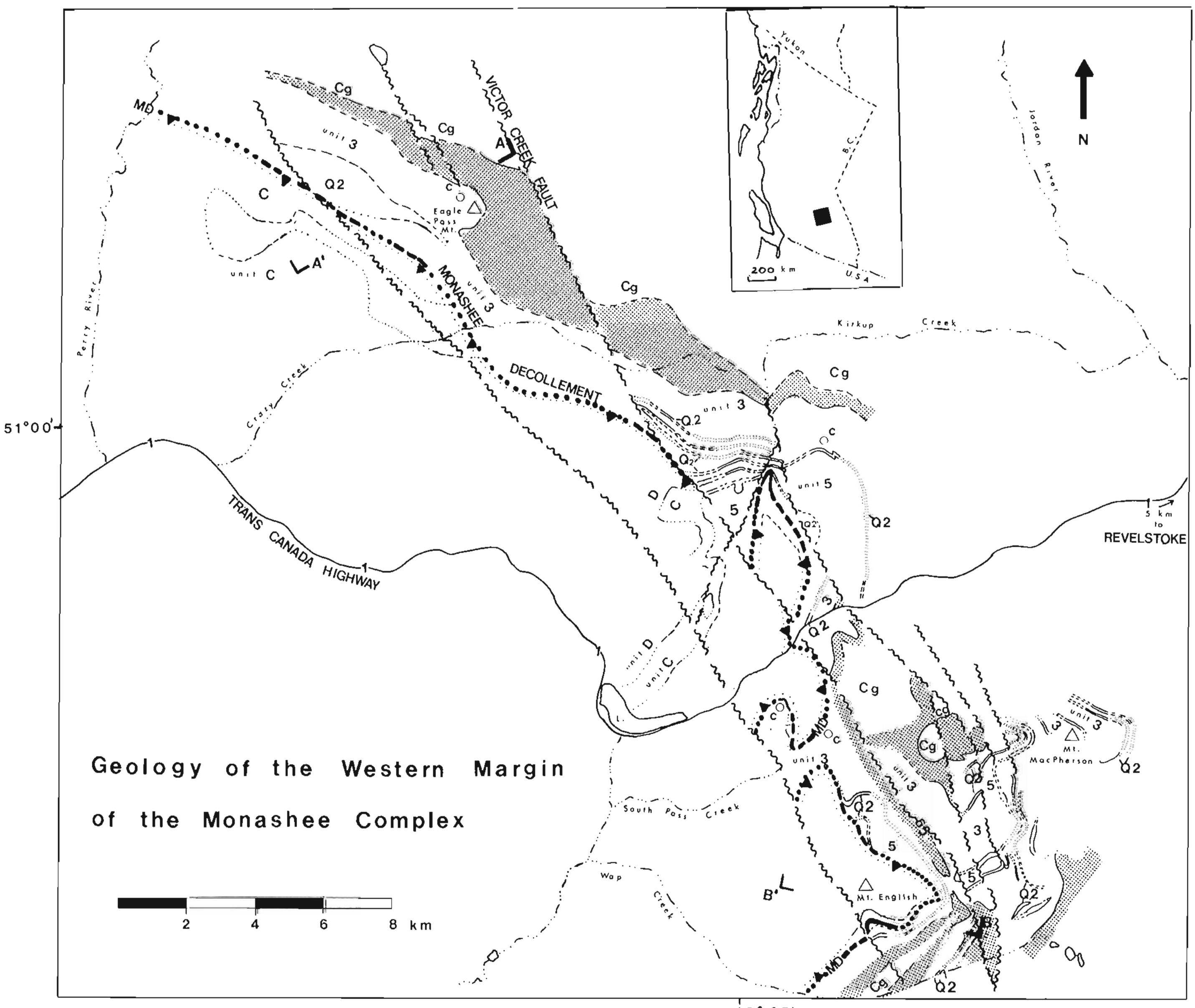


Figure 1. Simplified geological map of the western margin of the Monashee complex. Basement/cover contact and fault bounded slice immediately east of Victor Creek fault compiled in part from Read and Klepacki (1981) and Fyles (1970).

STRATIGRAPHY

Monashee complex

Within the area mapped, basement gneisses and an unconformably overlying cover sequence have been divided into five units distinguished on the basis of lithology and contact relations. The core or basement rocks were only locally mapped and are thus grouped together as one unit, while the cover sequence (mantling gneisses of earlier workers) makes up the other four. Figure 1 is a simplified map showing the plan view distribution of stratigraphic units, and Figure 2 illustrates two structural cross-sections.

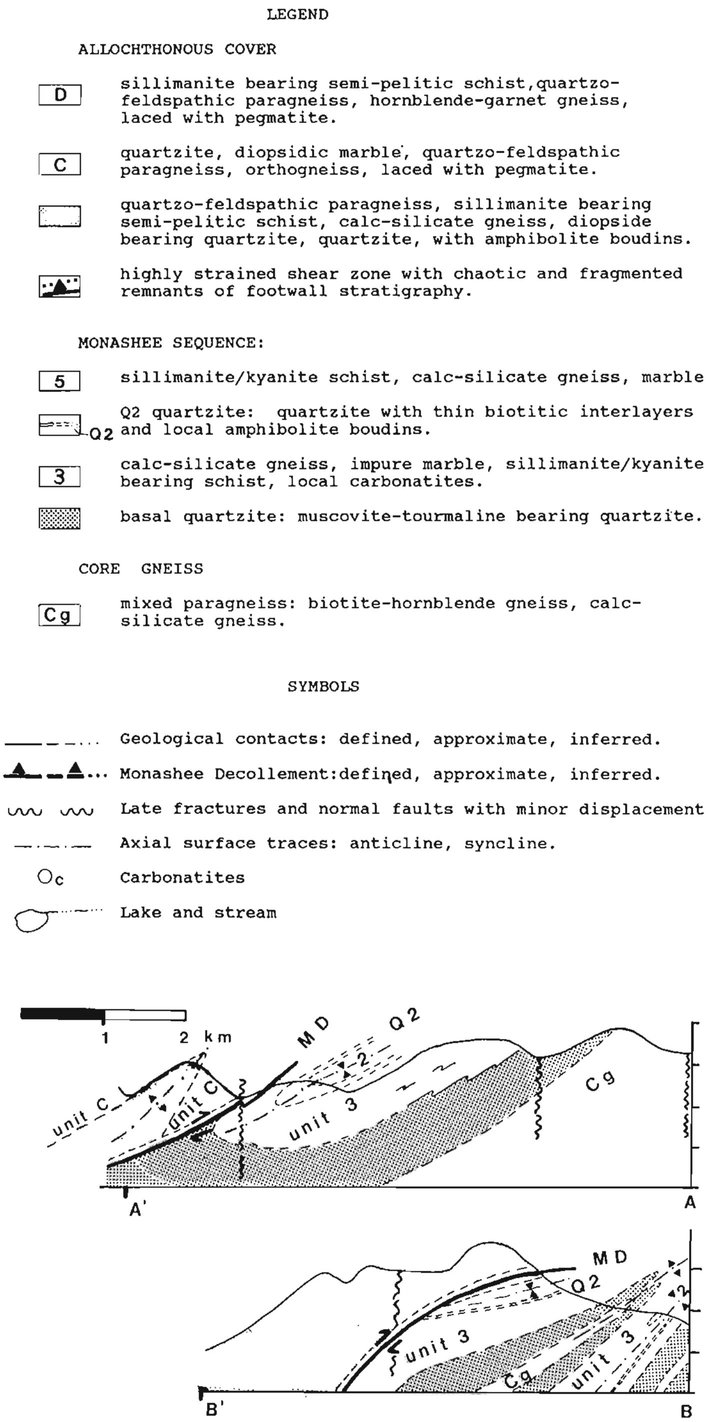


Figure 2. Cross sections illustrating the truncation of phase-two folds by the Monashee décollement.

The basement (unit 1) consists of para- and orthogneiss that is regionally variable but locally quite uniform. Calc-silicate bearing paragneiss (diopside- hornblende- garnet- biotite- plagioclase- quartz) with minor quartzofeldspathic orthogneiss was mapped north of the Trans-Canada Highway while dominantly semipelitic augen gneiss (quartz- feldspar- sillimanite- biotite- garnet) was mapped south of the highway.

Overlying the basement gneisses is a clean basal quartzite of variable thickness (<30 m to >150 m) with minor muscovite and tourmaline (unit 2). The quartzite contains concordant mafic to ultramafic boudins with no evident feeder dykes.

Unit 3 comprises calc-silicate gneiss (diopside- biotite- quartz- garnet) with interlayers of impure marble and psammitic gneiss. In some areas an extensive pelitic schist horizon separates two calc-silicate horizons, each with impure marble interlayers. This interlayer of pelitic schist becomes more extensive to the west of the thesis areas. The pelitic schist (quartz- feldspar- sillimanite- (kyanite)- garnet- biotite) is locally migmatitic. Stratabound carbonatites occur within the calc-silicate gneiss both north and south of the TCH, although those to the north are more extensively exposed.

Unit 4 is a thin (< 15 m) biotite-bearing quartzite, which contains abundant mafic to ultramafic concordant boudinaged pods. No feeders for the mafic to ultramafic layers were observed, likely due to the highly strained nature of the host quartzite. It is locally underlain by a diopsidic marble horizon.

Unit 5 comprises a pelitic schist of variable thickness locally overlain by diopside-garnet calc-silicate gneiss and thin impure marble horizons. The schist (sillimanite- kyanite- garnet- biotite- quartz- k-feldspar) is locally migmatitic and contains abundant augen.

Allochthonous cover (Selkirk Allochthon)

Allochthonous rocks comprise four recognizable units, of which only the lower two are mappable south of the Trans-Canada Highway. All are extensively pegmatized, somewhat chaotic and have gradational contacts.

The lowest package, unit A, is a highly disordered anastomosing shear zone assemblage with small lenses of both footwall and higher hanging wall stratigraphy visible on a very fine scale. The unit is thus defined in terms of high strain and lithologic chaos rather than constant lithologic properties and is perhaps more properly a composite rather than hanging wall unit. The chaotic zone contains the décollement proper and varies between 10 and 150 m in thickness, the widest occurrence being on the south slope of Mount. English, south of the highway.

Unit B comprises interbedded psammitic and calc-silicate gneiss, minor quartzite (locally diopsidic) and semipelitic schist (biotite-sillimanite-garnet) with massive amphibolite boudins which become more abundant upwards.

Unit B is overlain by a thick pegmatite-laced zone containing thin quartzite layers that are in turn overlain by a thin (1-2 m) impure diopsidic marble. The quartzite is underlain by a unit tentatively identified as an orthogneiss, also laced with pegmatite. The high degree of pegmatization in this unit makes subdivision on the basis of these locally observed components difficult.

The highest observed package, unit D, is made up of quartzofeldspathic to semipelitic gneiss (sillimanite- biotite-feldspar- quartz- garnet) laced with leucogranitic pegmatite. Numerous concordant garnet-amphibolite boudins occur throughout the package.

STRUCTURE AND METAMORPHISM

Monashee complex

Rocks of the footwall of the Monashee décollement were isoclinally folded by two distinct deformational events. Easterly verging pre-to early metamorphic first-phase folds (Read, 1980) are evident primarily due to stratigraphic repetitions; large-scale, northeasterly-verging, synmetamorphic, second phase structures fold the first phase micaceous foliation. The hinges of the second phase folds are parallel to the regional stretching lineation (Read and Klepacki, 1981; Scammell, 1986; Journeay, 1986) while the axial planes strike southeasterly and dip to the southwest. Regional postmetamorphic third phase folds are locally detectable as warps; no associated minor structures were observed within the mapped area.

Field evidence including S-C fabrics, shear bands, stepped mineral fibres and rotated augen indicate that the footwall zone has, in the mapped area, undergone shear with northeastward vergence. Notably, the quartzites of the complex preserve excellent stepped mineral fibres and S-C fabrics. Leucocratic layers in migmatites throughout have been dissected to form abundant asymmetric augen.

The footwall pelitic assemblage includes sillimanite — kyanite (parallel to the local stretching lineation) — garnet (rotated) — biotite — quartz — K-feldspar. Sillimanite occurs as mats in the biotite foliation and as pseudomorphs after kyanite and is oriented parallel to the stretching lineation. South of the highway, coarse, prismatic crystals crosscut the older sillimanite mats and kyanite is rare.

Thin section petrography reveals that kyanite has been progressively replaced by sillimanite. Chlorite and muscovite occur in syntectonic pull-aparts in grains oriented parallel to the lineation. Tourmaline in the basal quartzite (unit 2) is locally pulled apart, and may reside in thin lenses of syntectonic quartz pegmatite within the quartzite.

Monashee Décollement

The décollement occurs as an anastomosing shear zone which ranges from less than 10 to at least 150 m thick. The zone is mylonitic and intensely pegmatized. The décollement locally truncates footwall stratigraphy and is regionally subparallel to the second phase axial surfaces. This zone is chaotic and contains both footwall and hanging wall rocks throughout the mapped area. Lenses of transposed strata range from a few metres to a few tens of metres in size and are enclosed by a shear foliation discordant with their internal fabric. The lenses are concentrated immediately above the highest recognizable continuous footwall strata and the proportion of footwall lenses abruptly decreases upwards.

South of the highway, the décollement is exposed around the upper flank of Mount English (Fig. 1) and projects downslope to the highway immediately west of the Victor Creek fault. A mylonite with northeastward vergence is exposed on the highway, and the section to the west progressively climbs into higher hanging wall strata. North of the highway the décollement is offset by the Victor Creek fault but can be traced northwest near Eagle Pass Mountain (Fig. 1).

In the southern area shears with northeastward vergence locally are disrupted by discrete shears with southwestward vergence that cut down from continuous hanging wall stratigraphy into the chaotic zone.

The décollement places rocks of different metamorphic grade against each other. Kyanite has not been found in the hanging wall, but occurs in the footwall, although partially replaced by sillimanite. This apparently inverted metamorphic gradient is consistent with observations in the north of the complex (Journeay, 1986).

Hanging wall, or Allochthonous cover

There are two distinct fold sets in the hanging wall of the décollement, although the second occurs only in the northern portion of the mapped area. Tight to isoclinal folds have hinges parallel to the southwest-trending pervasive stretching-lineation and shallow, southeasterly, dipping axial planes. They are interpreted as second phase folds and form both minor structures and kilometre-scale folds. These folds may have formed during motion of the décollement and progressively rotated into parallelism with the regional stretching lineation. A later phase of open folds, also with hinges parallel to the stretching lineation, verges to the west and has shallow northwest dipping axial planes.

The hanging wall pelitic assemblage is similar to that observed in the footwall with the exception that kyanite was not observed and only one generation of sillimanite has so far been described. Muscovite occurs only as a retrogression product in the hanging wall. Leucogranitic pods are more common in the hanging wall.

Late structures

Joints, fracture zones and brittle faults with chlorite infilling and minor displacement cut the earlier structures throughout the area. Both the predominant joint set, and the faults, strike north-northwest and dip steeply both to the east and west. The displacement is west side down, with slickensides steeply plunging to the northwest, as observed on the Victor Creek fault. There is a rotational component to faulting as indicated by changing throw along the strike of the faults. Faults which strike to the north-northeast and dip moderately to the southeast were locally observed north of the Trans-Canada Highway; these had slickensides dipping shallowly to the northeast.

A previously unprojected high angle fault mapped to the north by Hoy and Brown (1980) was detected cutting across Mount English and northwestward towards Eagle Pass Mountain. It is visible in outcrop on Mount English and on airphotos to the north, and is tentatively labeled the Mount English fault.

CONCLUSIONS

1) The Monashee décollement crosses the Trans-Canada Highway immediately west of Victor Creek (Fig. 1).
2) The shear zone exhibits consistent northeastward vergence.
3) Shearing on the décollement happened at deep crustal levels as evidenced by high grade (upper amphibolite) synkinematic metamorphism.
4) Monashee complex mantling gneiss stratigraphy and structures are locally truncated by the décollement.
5) The décollement juxtaposes higher grade rocks on top of lower grade rocks, and resulted in inverted metamorphic gradients in the immediate footwall (Journeay, 1986).

ACKNOWLEDGMENTS

This research represents parts of two Master's theses in progress at Carleton University by Robert Bosdachin and Robin Harrap. The supervision of Richard L. Brown is most appreciated. The authors would like to thank Sharon Carr, Brad Johnson, Murray Journeay and Randy Parrish for helpful discussions, and Robin Harrap would like to thank Joyce Hostyn for assistance in the field. Funding of these projects, in addition to EMR research agreement 277-87, is provided by NSERC operating grant A2693 to Richard L. Brown. Robert Bosdachin gratefully acknowledges receipt of an NSERC postgraduate scholarship.

REFERENCES

Brown, R.L. and Journeay, J.M.
1987: Tectonic Denudation of the Shuswap Metamorphic terrane of southeastern British Columbia; Geology, v. 15, p. 142-146.

Brown, R.L. and Read, P.B.
1983: Shuswap terrane of British Columbia: a Mesozoic "core complex"; Geology, v. 11, p. 164-168.

Fyles, J.T.
1970: The Jordan River area near Revelstoke, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 57, 72 p.

Hoy, T. and Brown, R.L.
1980: Geology of the eastern margin of Shuswap Complex, Frenchman Cap area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 43.

Journeay, J.M.
1986: Stratigraphy, internal strain and thermotectonic evolution of northern Frenchman Cap Dome: exhumed duplex structure, Omineca Hinterland, S.E. Canadian Cordillera; unpublished Ph.D. thesis, Queen's University, 350 p.

Journeay, J.M. and Brown, R.L.
1986: Major tectonic boundaries of the Omineca Belt in southern British Columbia: a progress report; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 81-88.

Lane, L.S.
1984: Brittle deformation in the Columbia River Fault Zone, British Columbia; Canadian Journal of Earth Sciences, v. 21, p. 584-598.

Lane, L.S. and Brown, R.L.
1987: Structural relationships on the eastern margin of the Shuswap Metamorphic Complex near Revelstoke, British Columbia, Canada; Geological Society of America, Centennial Field Guide — Cordilleran Section, 1987, p. 413-418.

Read, P.B.
1980: Stratigraphy and structure: Thor-Odin to Frenchman Cap "domes", Vernon east-half map area, southern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 19-25.

Read, P.B. and Brown, R.L.
1981: Columbia River fault zone: southeastern margin of the Shuswap and Monashee complexes, southern British Columbia; Canadian Journal of Earth Sciences, v. 18, p. 1127-1145.

Read, P.B. and Klepacki, D.W.
1981: Stratigraphy and structure: northern half of Thor-Odin nappe, Vernon east-half map area, southern British Columbia; *in* Current Research, Part A, Geological Survey of Canada; Paper 81-1A, p. 169-173.

Scammell, R.J.
1986: Stratigraphy, structure and metamorphism of the north flank of the Monashee Complex, southeastern British Columbia: a record of Proterozoic extension and Phanerozoic crustal thickening; unpublished M.Sc. thesis, Carleton University.

Clay mineralogy of late Pleistocene glacial deposits in Chilliwack Valley, southwestern British Columbia

Bertrand Blaise[1] and John J. Clague[2]

Blaise, B and Clague, J.J., Clay mineralogy of late Pleistocene glacial deposits in Chilliwack Valley, southwestern British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 25-29, 1988.

Abstract

A preliminary study has shown clay mineral assemblages in these sediments have a typical glacial character, manifested by abundant, well crystallized, iron-rich chlorite and illite, both derived mainly from plutonic, volcanic, and metamorphic rocks. In general, secondary clay minerals such as smectite and irregular mixed-layers are much less common and probably have been recycled from older sediments and sedimentary rocks. However, diamicton directly above a paleosol at the study site has high amounts of smectite. This smectite, which is closely associated with a tephra, formed very rapidly by authigenesis during a brief interval of glacier retreat about 11 300 BP

Résumé

Une étude préliminaire a établi que l'association argileuse dans ce type de sédiments a un caractère glaciaire typique que distingue la présence abondante de chlorite et d'illite riches en fer, toutes deux bien cristallisées et provenant des roches plutoniques, volcaniques, et métamorphiques de la région. En règle générale, les minéraux accessoires comme la smectite et les minéraux interstratifiés irréguliers sont peu abondants; ils peuvent provenir d'anciens sédiments et roches sédimentaires de la région. Cependant, les dépôts glaciaires reposant directement au-dessus d'un paléosol renferment un important pourcentage de smectite. Cette dernière est étroitement associée à un niveau de cendres volcaniques et s'est développée très rapidement par authigénèse durant un bref retrait des glaces il y a environ 11 300 ans.

[1] Cordilleran and Pacific Geoscience Division, Sidney, B.C.
[2] Terrain Sciences Division, Vancouver

INTRODUCTION

Recent work on late Quaternary sediments in southwestern British Columbia has shown that there is a relationship between the clay mineralogy of these sediments and the climatic conditions that prevailed during deposition (Blaise, 1985, 1987). In this paper, we extend this work by describing and discussing the clay mineral composition of a well dated, late Pleistocene drift sequence in Chilliwack valley, 100 km east of Vancouver (Fig. 1).

SETTING

Chilliwack River basin (1230 km^2) lies south of Fraser Lowland in the Cascade Mountains of southwestern British Columbia and northwestern Washington. The westernmost part of the basin is underlain by Triassic and Jurassic pelite and sandstone. Pennsylvanian and Permian basic volcanic rocks, pelite, sandstone, and limestone are the main rock types in the middle part of the basin, and Tertiary granodiorite and quartz diorite dominate the headwater areas (Monger, 1970).

Remnants of a thick Quaternary fill are preserved in the middle and lower parts of Chilliwack valley. The stratigraphy and sedimentology of this fill have been extensively studied (Clague and Luternauer, 1982, 1983; Hicock et al., 1982; Saunders, 1985; Saunders et al., 1987), but, until now, no work has been done on the clay mineralogy of the deposits.

In this paper, we describe the clay mineral composition of late Pleistocene sediments exposed near the mouth of Tamihi Creek in the lower part of Chilliwack valley (''Tamihi Slide'' section of Saunders et al., 1987; 49°04.9'N, 121°50.6'W). This succession comprises, from bottom to top, more than 18 m of weakly stratified, clast-supported gravel, 1 m of laminated silt, stony silt, and sand, and more than 100 m of massive, matrix-supported diamicton (Fig. 2). The lower two units accumulated in ice-marginal environments; the uppermost unit is till deposited by a lobe of ice that flowed into Chilliwack valley from Fraser Lowland (Saunders et al., 1987). The diamicton unit is divisible into two nearly identical subunits separated by a woody layer, paleosol, and tephra. Radiocarbon dates indicate that the diamicton and the underlying laminated silt and sand were deposited between 11 600 and 11 200 BP; it is likely that the paleosol that separates the two diamicton subunits developed in 100-300 years (Saunders et al., 1987).

ANALYTICAL METHODS

Grain-size and clay mineral analyses were performed on samples of laminated silt and diamicton from the Tamihi Slide section.

Grain-size analyses (< 2 mm fraction) were done at the Pacific Geoscience Centre at Sidney, British Columbia, using a settling tube for sand-size material and a sedigraph for silt and clay.

Clay mineral determinations were undertaken at the Ottawa laboratories of the Geological Survey of Canada. Samples were disaggregated in distilled water and then treated with hydrochloric acid (N/5) to remove calcium carbonate. Excess acid was removed by centrifuging. Sediment finer than 2 μm was collected by decantation, with settling times determined by Stoke's law. Oriented pastes of the less than 2 μm fraction were then made on glass slides. X-ray diffraction analyses were carried out with a Philips model PW 1130 generator, a PW 1050/85 vertical goniometer, and PM 8210 printing recorder controlled by a PW 1710 microprocessor. Diffractograms (2.5-30° 2Θ) were made for untreated and glycolated subsamples and for subsamples heated for 2 hours at 490°C. Clay minerals were identified and their relative abundances determined in accordance with methods used at the Universite des Sciences et Techniques des Lille (Holtzapffel, 1985); percentages are thought to be accurate to ±5 %.

RESULTS

Most samples within the thick diamicton unit have similar grain-size and clay mineral characteristics (Fig. 2). Clay mineral assemblages of all samples, except those at and just above the contact of the two diamicton subunits, are dominated by chlorite (38-51 %, mean 43 %) and illite (29-36 %, mean 33 %), with lesser amounts of smectite (6-23 %, mean 14 %) and undifferentiated irregular mixed-layers (7-12 %; mean 9 %). Mixed-layer minerals includes illite-smectite, illite-vermiculite, chlorite-smectite, and chlorite-vermiculite. Diffraction peaks of chlorite and illite are narrow, sharp, and high, reflecting the well preserved state of these minerals (Fig. 3).

A different clay mineral assemblage characterizes the paleosol, the tephra, and the base of the overlying diamicton (Fig. 4). Secondary clay minerals (smectite and irregular mixed-layers) are slightly more abundant in the paleosol than in the diamicton below. Large amounts of illite (up to 52 % of total clay minerals) occur in the tephra above the paleosol; chlorite is less abundant there than elsewhere in the sequence. Smectite dominates (67 %) the clay mineral assemblage of a sample of diamicton directly above the tephra, but is a subordinate constituent throughout the remainder of the upper diamicton subunit.

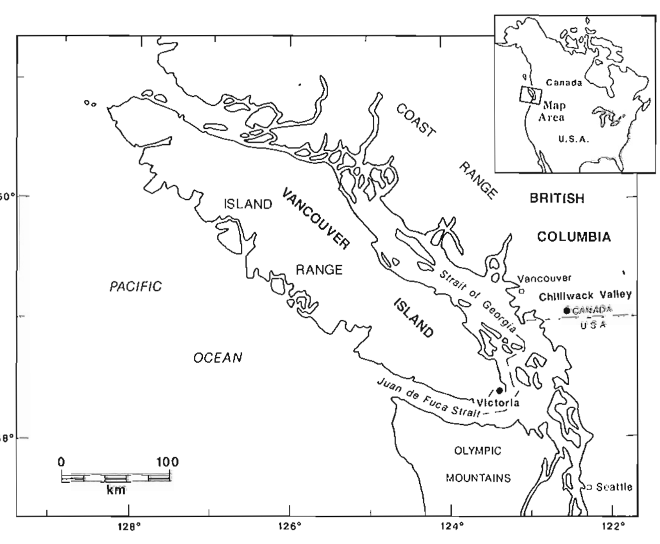


Figure 1. Location map.

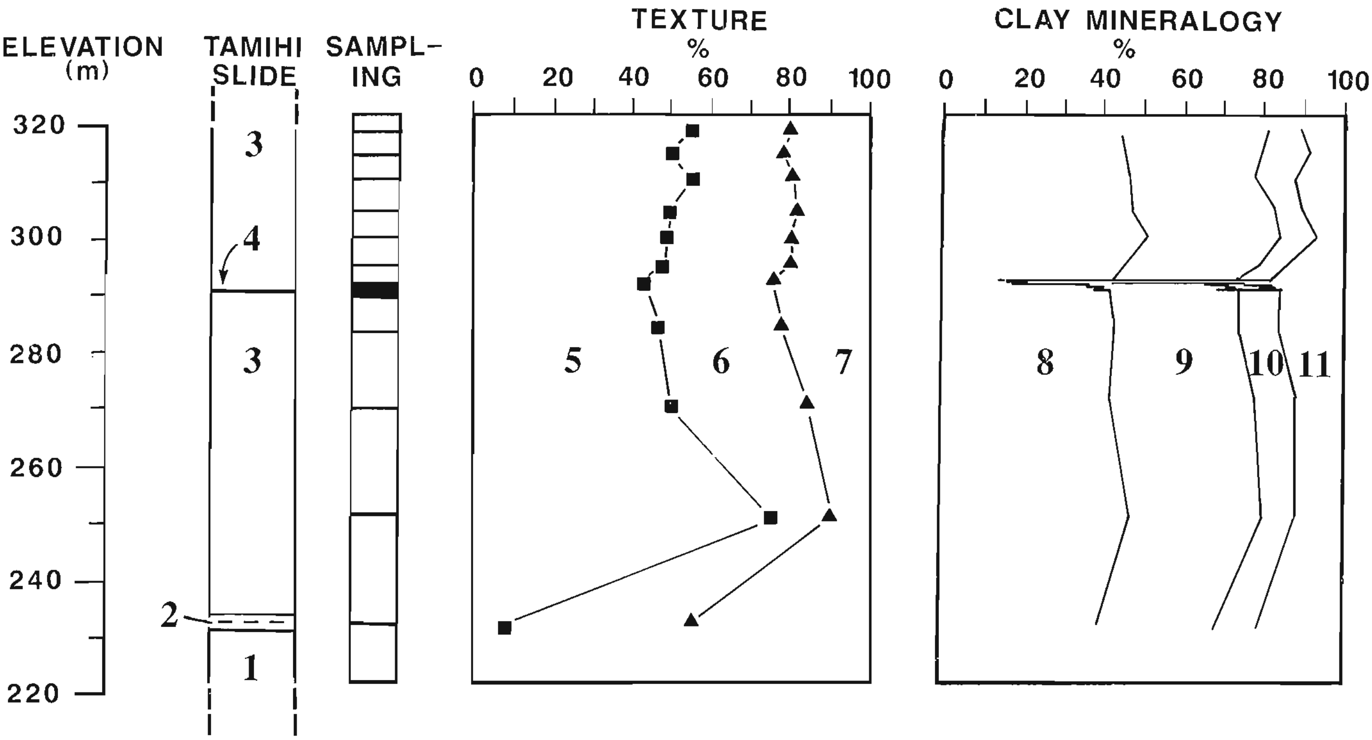


Figure 2. Stratigraphy, grain size, and clay mineralogy of the sediments at Tamihi Slide. 1: gravel; 2: silt, sand; 3: diamicton; 4: paleosol, tephra; 5: sand; 6: silt; 7: clay (<2 microns); 8: chlorite; 9: illite; 10: irregular mixed-layers; 11: smectite.

Iron content in chlorite

The distribution and amount of heavy atoms (mainly iron) in chlorite provide a measure of the state of weathering of the mineral (Ross and Kodama, 1976; Brindley and Brown, 1980). The degree of asymmetry (D) of chlorite in most of the diamicton at Tamihi Slide, calculated as the I(003)/I(001) peak ratio, is close to or less than 0 (Fig. 4, 6). This indicates an equal distribution of heavy atoms in the octahedral and tetrahedral layers, which, in turn, suggests that the mineral is unweathered. However, D values are higher in the tephra and the paleosol, suggesting that there has been some oxidation of iron atoms in the octahedral layer of the chlorite structure (Ross and Kodama, 1976).

Other chlorite peak ratios substantiate these conclusions. [I(004)+I(002)]/I(003) and [I(004)+I(002)]/[I(003)+I(001)] peak ratios indicate that the iron content of chlorites in most diamicton samples is close to or greater than 6 for a 20 oxygen structure (Fig. 4, 6). However, samples from the paleosol and directly above the tephra have a lower chlorite iron content, suggesting some weathering.

Illite mineralogy

Illite crystallinity (= half width of I(001) reflection at half intensity) ranges from 0.3 to 0.5° 2Θ. The lowest values (i.e., highest crystallinity) are associated with samples from the tephra and the lower part of the upper diamicton subunit.

I(002)/I(001) peak ratios for illites in the Tamihi Slide samples range from 0.33 to 0.52 (mean 0.43). These values indicate that the illites are not pure, but rather are mixtures of aluminum-rich and iron-rich micas which are characterized by I(002)/I(001) peak ratios of close to 0.8 and 0, respectively.

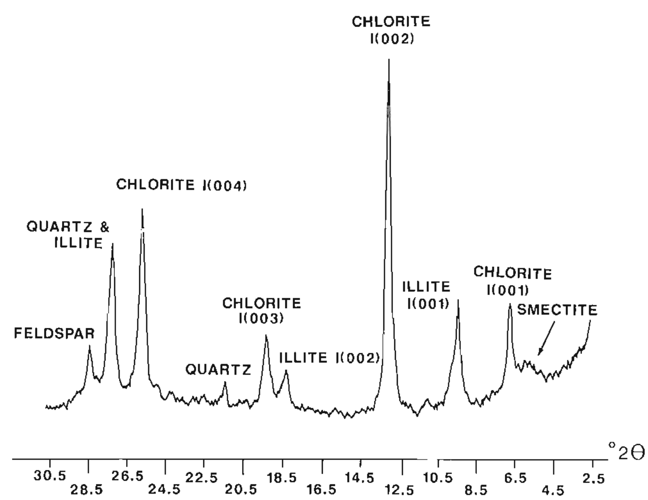


Figure 3. X-ray diffractogram of sample CH3-9 from the lower diamicton subunit (elevation 269 m, Fig. 2), showing typical glacial clay mineral assemblage.

DISCUSSION

Hydrolysis, temperature, and drainage are the three most important factors affecting mineral changes during weathering. These factors, in turn, are determined by climate and relief. Depending on substrate type, certain clay minerals form under specific climatic conditions (Millot, 1964). For example, under a cold dry climate, physical weathering dominates over chemical weathering, and abundant iron-rich chlorite and illite are produced. A change to a warmer, more humid climate favours the formation of smectite and irregular mixed-layers, although other factors, notably local relief, drainage, and geology, may also play a role.

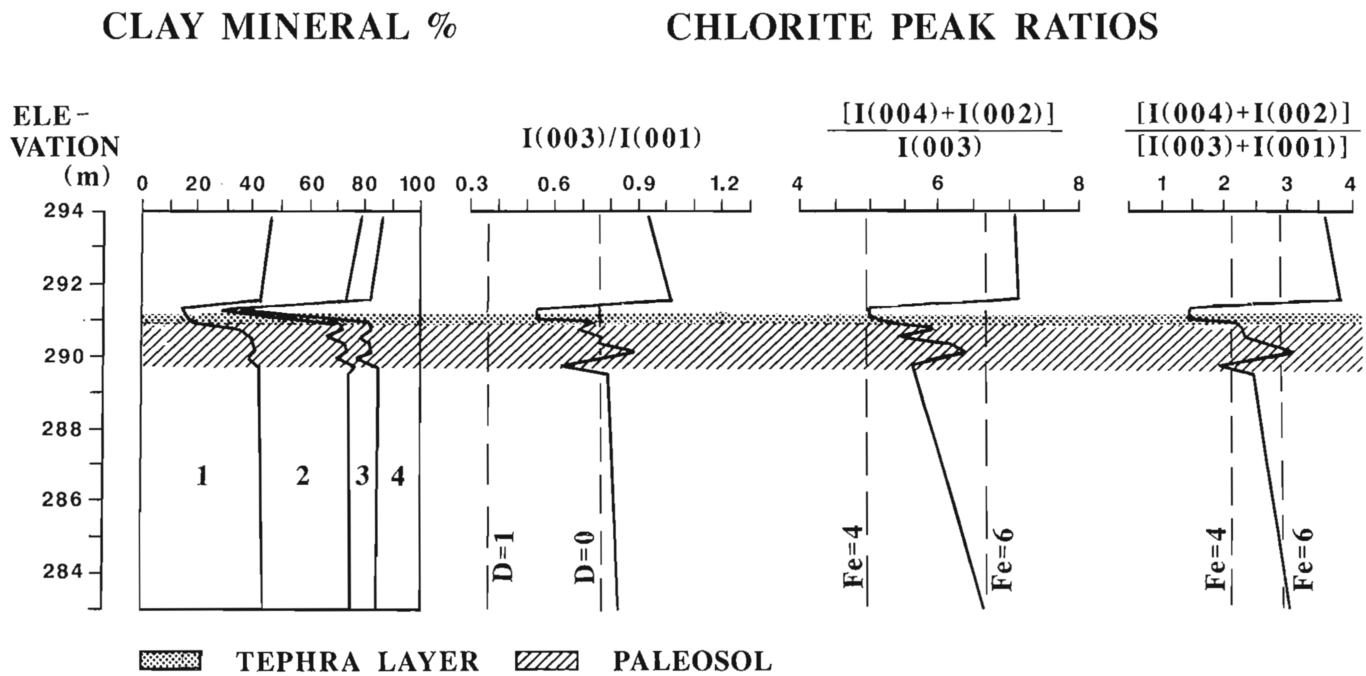


Figure 4. Clay mineralogy and chlorite peak ratios of the paleosol, tephra, and adjacent diamicton at Tamihi Slide. 1: chlorite; 2: illite; 3: irregular mixed-layers; 4: smectite; D: degree of asymmetry of chlorite; Fe: heavy atom (iron) content in chlorite structure.

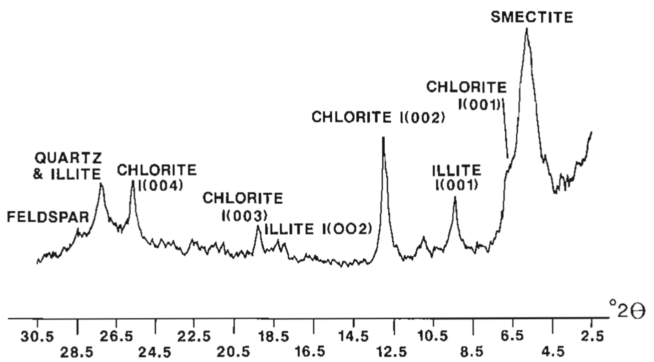


Figure 5. X-ray diffractogram of sample CH1-9 from the base of the upper diamicton subunit (elevation 291 m, Fig. 2). Note the high content of smectite.

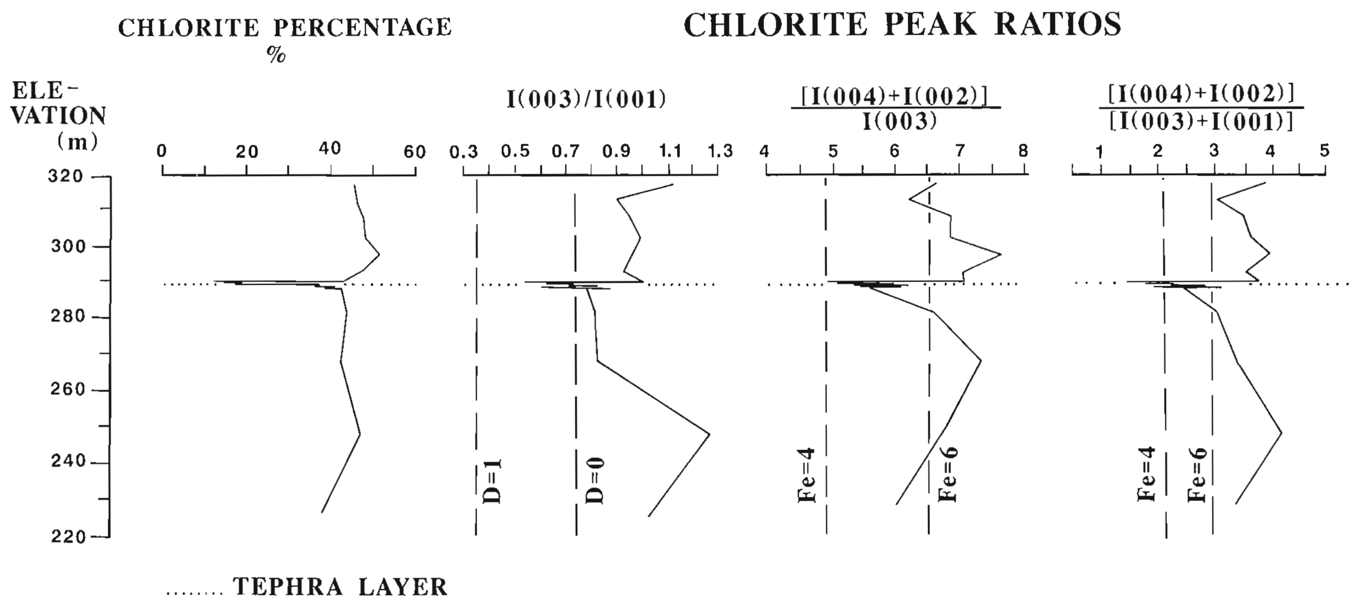


Figure 6. Chlorite percentages and chlorite peak ratios of the sediments at Tamihi Slide. D: degree of asymmetry of chlorite; Fe: heavy atom (iron) content in chlorite structure.

The general clay mineral assemblage of the Tamihi Slide diamicton is similar to assemblages found in glacial deposits on Vancouver Island (Blaise, 1985, 1987). All are dominated by iron-rich chlorite and illite of primary origin.

The Tamihi Slide paleosol has only slightly more smectite and irregular mixed-layer clay minerals than associated unweathered glacial deposits. This may be a consequence of the short time available for soil formation, perhaps as little as 100 years.

In contrast, the tephra and the base of the overlying diamicton are enriched in illite and smectite. The largest amount of smectite is found directly above the tephra, suggesting that this mineral may have formed in response to rapid weathering of volcanic glass before the site was last overridden by ice. The formation of smectite from volcanic ash by authigenesis has been widely reported and is thought to take place rapidly (Millot, 1964; Chamley and Millot, 1972; Konta, 1986). The radiocarbon dates from the Tamihi Slide section indicate that such authigenesis can occur in as little as 100-300 years. Data presented in this paper also support suggestions made by Millot (1964), Petersen and Rasmussen (1980), and Parra et al. (1985) that secondary clays, under certain circumstances, can form under a cold climate.

Two possible explanations are offered for the high content of illite in the Tamihi Slide tephra: (1) this mineral, like smectite, may be a product of authigenesis after tephra deposition; (2) the illite may be a primary mineral associated with the tephra at the time of its eruption.

Inspection of the grain-size and clay mineral data from the Tamihi Slide section (Fig. 2) shows that up to 13 % of the matrix (<2 mm) of the diamicton directly above the tephra is smectite. Smectite is a swelling mineral that can drastically affect the geotechnical properties and stability of associated sediments and slopes. This concern highlights the practical importance of studying clay minerals. In areas undergoing development, special attention should be paid to materials such as tephra that are readily transformed into expandable clay minerals.

REFERENCES

Blaise, B.

1985: Sédimentation et paléoenvironnements plio-quaternaires sur la bordure Nord-Est de l'Océan Pacifique; Thèse de docteur de troisième cycle, Université des Sciences et Techniques de Lille, Lille, 227 p.

1987: Clay mineral stratigraphy of late Quaternary deposits on Vancouver Island (SW British Columbia, Canada); International Union for Quaternary Research, 12th International Congress (Ottawa), Programme with Abstracts, p. 131.

Brindley, G.W. and Brown, G. (ed.)

1980: Crystal structures of clay minerals and their X-ray identification; Mineralogical Society of London, Monograph No. 5, 495 p.

Chamley, H. et Millot, G.

1972: Néoformation de montmorillonite à partir de diatomées et de cendres dans les sédiments marins de Santorin (Méditerranée orientale); Académie des Sciences, Comptes Rendus, Série D, v. 274, p. 1132-1134.

Clague, J.J. and Luternauer, J.L.

1982: Excursion 30A: Late Quaternary sedimentary environments, southwestern British Columbia; International Association of Sedimentologists, 11th International Congress on Sedimentology (Hamilton), Field Excursion Guide Book, 167 p.

1983: Late Quaternary geology of southwestern British Columbia; Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Joint Annual Meeting (Victoria), Field Trip Guidebook No. 6, 112 p.

Hicock, S.R., Hobson, K., and Armstrong, J.E.

1982: Late Pleistocene proboscideans and early Fraser glacial sedimentation in eastern Fraser Lowland, British Columbia; Canadian Journal of Earth Sciences, v. 19, p. 899-906.

Holtzapffel, T.

1985: Les minéraux argileux: préparation, analyse diffractométrique et détermination; Annales de la Société Géologique du Nord, Mémoire 12, 136 p.

Konta, J.

1986: Textural variation and composition of bentonite derived from basaltic ash; Clays and Clay Minerals, v. 34, p. 257-265.

Millot, G.

1964: Géologie des argiles, altérations, sédimentologie, géochimie; Masson, Paris, 499 p.

Monger, J.W.H.

1970: Hope map-area, west half (92 H W1/2), British Columbia; Geological Survey of Canada, Paper 69-47, 75 p.

Parra, M., Delmont, P., Ferragne, A., Latouche, C., Pons, J.C., and Puechmaille, C.

1985: Origin and evolutions of smectites in Recent marine sediments of the NE Atlantic; Clay Minerals, v. 20, p. 335-346.

Petersen, L. and Rasmussen, K.

1980: Mineralogical composition of the clay fraction of two fluvio-glacial sediments from East Greenland; Clay Minerals, v. 15, p. 135-145.

Ross, G.J. and Kodama, H.

1976: Experimental alteration of a chlorite into a regularly interstratified chlorite-vermiculite by chemical oxidation; Clays and Clay Minerals, v. 24, p. 183-190.

Saunders, I.R.

1985: Late Quaternary geology and geomorphology of the Chilliwack River valley, British Columbia; M.Sc. thesis, Simon Fraser University, Burnaby, 140 p.

Saunders, I.R., Clague, J.J., and Roberts, M.C.

1987: Deglaciation of Chilliwack River valley, British Columbia; Canadian Journal of Earth Sciences, v. 24, p. 915-923.

Activité hydrothermale et altération de sédiments hémipélagiques dans une ancienne vallée axiale, vallée Middle, dorsale de Juan de Fuca, nord-est du Pacifique

B. Blaise[1], J.M. Franklin[2], W.D. Goodfellow[2], I.R. Jonasson[2], F.E.L. Harvey-Kelly[2], et C.D. Anglin[2]

Blaise, B., Franklin, J.M., Goodfellow, W.D., Jonasson, I.R., Harvey-Kelley, F.E.L., et Anglin, C.D., Activité hydrothermale et altération de sédiments hémipélagiques dans une ancienne vallée axiale, vallée Middle, dorsale de Juan de Fuca, nord-est du Pacifique; dans Recherche en cours, partie E, Commission géologique du Canada, Étude 88-1E, p. 31-37, 1988.

Résumé

Trois campagnes océanographiques successives ont mis en évidence des dépôts hydrothermaux dans une ancienne vallée axiale remplie de sédiments, au nord de la dorsale de Juan de Fuca. Les renseignements recueillis grâce à l'utilisation de caméras vidéo, prises de vue sous-marines, forages, draguages et carottages, ont permis la cartographie à grande échelle des événements hydrothermaux. Les premiers résultats de la dernière campagne en mer (juin 1987) montrent des sédiments hémipélagiques pas, peu, ou très altérés, parfois associés à des sulfures massifs. Certains sédiments enregistrent parfois des teneurs élevées en smectite ou en chlorite, tandis que d'autres sont riches en Ba, Cu, Pb, Sr et Zn. Les altérations hydrothermales se produisent tout d'abord dans les sédiments à texture fine, riches en minéraux argileux. Ces derniers subissent une déshydratation puis une dessication dues à l'augmentation de température. Les vides ainsi créés favorisent la circulation des fluides hydrothermaux et la précipitation de sulfures. La répartition des anomalies de flux de chaleur, des sulfures massifs, des évents actifs et des sédiments de nature altérée ou non altérée, permet de distinguer trois stades dans l'évolution hydrothermale du secteur: 1) des évents actifs et des sédiments très altérés associés à des flux de chaleur anormalement élevés; 2) des sulfures massifs abondants et des sédiments altérés ou non, et 3) la formation de monticules (400 m de diamètre, 50 m de hauteur), forme que prennent les accumulations de sulfures massifs recouvertes de sédiments hémipélagiques.

Abstract

Three successive cruises have investigated the occurence of hydrothermal activity in a sediment-filled valley. A detailed geological map has been compiled using information from video and underwater photos, rock drilling, coring and dredging. Preliminary results of the last cruise (June 1987) show hydrothermaly altered hemipelagic sediments, some with high smectite or chlorite content, and some rich in Ba, Cu, Pb, Sr and Zn. The hydrothermal alteration primarily takes place in fine grained sediments rich in clays. When heated these sediments are dessicated and open spaces are created, which process facilitates fluid circulation and sulphide precipitation. The distribution of high heat flow anomalies, massive sulphides, active chimneys, altered and non-altered hemipelagic sediments lead to the distinction of three stages of the hydrothermal system: (1) a highly active black smoker area with altered sediments associated with exceptionally high heat flow; (2) a large accumulation of massive sulphides and altered sediments and (3) mound formation (400 m in diameter, 50 m high) consisting of massive sulphides and sulphidic sediments capped by hemipelagic sediment.

[1] Division géoscientifique de la Cordillère et du Pacifique, Centre géoscientifique du Pacifique, C.P. 6000, Sidney, C.B., V8L 4B2

[2] Division des ressources minérales, 601, rue Booth, Ottawa, Ont., K1A 0E8

INTRODUCTION

Découvertes en 1985 lors de la campagne océanographique HOTMUD'85 (Davis et coll. 1987; Blaise et Bornhold, 1987; Goodfellow et Blaise, sous presse), les localités hydrothermales de la vallée Midle (segment nord fossile de la dorsale de Juan de Fuca, fig. 1) ont de nouveau fait l'objet de visites et d'échantillonages en 1986 et 1987. Lors de ces campagnes, l'utilisation simultanée de deux systèmes de navigation (de type GPS de surface et de type Transponder sur le fond marin) a permis d'esquisser une cartographie à grande échelle de la zone sédimentaire affectée par les émissions hydrothermales. Les renseignements recueillis grâce à l'utilisation de caméras vidéo, prises de vue sous-marines, forages, draguages et carottages ont permis les travaux de cartographie. Au cours de la dernière campagne océanographique TUL 87B, 16 carottes ont été prélevées à l'aide de carottiers à piston et par gravité; elles contiennent des sédiments hémipélagiques pas, peu, ou très altérés et des sulfures qui peuvent être, ou ne pas être disséminés dans les sédiments (fig. 2). Le présent rapport récapitule brièvement les premières données sédimentologiques, minéralogiques et géochimiques obtenues sur quelques-unes de ces carottes et cherche à les intégrer dans une esquisse de modèle hydrothermal du secteur concerné (Franklin et coll. 1987).

LOCALISATION

La dorsale de Juan de Fuca, localisée à quelques centaines de kilomètres des côtes de l'état de Washington et de la Colombie-Britannique (fig. 1), présente un taux d'expansion océanique moyen de l'ordre de 60 mm/a. Les vallées axiales sont soit localisées au sommet de dorsales océaniques à fort relief, soit au niveau de vallées axiales plus profondes avec des taux d'expansion plus faibles. La proximité du continent et le relief de ces vallées ont permis l'accumulation très rapide d'importants volumes de sédiments, enfouissant les vallées axiales en plusieurs endroits. Au niveau de la vallée Middle, où ce phénomène s'est produit, la croûte à un âge de 50 à 200 ka (Karsten et coll., 1986) et l'épaisseur de la couche sédimentaire varie de 300 à 1500 m dans la zone axiale de la vallée (Villinger et Davis, 1986). Les taux de sédimentation calculés se situent entre 1,5 et 300 m par millier d'années. Pour la partie supérieure de la couverture, le taux de sédimentation et de l'ordre de la dizaine de cm par millier d'années (Goodfellow et Blaise, sous presse). La cartographie du secteur à l'aide des systèmes SEA-MARC I et II et SEABEAM (Davis et coll., 1985), permet d'identifier plusieurs monticules sur le plancher de la vallée. Ils ont jusqu'à 400 m de diamètre et 50 m de hauteur. La formation de ces monticules est vraisemblablement liée à l'activité hydrothermale du secteur (Franklin et coll., 1987; Goodfellow et coll., 1987; Goodfellow et Blaise, sous presse). Cette dernière est contrôlée par un système de structures à orientation N-S, parallèle à la marge est faillée de la vallée Middle (Franklin et coll., 1987). Au sud d'un de ces monticules, et à quelques kilomètres au nord de ce dernier, des anomalies importantes de flux de chaleur ont été mesurées (Villinger et Davis, 1986; Davis et coll., 1987). La dernière phase de carottage a eu lieu aux alentours de ce même monticule (fig. 2).

ÉCHANTILLONAGE ET MÉTHODES D'ÉTUDE

Les échantillons analysés proviennent principalement de la partie basale des carottes (CC: core catcher) et de la carotte TUL 87B-03 contenant des brèches sédimentaires non indurées.

Pour la granulométrie, on utilise un sédiment au préalable lyophylisé; puis, les fractions sableuses et silteuses sont séparées à l'aide d'un tamis dont les mailles mesurent 63 μ; la fraction grossière est ensuite analysée à l'aide d'un tube à décantation long de 2 m, et la fraction fine grâce à un Sedigraph 5000 D. La fraction argileuse (inférieure à 2 μ) est séparée par décantation d'échantillons décarbonatés à l'aide de HCl (N/5); elle est ensuite orientée sur lame de verre rainurée, puis analysée à l'aide d'un générateur Philips PW 1130 muni d'un goniomètre vertical PW 1050/85 et d'une table imprimante PM 8210 contrôlée par un microprocesseur PW 1710 (tube Cu, filtre Ni). Le détecteur est un compteur proportionnel PW 1711/10. Chaque échantillon donne trois diffractogrammes, soit (1) naturel, (2) glycolé, et (3) chauffé à 490°C pendant deux heures. La reproductibilité des mesures est de l'ordre de 5 %. Les analyses géochimiques sont réalisées par ICP pour tous les éléments, sauf Pb

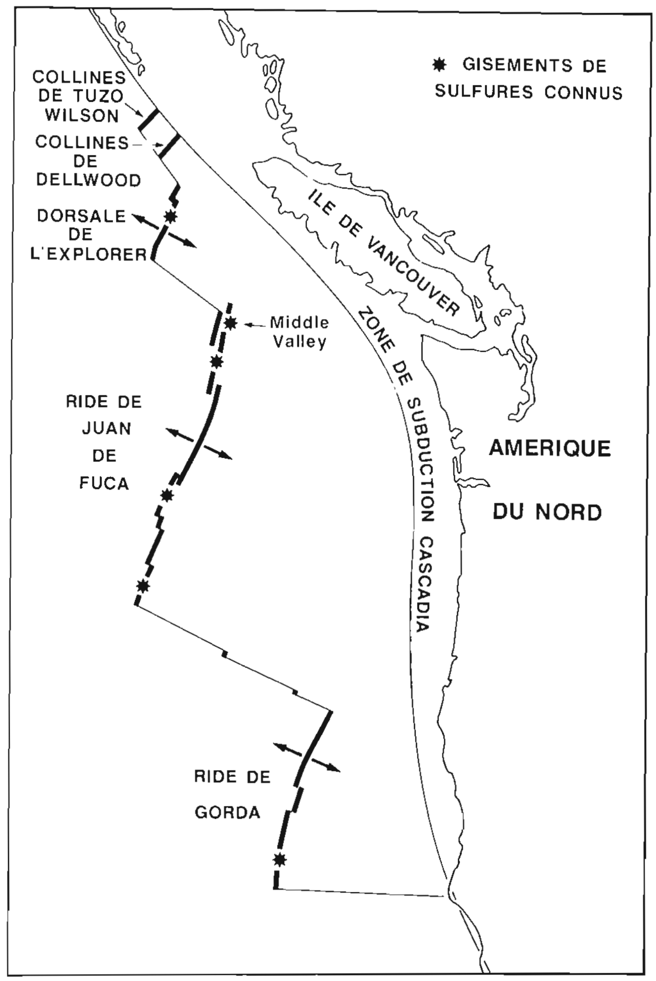


Figure 1. Localisation générale de la vallée Middle et des zones riches en sulfures au niveau du système de la dorsale de Juan de Fuca.

que l'on détermine par absorption atomique, et FeO, CO_2, C, S et LOI obtenus par voie chimique (Goodfellow et Blaise, sous presse).

RÉSULTATS

Les sédiments hémipélagiques comprennent des argiles silteuses dont la couleur varie de gris olive à gris noir, et des silts argileux généralement gris noir (tab. 1). Au sommet des carottes et à plusieurs reprises dans les carottes TUL 87B-01 et 08, des sédiments bruns sont rencontrés. Ces carottes renferment d'ailleurs des niveaux bruns fréquemment délimités de manière abrupte par des silts argileux (fig. 3). Des sédiments verts à vert olive, répartis de manière diffuse ou en lits centimétriques, se manifestent dans de nombreuses carottes, parfois en association avec des amas noirâtres de matière organique (fig.3). Les niveaux les plus sombres et les plus grossiers présentent des granoclassement normaux et des zones perturbées; ils sont interprétés dans le secteur comme des turbidites déposées au cours de la fin du Pléistocène (Griggs et coll., 1969; Griggs et Kulm, 1970; Goodfellow et Blaise, sous presse; fig. 3). Des sédiments hémipélagiques fortement altérés apparaissent dans les carottes TUL 87B-02 et 14. La carotte TUL87B-02 comprend, au sommet, des laminations millimétriques riches en oxydes de fer et de manganèse. Ces laminations recouvrent des sédiments déshydratés de teinte verdâtre à brunâtre présentant des fentes de dessication millimétriques principalement verticales aux parois couvertes de sulfures. La carotte TUL 87B-14 comprend de nombreuses zones riches en nodules de carbonate; elle ressemble à la carotte PAR 85-34 décrite par Goodfellow et Blaise (sous presse). Dans cette dernière de nombreux sulfures et sulfates (gypse et barite) sont décrits, en association avec des silicates de magnésium, dans un sédiment partiellement cimenté par de la silice amorphe et de la calcite. Enfin, les carottes TUL 87B-05, 07, 09, 11 et 15, dont l'étude se poursuit, contiennent des sulfures massifs intercalés dans des sédiments hémipélagiques.

À part deux échantillons, la minéralogie des argiles montre une forte ressemblance aux assemblages terrigènes décrits dans le secteur (Blaise et Bornhold, 1986; 1987; Blaise et coll., 1987; Al-aasm et Blaise, 1987; Goodfellow et Blaise, sous presse). Les assemblages se composent de smectite (31 à 55 %), chlorite (13 à 30 %), illite (17 à 34 %) et de minéraux interstratifiés irréguliers (6 à 15 %) comprenant de l'illite et smectite (10-14s), de l'illite et vermiculite (10-14v) et de la chlorite et smectite et de la chlorite et vermiculite indifférenciées (14-14) (tab. 1). À ces minéraux viennent s'ajouter des feldspaths, des amphiboles et du quartz en moins grande quantité. Les pourcentages anormaux enregistrés, sont asso-

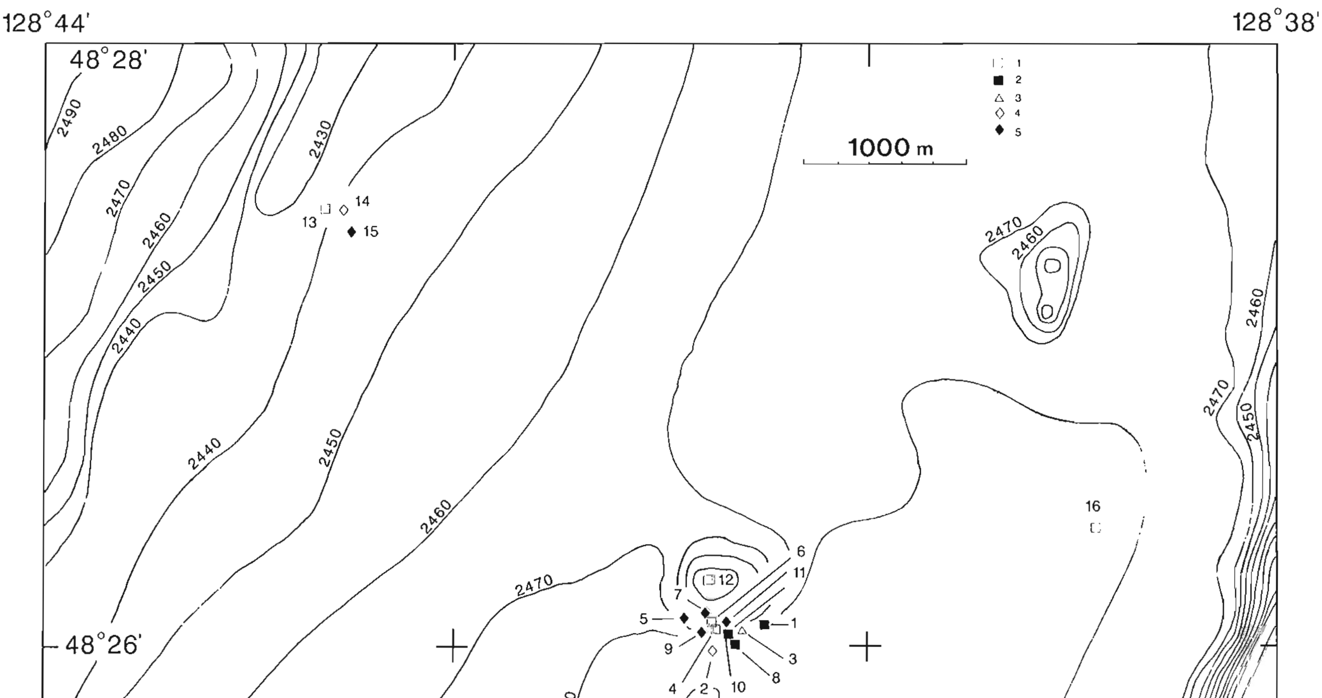


Figure 2. Distribution préliminaire des carottes prélevées lors de la campagne TUL 87B effectuée dans la partie sud de Middle Valley (voir fig. 1). Profondeur en m, d'après la bathymétrie préliminaire du Seabeam, modifiée d'après Malahoff et coll. (1985).
1: sédiment hémipélagique;
2: sédiment hémipélagique contenant des niveaux bruns;
3: sédiment hémipélagique contenant des brèches sédimentaires non indurées;
4: sédiment hémipélagique altéré;
5: sulfures massifs associés à des sédiments hémipélagiques.

ciés aux sédiments altérés, et à un très fort taux de smectite (81 %) à la base de la carotte TUL 87B-02 et de chlorite (50 %) dans le cas de la carotte TUL 87B-14.

Les analyses géochimiques ont donné des résultats relativement uniformes pour les éléments majeurs tandis que des variations importantes ont été notées pour les éléments en traces (tab. 2). Ba, Cu, Sr et Zn présentent des taux élevés pour les sédiments associés aux dépôts hydrothermaux, ainsi que Pb de manière plus ponctuelle. Dans la carotte TUL 87B-03, les sédiments grossiers sont pauvres en éléments en traces (160-162 cm) tandis que les niveaux sédimentaires vert olive sont riches en Fe, Ba, Cu, Sr et Zn. Ils correspondent à des niveaux de sédiments fins surmontant les brèches sédimentaires non indurées.

DISCUSSION

La présence d'évents hydrothermaux actifs (Franklin et coll., 1987), d'anomalies élevées de flux de chaleur (Villinger et Davis, 1986; Davis et coll., 1987) et de sulfures massifs (Goodfellow et coll., 1987; Davis et coll., 1987; Goodfellow et Blaise, sous presse) sont assez d'éléments qui permettent d'attribuer une origine hydrothermale à l'altération des sédiments hémipélagiques rencontrés. Cette influence semble se confiner préférentiellement dans les sédiments fins. L'augmentation de température induite par les fluides hydrothermaux provoque une déshydratation progressive des sédiments riches en minéraux argileux, suivie de leur dessication. Les vides ainsi créés favorisent la circulation des fluides et la précipitation de sulfures et d'autres phases minérales. D'autres réactions impliquant les minéraux préexistants et les fluides hydrothermaux seraient à l'origine des minéraux argileux rencontrés en concentration anormale.

L'histoire hydrothermale du secteur peut être en partie éclaircie grâce à la répartition horizontale et verticale des sédiments hémipélagiques altérés et des sulfures. Au niveau du monticule représenté sur la figure 2, les sédiments prélevés ne sont pas altérés et aucun sulfure n'a été décrit. Ce phénomène semble indiquer que si le monticule est d'origine hydrothermale (Franklin et coll., 1987; Davis et coll., 1987; Goodfellow et Blaise, sous presse), il s'agit de dépôts hydrothermaux restreints dans une zone non échantillonée ou de dépôts hydrothermaux de nature fossile recouverts par une épaisseur conséquente de sédiments hémipélagiques. Goodfellow et Blaise (sous presse) ont décrit la présence de sédiments altérés à la base des carottes PAR 85-27 et 28 (345

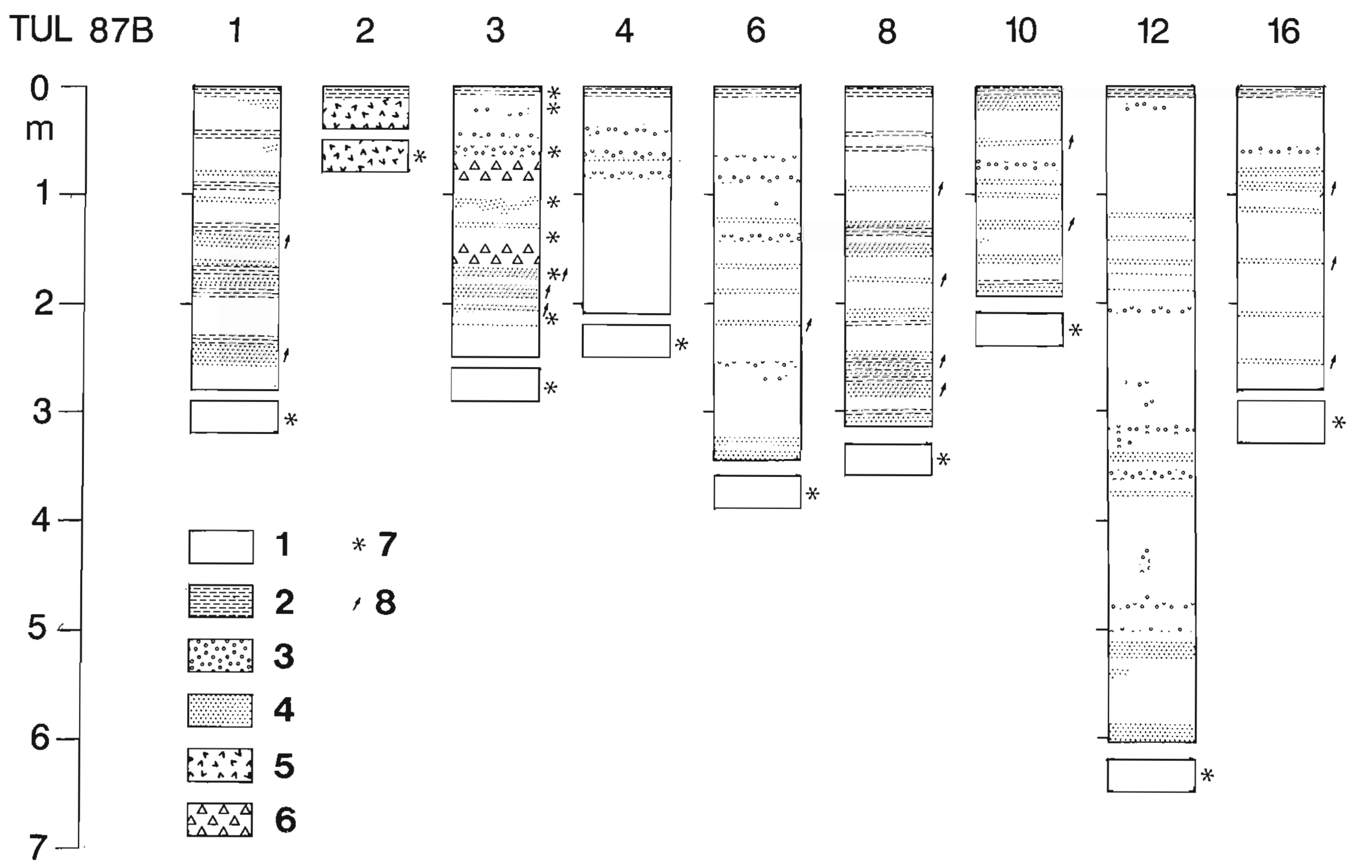


Figure 3. Description lithologique de quelques carottes prélevées lors de la campagne TUL 87B.

1: argiles silteuses gris olive à gris noir;
2: sédiments bruns;
3: sédiments verts à vert olive;
4: silts argileux gris noir;
5: sédiments hémipélagiques très altérés;
6: brèches sédimentaires non indurées;
7: échantillonage pour analyses granulométriques, minéralogiques et géochimiques;
8: silts argileux avec granoclassement vertical.

et 420 cm de longueur respectivement), toutes deux localisées sur le monticule. De nombreuses autres carottes prélevées à cet endroit montrent l'existence d'au moins 2,5 m de sédiments hémipélagiques sans traces d'altérations. Ces données et l'absence d'anomalies de flux de chaleur au niveau du mont confirmerait l'hyphothèse d'une activité hydrothermale de nature fossile dont les dépôts seraient recouverts par la sédimentation hémipélagique.

Dans la région localisée juste au sud du mont, des débris d'évents, des sulfures massifs et des sédiments hémipélagiques très altérés, dénudés de sédiments non altérés, témoignent d'une activité hydrothermale récente (Goodfellow et Blaise, sous presse). Les données géochimiques associées aux sédiments altérés permettent d'interpréter les niveaux riches en Ba, Cu, Sr et Zn de la carotte TUL 87B-03 comme ayant probablement subis une influence hydrothermale. L'association des brèches non indurées et des anomalies géochimiques dans les niveaux les surmontant, permet de relier dans le temps la déstabilisation de la couverture sédimentaire et les manifestations hydrothermales. Toujours dans le même secteur, la présence de niveaux bruns dans les carottes TUL 87B-01 et 08 peut être due à deux phénomènes: (1) soit qu'une sédimentation lente dans un secteur protégé ait permis le développement à l'interface eau-sédiment d'une zone d'oxydation (rencontrée au sommet des carottes), que l'arrivée soudaine d'une masse sédimentaire importante (courant de turbidité) ait scellé le système et fossilisé la zone d'oxydation et qu'ainsi un phénomène répétitif ait entraîné le dépôt successif des niveaux bruns; (2) soit que ces dépôts aient pu résulter de la précipitation de particules oxydées contenues

Tableau 1. Analyses des minéraux argileux et granulométrie des échantillons des carottes, TUL 87B. CC: core catcher, extrémité basale des carottes.

MINERALOGIE DES ARGILES ET GRANULOMETRIE

NUMERO D'ECHANTILLON	CHLORITE %	ILLITE %	(10-14s) %	(10-14v) %	(14-14) %	SMECTITE %	SABLE %	SILT %	ARGILE %
TUL 87B-01- CC	14	32	5	0	8	41	0.37	39.34	60.29
TUL 87B-02- CC	4	6	0	0	10	81	0.55	30.44	69.00
TUL 87B-03- 0 / 2 cm	13	34	2	0	10	41	0.70	38.11	61.19
TUL 87B-03- 15 / 17 cm	14	22	3	1	8	52	1.75	39.62	58.63
TUL 87B-03- 60 / 62 cm	24	35	2	2	12	25	1.11	27.31	71.58
TUL 87B-03- 103 / 105 cm	18	29	1	0	5	47	0.74	23.30	75.97
TUL 87B-03- 139 / 141 cm	16	22	4	0	6	52	2.00	22.49	75.51
TUL 87B-03- 160 / 162 cm	20	30	3	1	5	41	7.84	60.56	31.59
TUL 87B-03- 215 / 217 cm	30	29	2	0	8	31	0.38	26.22	73.41
TUL 87B-03- CC	26	26	3	0	8	37	0.91	36.70	62.39
TUL 87B-04- CC	20	21	5	0	3	51	0.32	44.51	55.17
TUL 87B-06- CC	16	20	3	2	10	49	1.59	22.82	75.59
TUL 87B-07- 0 / 2 cm	15	17	2	1	10	55	11.21	29.31	59.48
TUL 87B-08- CC	14	20	2	2	9	53	1.75	39.95	58.29
TUL 87B-09- CC	17	16	5	0	8	54	3.00	31.22	65.78
TUL 87B-10- CC	13	24	1	0	7	55	1.22	36.41	62.38
TUL 87B-12- CC	19	27	4	0	8	42	0.65	41.83	57.52
TUL 87B-14- CC	50	27	0	0	8	15	1.11	24.04	74.84
TUL 87B-15- 514 / 516 cm	17	23	6	0	6	48	3.57	35.68	60.75
TUL 87B-15- CC	19	18	2	0	7	54	1.77	28.49	69.74
TUL 87B-16- CC	12	24	3	0	8	53	0.18	35.99	63.83
MOYENNE	18	23	3	0	8	48	2.04	34.02	63.95
DEVIATION STANDARD	8.72	6.90	1.67	0.72	2.05	13.77	2.62	8.89	9.82
MAXIMUM	50	35	6	2	12	81	11.21	60.56	75.97
MINIMUM	4	6	0	0	3	15	0.18	22.49	31.59

CC : core catcher

Tableau 2. Analyses géochimiques des échantillons des carottes TUL 87B. Les erreurs absolues sont les suivantes: SiO_2: 0,4%, TiO_2 et P_2O_5: 0,02%, Al_2O_3 et FeO: 0,2%, Fe_2O_3 total, MgO, CaO, Na_2O, K_2O et CO_2: 0,1%, MnO: 0,01%, S: 0,04%, Ba et Pb: 20 ppm, Be et Yb: 0,5 ppm, Co et V: 5 ppm, Cr, Cu, La et Ni: 10 ppm.

ELEMENTS MAJEURS : POURCENTAGE

NUMERO D'ECHANTILLON	SIO2	TIO2	AL203	FE203T	FE203	FEO	MNO	MGO	CAO	NA20	K20	C	CO2	P205	S	LOI
TUL87B-01-CC	54.1	0.85	16.30	7.90	3.12	4.30	0.11	3.62	3.85	3.61	2.28	0.43	1.40	0.21	0.16	8.2
TUL87B-02-CC	54.5	0.77	14.30	7.12	4.89	2.00	0.07	3.61	1.92	3.80	2.14	0.35	0.00	0.48	0.39	8.7
TUL87B04-CC	56.9	0.80	15.40	6.98	1.75	4.70	0.09	3.98	2.52	3.61	2.35	0.43	0.40	0.22	0.30	6.8
TUL87B06-CC	48.7	0.66	14.10	6.69	2.91	3.40	0.08	3.52	7.94	3.39	2.36	0.51	5.10	0.15	0.22	13.1
TUL87B07-00	53.9	0.66	13.20	7.24	5.23	1.80	0.36	3.25	3.13	4.46	2.04	1.08	0.90	0.22	0.23	12.5
TUL87B08-CC	56.2	0.82	15.30	6.92	2.25	4.20	0.11	3.14	4.58	3.65	2.36	0.43	1.90	0.21	0.25	8.4
TUL87B09-CC	47.7	0.70	13.80	11.60			0.10	3.44	5.20	3.87	2.21	0.57	2.70	0.19	1.91	9.1
TUL87B10-CC	53.0	0.87	14.60	7.05	2.83	3.80	0.09	3.13	4.67	3.44	2.48	0.32	2.40	0.22	0.27	9.4
TUL87B12-CC	55.9	0.75	14.60	6.90	1.79	4.60	0.11	3.18	4.96	3.62	2.09	0.27	1.90	0.20	0.33	7.2
TUL87B14-CC	55.0	0.79	15.50	8.31			0.13	5.21	1.73	3.42	2.17	0.35	0.10	0.20	1.87	7.5
TUL87B15-CC	52.0	0.79	14.70	8.09			0.09	3.19	4.82	3.30	2.49	0.35	2.40	0.20	1.81	7.6
TUL87B16-CC	54.3	0.84	15.50	6.96	3.62	3.00	0.11	2.93	3.36	3.06	2.82	0.30	1.70	0.22	0.13	8.5
TUL87B15-00	50.8	0.67	13.30	7.49			0.12	5.25	1.89	4.03	2.21	1.32	0.00	0.16	1.49	11.6
TUL87B-03-00/02 cm	56.1	0.83	16.30	6.62	4.61	1.80	0.10	2.93	3.08	3.17	2.70	0.22	1.10	0.18	0.06	8.8
TUL87B-03-15/17 cm	51.5	0.75	15.10	6.43	3.54	2.60	0.08	3.05	7.26	3.37	2.35	0.27	4.20	0.18	0.11	11.2
TUL87B-03-60/62 cm	52.0	0.76	16.10	7.52	3.29	3.80	0.11	3.76	4.28	4.04	2.23	0.43	1.00	0.19	0.15	8.4
TUL87B03-103/105 cm	50.9	0.69	14.40	7.29	3.06	3.80	0.09	3.41	4.70	3.82	2.52	0.59	2.40	0.19	0.29	10.7
TUL87B03-139/141 cm	46.1	0.62	13.70	6.64	3.19	3.10	0.08	3.21	9.10	3.37	2.06	0.62	6.00	0.15	0.25	14.4
TUL87B03-160/162 cm	61.4	0.72	14.50	5.93	1.93	3.60	0.09	2.84	4.71	3.93	1.79	0.24	0.90	0.19	0.19	5.1
TUL87B03-215/217 cm	53.8	0.82	15.60	7.76	3.09	4.20	0.13	3.90	4.07	3.76	2.24	0.38	1.10	0.20	0.14	8
TUL87B03-CC	55.2	0.83	16.00	7.61	2.49	4.60	0.12	3.79	3.62	3.55	2.39	0.43	0.90	0.21	0.17	7.3
MOYENNE	53.3	0.76	14.87	7.38	3.15	3.49	0.11	3.54	4.35	3.63	2.30	0.47	1.83	0.21	0.51	9.17
DEVIATION STANDARD	3.34	0.07	0.92	1.10	0.99	0.94	0.06	0.63	1.86	0.32	0.23	0.26	1.57	0.06	0.62	2.24
MAXIMUM	61.4	0.87	16.30	11.60	5.23	4.70	0.36	5.25	9.10	4.46	2.82	1.32	6.00	0.48	1.91	14.40
MINIMUM	46.1	0.62	13.20	5.93	1.75	1.80	0.07	2.84	1.73	3.06	1.79	0.22	0.00	0.15	0.06	5.10

ELEMENTS TRACES : PARTIES PAR MILLION (P.P.M.)

NUMERO D'ECHANTILLON	BA	BE	CO	CR	CU	LA	NI	PB	SR	V	YB	ZN
TUL87B-01-CC	590	1.58	26	89	62	25	59	26	230	150	2.23	120
TUL87B-02-CC	11000	1.64	22	90	99	27	0	38	1300	150	2.28	280
TUL87B04-CC	600	1.55	25	95	62	28	60	21	260	140	2.59	130
TUL87B06-CC	1400	1.60	25	85	75	27	60	25	350	130	2.20	150
TUL87B07-00	3000	1.50	25	89	89	27	62	44	320	130	2.49	280
TUL87B08-CC	640	1.72	25	77	64	30	51	19	270	140	2.68	130
TUL87B09-CC	1700	1.51	31	78	610	26	22	110	310	160	2.34	8100
TUL87B10-CC	720	1.99	25	68	63	34	45	23	240	130	2.82	140
TUL87B12-CC	630	1.48	26	83	64	28	56	13	320	130	2.44	130
TUL87B14-CC	930	1.45	33	98	72	23	71	17	180	150	2.21	140
TUL87B15-CC	640	1.77	25	80	77	31	48	29	210	130	2.66	110
TUL87B16-CC	620	2.13	23	61	56	36	39	25	200	120	2.89	120
TUL87B15-00	15000	1.55	26	83	420	24	0	47	480	160	2.41	310
TUL87B-03-00/02 cm	610	2.17	23	72	50	37	47	24	200	120	2.72	140
TUL87B-03-15/17 cm	710	1.76	25	69	57	30	47	15	300	120	2.27	130
TUL87B-03-60/62 cm	1400	1.35	28	74	160	22	46	38	310	150	2.01	330
TUL87B03-103/105 cm	1400	1.61	25	87	67	26	55	25	290	140	1.93	170
TUL87B03-139/141 cm	1500	1.53	23	80	65	25	54	14	360	120	1.82	140
TUL87B03-160/162 cm	620	1.26	21	70	43	25	46	10	340	110	2.01	96
TUL87B03-215/217 cm	890	1.45	31	91	80	24	64	15	270	150	2.06	140
TUL87B03-CC	660	1.53	28	98	66	26	71	16	240	150	2.16	150
MOYENNE	2080	1.62	26	82	112	28	48	28	331	136	2.33	525
DEVIATION STANDARD	3550	0.22	3	10	132	4	19	20	221	14	0.29	1654
MAXIMUM	15000	2.17	33	98	610	37	71	110	1300	160	2.89	8100
MINIMUM	500	1.26	21	61	43	22	0	10	180	110	1.82	96

dans les exhalations hydrothermales, leur conservation aurait été identique à celle envisagée ci-dessus). La présence de nombreux dépôts hydrothermaux dans le secteur et l'absence de niveaux sédimentaires bruns dans les carottes prélevées sur le monticule ou le taux de sédimentation est deux fois moindre que sur le plancher de la vallée (Goodfellow et Blaise, sous presse), rendent la seconde hypothèse plus attrayante. La zone située au NO du mont se caractérise par la présence d'évents actifs (Franklin et coll., 1987) et de sédiments altérés de manière plus ou moins intense (Franklin et coll., 1987; Goodfellow et coll., 1987; Goodfellow et Blaise, sous presse). De plus, les anomalies de flux de chaleur sont les plus intenses bien qu'aucun relief ne soit présent.

CONCLUSIONS

Plusieurs étapes dans les manifestations hydrothermales peuvent être déduites de ces observations. Les localités actives au NE du monticule associées aux anomalies importantes de flux de chaleur pourraient représenter le premier stade dans l'évolution du système hydrothermal. La zone au sud du monticule correspondrait soit à un stade de maturation avancée, soit à un système hydrothermal avorté. Le monticule lui-même constituerait le stade ultime de l'évolution du système dont les dépôts seraient recouverts par la sédimentation hémipélagique.

Afin d'établir la meilleure modélisation possible du phénomène rencontré dans la vallée Middle et de pouvoir l'appliquer aux dépôts sédimentaires anciens, de nombreux points restent à être éclaircis. Il suffit, par exemple, d'examiner les relations qui existent entre sédiments et dépôts hydrothermaux: tout d'abord, la distinction entre sédiments métallifères d'origine hydrothermale et diagénétique dans une zone à forte influence terrigène; puis l'importance de la couverture sédimentaire sur la chimie des fluides hydrothermaux, les premières études isotopiques indiquant une contribution non négligeable des sédiments (Goodfellow et coll., 1987; Goodfellow et Blaise, sous presse); et enfin, la distinction entre apports terrigènes, marins et hydrothermaux et les modifications minéralogiques et chimiques subies par les dépôts antérieurs aux manifestations hydrothermales.

REMERCIEMENTS

Les auteurs tiennent à remercier particulièrement le capitaine, les officiers et l'équipage du C.S.S. J.P. Tully de leur précieuse collaboration, ainsi que MM. R. MacDonald et J. Horel, responsables des systèmes de navigation et de l'assistance technique à bord. Ils remercient également MM. T. Forbes et R. Smith pour les analyses granulométriques, M. K. Conway pour la radiographie des carottes, Mme G. Lecheminant pour les analyses diffractométriques et MM. G. Lachance et P. Bélanger pour les analyses géochimiques.

RÉFÉRENCES BIBLIOGRAPHIQUES

Al-aasm, I.S. and Blaise, B.
1987: Hydrothermal fluid effect on the sediment column in Middle Valley, Juan de Fuca Ride (N.E. Pacific); American Association of Petroleum Geologist, program with abstract, Los Angeles.

Blaise, B. and Bornhold, B.D.
1986: Different sources for iron-rich smectite; EOS transaction, program with abstract, American Geophysical Union, 67, p.1232.

Blaise, B., Bornhold, B.D. and Maillot, H.
1987: Clay mineralogy of Plio- Pleistocene sediments, North-East Pacific, DSDP Leg 18, Site 177-177A; International Union for Quaternary Research, program with abstract, Ottawa, p. 131.

RÉFÉRENCES

Blaise, B. and Bornhold, B.D.
1987: Geochemistry of Northern Juan de Fuca Ridge sediments, northeast Pacific; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 127-142.

Davis, E., Currie, R., Sawyer, B., Riddihough, R. and Holmes, M.
1985: Juan de Fuca Ridge: Seamarc II Acoustic Image Mosaic (Northern Juan de Fuca Ridge); Geological Survey of Canada, Open File 1144.

Davis, E.E., Goodfellow, W.D., Bornhold, B.D., Adshead, J., Blaise, B., Villinger, H. and LeCheminant, G.
1987: Massive sulphides in a sedimented rift valley, Northern Juan de Fuca Ridge; Earth and Planetary Science Letters, 82, p. 49-61.

Franklin, J.M., Goodfellow, W.D., Blaise, B., Anglin, C.D., Harvey-Kelly, F.L., Macdonald, R. and Kapel, E.
1987: Geological map and distribution of sulphide deposits in Middle Valley, Northern Juan de Fuca Ridge; EOS, American Geophysical Union.

Griggs, G.B., Carey, A.G., Jr., and Kulm, L.D.
1969: Deep-sea sedimentation and sediment-fauna interaction in Cascadia Channel and on Cascadia Abyssal Plain; Deep-Sea Research, 16, p. 157-170.

Griggs, G.B. and Kulm, L.D.
1970: Sedimentation in Cascadia Deep-sea channel; Geological Society of America Bulletin, 81, p. 1361-1384.

Goodfellow, W.D. and Blaise, B.
— Sulphide formation and hydrothermal alteration of hemipelagic sediment in Middle Valley, northern Juan de Fuca Ridge; Canadian Mineralogist, (in press).

Goodfellow, W.D., Jonasson, I.R., Blaise, B. Franklin, J.M. and Grapes, K.
1987: Nature of sulphide rich mounds in sedimented-filled Middle Valley, Northern Juan de Fuca Ridge; EOS, American Geophysical Union.

Karsten, J.L., Hammond, S.R., Davis, E.E. and Currie, R.G.
1986: Detailed Geomorphology and Neotectonics of the Endeavour Segment, Juan de Fuca Ridge. New results from Seabeam swath mapping; Geological Society of American Bulletin, 97, p. 213-221.

Villinger, H. and Davis, E.E.
1986: Hydrothermal regime of a sedimented rift valley, Northern Juan de Fuca Ridge; EOS, program with abstract, American Geophysical Union, p. 1232.

Preliminary report on the geology of McLeod Lake area, British Columbia

L.C. Struik and E.A. Fuller[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Struik, L.C. and Fuller, E.A., Preliminary report on the geology of McLeod Lake area, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, pp. 39-42, 1988.

Abstract

The McLeod Lake 1:250,000 revision mapping project (93J) was initiated in summer 1987 with reconnaissance examinations throughout much of the map area. Both bedrock and Quaternary cover sequences were studied.

Résumé

On a entrepris durant l'été 1987 le projet de révision de la carte du lac McLeod au 1:250 000, en effectuant des levés de reconnaissance dans une grande partie de la région cartographiée. On a étudié à la fois les séquences de la roche en place et les séquences de la couverture quaternaire.

[1] University of Western Ontario, London, Ontario N6A 5B7

INTRODUCTION

The McLeod Lake project was started during the summer of 1987 and will continue through two more field seasons. The object is to re-evaluate the 1:250 000 scale geology of Muller and Tipper (1969) by remapping selected areas and adding coverage where possible. Several advances in the geological understanding of the Canadian Cordillera since Muller and Tipper compiled their map have prompted the updating project. Gabrielse (1985), Struik (1985a, b), Eisbacher (1985), Mansy (1986), Price and Carmichael (1986) and others have suggested that dextral strike-slip motion from the Northern Rocky Mountain Trench is translated to the northern part of the Southern Rocky Mountain Trench and the Bowron River-Matthew River valleys by the McLeod Lake Fault and adjacent parallel and obligue faults. Such suggestions with their regional implications for the geology of southern British Columbia have yet to be tested in the McLeod Lake sheet. In the Cordillera of the United States and southern British Columbia much has recently been written about the structural and economic significance of sedimentary and volcanic rocks in contact with high grade metamorphic rocks on shallowly dipping extension faults (Coney, 1980; Armstrong, 1982; Tempelman-Kluit and Parkinson, 1986; Parrish, 1986; Wilkins et al., 1986). The concept is that the crust was extended or stretched and the ductile lower crust was thinned, denuded and uplifted as the brittle low-grade cover rocks slid off along shallow faults. The extension caused thinning of the crust and the elevation of hot lower crustal rocks. The source of heat at relatively shallow depth generated circulation of meteoric and metamorphic water (mineral brines) that rose to shallow levels along the extension faults. The brines precipitated minerals in suitable environments along and near the shallow extension faults. Such a scenario may have been active in the McLeod Lake map area where low-grade volcanic rocks of the Takla and Slide Mountain groups lie adjacent to high grade rocks of the Wolverine Metamorphic Complex. The mineral showings and geochemical anomalies that cluster in the low-grade rocks around the Wolverine Complex at Carp Lake and Mount Mackinnon may have formed during such an extension process. It is with these geological ideas, generated elsewhere, that the geology of the McLeod Lake map area has taken on a new significance.

OVERVIEW

In the map area (Fig. 1), west of highway 97, Quaternary deposits cover most of the bedrock of mainly upper Paleozoic and Mesozoic basalts and Precambrian(?) to Tertiary metamorphosed sediments intruded by felsic dykes and plutons. To the east, Paleozoic and Precambrian sedimentary and some mafic volcanic and intrusive rocks underlie two northwest trending ranges separated and transected by Tertiary river channels. Both the Quaternary cover and the bedrock contain complex histories obscured by poor exposure — the bedrock because of the Quaternary cover and the Quaternary cover because in only a few places have rivers cut through them to expose stratigraphic sections.

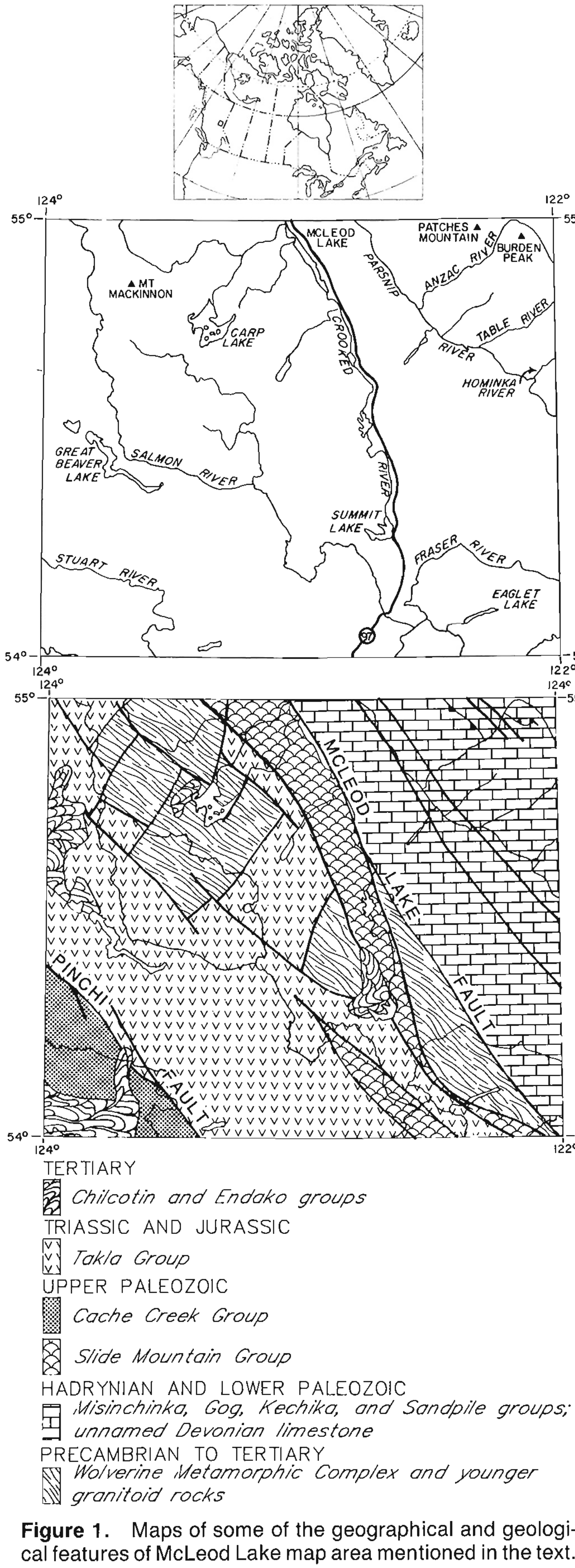


Figure 1. Maps of some of the geographical and geological features of McLeod Lake map area mentioned in the text.

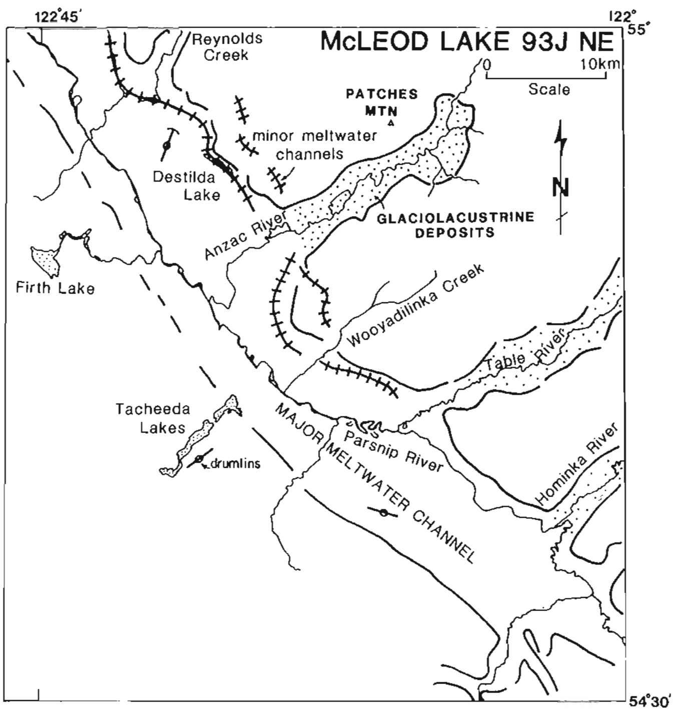


Figure 2. Distribution of glaciolacustrine deposits and glacial meltwater channels in the northeast of McLeod Lake map area.

Age for the youngest tectonism

Rocks in the McLeod Lake area may have been faulted and uplifted as recently as the latest Eocene and early Oligocene. At Eaglet Lake a fault between granodiorite (Eaglet pluton), that intrudes the Wolverine Complex paragneiss, and serpentinite of the Slide Mountain Group has a ductile and brittle history younger than the pluton. The Eaglet pluton is dated at 36 ma (K-Ar on biotite, Wanless et al., 1970, p. 24) and has been sheared into mylonite against mylonitic marble and serpentinite to the southwest. The ductile shear should therefore be 36 ma or younger. The mylonitic rocks are in turn sheared in a broken zone of phacoidal marble, black phyllonite and serpentinite which in turn is intruded by a quartz-feldspar porphyry rhyolite dyke. The brittle shear is younger and shallower than the ductile deformation that produced the mylonite implying uplift after 36 ma. The porphyry dyke is younger than the brittle shear and presumably was intruded when the rocks were still at a shallow depth. All of these tectonic features were then further uplifted to expose them at surface. The McLeod Lake Fault is parallel to the fault at the south end of Eaglet Lake, and, like the Eaglet Lake fault, juxtaposes Wolverine Complex rocks against low-metamorphic grade rocks. Therefore, the McLeod Lake Fault may also have had Oligocene or younger motion. Several suites of crosscutting granitic rocks that are folded and faulted will be isotopically dated to test such a young age for some of the major tectonic events.

COVER

During parts of the Pleistocene the McLeod Lake map area was covered by the Cordilleran ice sheet, locally greater than 6000 ft (1829 m) above sea level (Tipper, 1971). In particular, three ice lobes converged over the map area; one coming out of the Cariboo Mountains, another from the Coast Ranges, and a third from the northern Interior Plateau (Tipper, 1971). We made a reconnaissance of the geomorphic features and unconsolidated deposits left by the ice sheets to test if more detailed work was justified during this project. We examined the Pleistocene lake deposits concentrated in the south (described by Tipper, 1971; and to the south of the map area by Clague, 1987; and Berger et al., 1987), and in the Parsnip, Anzac, Table, and Hominka River valleys in the northeast. Parts of the drumlin, esker and outwash fields to the west were also examined. In addition, recent lake bottom sediments were cored to find possible earthquake induced disturbances, of which none were identified, and to measure Holocene magnetic secular variations recorded in these sediments (see Fuller, 1988).

In the northwest, glacial lake sediments were mapped (Fig. 2) in the valleys of the Anzac, Table, and Hominka rivers. They probably were deposited in lakes that formed when valley glaciers of the Rocky Mountains melted before the last advance of Cordilleran ice, which occupied the Parsnip River valley and dammed the tributaries flowing from the east. From the northeast, meltwater channels cut bedrock at successively lower elevations toward the Parsnip River, and record the extent of the ice and its history of downwastage. Ice stagnation at the end of glaciation left hummocky sand and gravel deposits in Tacheeda Lakes valley and an ice contact feature at the head of outwash deposited in the Parsnip valley.

We found several localities of mineralized clasts (galena, molybdenite, pyrite) in the drumlin and esker fields in the central and western parts of the map area. The profusion of new forest access roads has made searching the drift a feasible method of prospecting.

BEDROCK

The project was started with a reconnaissance of the bedrock throughout most of the map area (except the southwest) and late in the season mapping was concentrated on known exposures of the Wolverine Metamorphic Complex. From the scattered observations, little can be added to the stratigraphic understanding of the map sheet, however some preliminary statements can be made on the tectonics.

Strike-slip faults

Rocks bordering the Parsnip River are generally sheared along steeply dipping surfaces that contain boudins and rootless isoclinal folds. The structures formed by flattening and subhorizontally stretching that is indicative of strike-slip faults. Similar stretching fabric occupies narrow zones through the ridge system between the Crooked and Parsnip rivers and locally near Patches Mountain.

Extension faults?

Gently and moderately dipping shear zones were found in several places between the Takla Group and underlying Wolverine Complex. Along the east side of Carp Lake the Takla Group augite porphyry basalt is strongly foliated and lineated; the foliation parallels the contact with the Wolverine Complex (represented there mainly by pegmatitic granite). In places near the contact, siliceous mylonite of unknown protolith is interlayered with amphibolite. The ductile shearing that produced the mylonite was probably formed at mid-crustal levels as were several younger episodes of deformation. Pegmatitic granite veinlets intrude the mylonite and are foliated parallel to the mylonitic fabric, and the mylonitic layering is tightly and recumbently folded. Of those seen, structural indicators of the relative shear sense were ambiguous, possibly due to the later tight folds. The superposition of the low-grade Takla Group basalt on the pegmatitic granite and minor paragneiss of the Wolverine Complex may indicate that the intervening mylonite zone marks a low angle extension fault.

REFERENCES

Armstrong, R.L.
1982: Cordilleran metamorphic core complexes-from Arizona to southern Canada; Annual Review of Earth and Planetary Sciences, 10, p. 129-154.

Berger, G.W., Clague, J.J., and Huntley, D.J.
1987: Thermoluminescence dating applied to glaciolacustrine sediments from central British Columbia; Canadian Journal of Earth Sciences, v. 24, p. 425-434.

Clague, J.J.
1987: Quaternary stratigraphy and history, Williams Lake, British Columbia; Canadian Journal of Earth Sciences, 24, p. 147-158.

Coney, P.J.
1980: Cordilleran metamorphic core complexes-an overview; *in* Cordilleran metamorphic core complexes, Crittenden, M.D., et al. (eds.), Geological Society of America, Memoir 153, p. 4-34.

Eisbacher, G.H.
1985: Pericollisional strike-slip faults and synorogenic basins, Canadian Cordillera; *in* Strike-slip Deformation, Basin Formation, and Sedimentation, Biddle, K.T. and Christie-Blick, N. (eds.), Society of Economic Paleontologists and Mineralogists, Special Publication No. 37, p. 265-282.

E.A. Fuller
1988: Paleomagnetism of lake sediment cores from McLeod Lake and McBride map areas, central British Columbia; *in* Current Research Part E, Geological Survey of Canada, Paper 88-1E.

Gabrielse, H.
1985: Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia; Geological Society of America Bulletin, 96, p. 1-14.

Mansy, J-L.
1986: Géologie de la chaine d'Omineca des Rocheuses aux Plateaux Intérieurs (Cordillère Canadienne), son évolution depuis le précambrien; Société Géologigue du Nord, Publication No. 13, p. 718 p.

Muller, J.E., and Tipper, H.W.
1969: Geology of the McLeod Lake map area, British Columbia; Geological Survey of Canada, Map 1204A.

Parrish, R.
1986: Timing and mechanics of Eocene extension and implications for Eocene and pre-extensional geology of southern Omineca Belt, British Columbia; *in* Programme with Abstracts, Joint Meeting of the Geological Association of Canada, Mineralogical Association of Canada and the Canadian Geophysical Union, Ottawa '86; v. 11, p. 112.

Price, R.A. and Carmichael, D.M.
1986: Geometric test for late Cretaceous-Paleogene intracontinental transform faulting in the Canadian Cordillera; Geology, v. 14, p. 468-471.

Struik, L.C.
1985a: Dextral strike-slip through Wells Gray Provincial Park, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 305-309.
1985b: Pre-Cretaceous terranes and their thrust and strike-slip contacts, Prince George east half and McBride west half, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 267-272.

Tempelman-Kluit, D., and Parkinson, D.
1986: Extension across the Eocene Okanagan crustal shear in southern British Columbia; Geology, v. 14, p. 318-321.

Tipper, H.W.
1971: Glacial geomorphology and Pleistocene history of central British Columbia; Geological Survey of Canada, Bulletin 196, 89 p.

Wanless, R.K., Stevens, R.D., Lachance, G.R., and Delabio, R.N.
1970: Age determinations and geological studies K-Ar isotopic ages, report 9; Geological Survey of Canada, Paper 69-2A, 78 p.

Wilkins, J. Jr., Beane, R.E., and Heidrick, T.L.
1986: Mineralization related to detachment faults: A model; *in* Frontiers in Geology and Ore Deposits of Arizona and the southwest, Beatty, B. and Wilkinson, P.A.K. (eds.), Arizona Geological Society Digest, v. 16, p. 108-117.

Jurassic and Triassic volcanic and sedimentary rocks in Spatsizi map area, north-central British Columbia

Derek J. Thorkelson[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Thorkelson, D.J., Jurassic and Triassic volcanic and sedimentary rocks in Spatsizi map area, north-central British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 43-48, 1988.

Abstract

On Stikinia, Lower to Middle Jurassic volcanic and associated sedimentary rocks of the Hazelton Group unconformably overlie volcano-sedimentary rocks of the Upper Triassic Stuhini and Takla groups. In Spatsizi map area, where Hazelton rocks have been informally named the Cold Fish volcanics, Jurassic and Triassic units occupy a northwest-trending belt 85 km long and 10 km wide.

The Cold Fish volcanics, ranging from early Pliensbachian to early Toarcian in age, comprise subaerial to submarine felsic to mafic lava and tuff, and minor shale and limestone. Pliensbachian Cold Fish volcanics from near Nation Peak are arc-related, bimodal rhyolite and basalt-to-trachyte. Rhyolites are mostly tholeiitic whereas the basalt-trachyte suite is transitionally tholeiitic to alkaline.

Stuhini rocks comprise marine and nonmarine flows, and clastites including chert- and limestone-bearing olistostrome and conglomerate. These coarse deposits may yield information on aspects of tectonism during an interval near the Jurassic-Triassic boundary.

Résumé

Dans la région de Stikinia, les roches volcaniques et les roches sédimentaires associées du Jurassique inférieur à moyen sont appelées groupe de Hazelton. Elles sont séparées par une lacune des roches volcano-sédimentaires sous-jacentes du groupe de Stuhini-Takla du Trias supérieur. Dans le secteur de carte de Spatsizi, où les roches de Hazelton sont appelées roches volcaniques de Cold Fish, les unités jurassiques et triasiques occupent une zone d'orientation générale nord-ouest, de dimensions 85 × 10 km.

La succession de Cold Fish, qui se situe entre le Pliensabachien inférieur et le Toarcien inférieur, comprend des laves et tufs subaériens à sous-marins, et quelques schistes argileux et calcaires. Les roches de Cold Fish, du Pliensbachien, qui proviennent des environs de Nation Peak, sont des rhyolites bimodales et des roches basaltiques à trachytiques. Les rhyolites sont principalement tholéiitiques, tandis que la suite des basaltes aux trachytes représente une transition des roches tholéiitiques aux roches alcalines.

Les roches de Stuhini-Takla de la région de Spatsizi comprennent des coulées marines et non marines et des clastites, y compris des olistostromes et des conglomérats contenant des cherts et des calcaires. Ces dépôts grossiers peuvent nous renseigner sur des aspects tectoniques de la limite du Jurassique et du Trias.

[1] Ottawa-Carleton Geoscience Centre, Department of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6

INTRODUCTION

Fieldwork on the Cold Fish volcanic rocks, an informal division of the Jurassic Hazelton Group in Spatsizi (104H) map area, began in 1986. In 1987, investigations continued and expanded to include some nearby Upper Triassic volcanic and sedimentary rocks of the Stuhini Group. These units in the study area (Fig. 1) occur in a northwesterly-trending belt approximately 85 km long and 10 km wide extending from near the confluence of the Stikine and Klappan rivers to 15 km east of Spatsizi River. Because analysis of data began only after the 1987 field season, results are preliminary.

Acknowledgments

The writer is grateful to S. Hedberg, R.B. McFarlane, J. Pardoe and M.D. McPherson for capable and devoted assistance, and C.A. Evenchick and H. Gabrielse for logistical support and intellectual stimulation. Geochemical analyses, provided by the Geological Survey of Canada, were performed by wavelength dispersive X-ray fluorescence on fused disks. Analyses were recalculated to 100 % on a volatile-free basis.

REGIONAL SETTING

Upper Triassic and Lower to Middle Jurassic volcanic and volcano-sedimentary rocks occupy much of Stikinia, the largest accreted terrane in the Canadian Cordillera. In northern British Columbia, Upper Triassic rocks of Stikinia are known as the Stuhini Group; to the south they are called the Takla Group (see Souther, 1977, for distribution). Both groups, which appear to constitute a single volcanic belt, are typified by mafic, alkaline to subalkaline augite porphyry and bladed plagioclase porphyry, and associated breccia, sandstone, limestone and shale (Monger and Church, 1977; Tipper and Richards, 1976; Anderson, 1980). They rest on Late Paleozoic volcanic and sedimentary rocks, notably the Permian Asitka Group. Although generally of Carnian and Norian ages, some sequences, specifically the Moosevale Formation in McConnell map area (94D) southeast of the study area, contain strata of earliest Jurassic age. Submarine facies dominate the Stuhini and Takla groups and subaerial sequences are apparently restricted to local volcanoes that rose above sea level. On the Quesnel Terrane to the southeast, Nicola Group volcanic rocks have similar petrology and volcanic facies and may share elements of a common history with the Upper Triassic succession of Stikinia.

Jurassic volcanic and associated sedimentary rocks are known throughout Stikinia as the Hazelton Group. They commonly rest unconformably on Stuhini and Takla group rocks and are separated from them by a polymictic conglomerate suggestive of an intervening period of uplift and erosion (Tipper and Richards, 1976; Monger and Church, 1977; Mihalynuk and Ghent, 1986). Near Terrace, the conglomerate comprises clasts of Permian limestone in an iron-oxide-stained volcanic matrix (Mihalynuk and Ghent, 1986). Monger and Church (1977) reported a similar unit in McConnell Creek map area containing volcanic detritus from the Takla Group and limestone and chert from the Asitka Group.

Tipper and Richards (1976) restructured the poorly-defined Hazelton Group, identifying three constituent formations and several members and facies. Their work, based on extensive mapping and sampling in the McConnell Creek, Hazelton (93M) and Smithers (93L) map areas, divided the group into the lower Sinemurian to early Pliensbachian Telk-

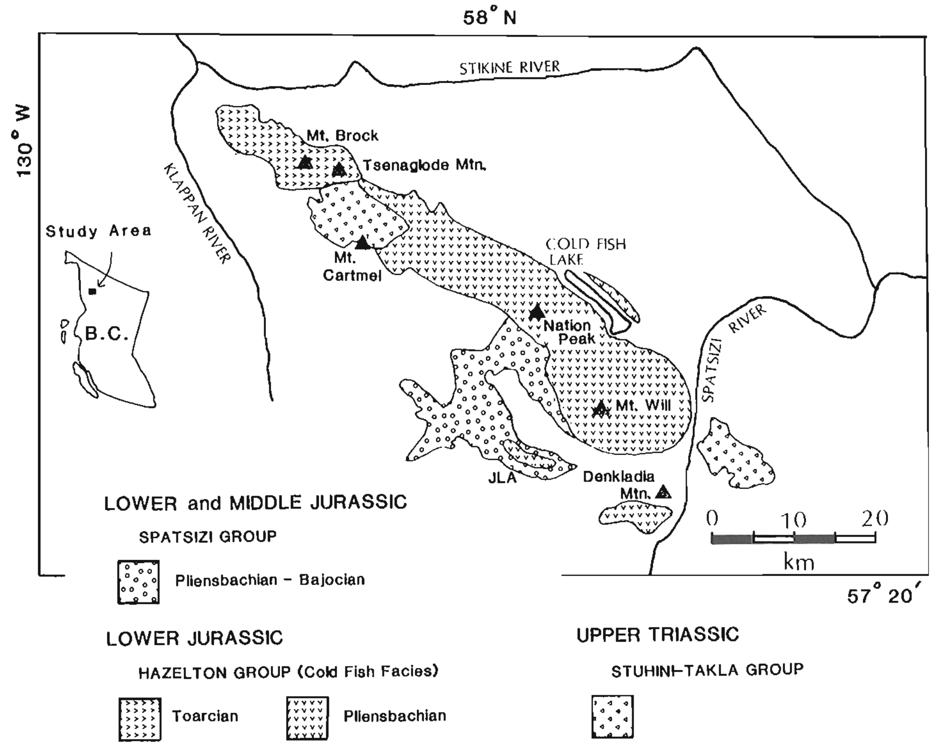


Figure 1. Distribution of Lower Jurassic and Upper Triassic volcanic and sedimentary rocks in Spatsizi (104H) map area, southeast of the confluence of Klappan and Stikine rivers. JAL = Joan Lake Anticline.

wa, the early Pliensbachian to middle Toarcian Nilkitkwa and the middle Toarcian to lower Callovian Smithers formations. They included the chert- and carbonate-bearing heterolithic conglomerate in the Sikanni (basal) facies of the Telkwa. Other facies of that formation are dominated by proximal, submarine and subaerial volcanic rocks, largely calc-alkaline basalt and rhyolite. In contrast, the younger Nilkitkwa Formation comprises mainly volcaniclastic units suggestive of more distal facies. Exceptions are the Pliensbachian and Toarcian submarine to subaerial basalts of the Ankwell and Carruthers members. The trend of younger Hazelton rocks having higher epiclastic/lava ratios is further demonstrated by the Smithers Formation which consists mainly of sandstone and shale with lesser amounts of conglomerate, limestone and tuff. The Smithers is overlain, generally disconformably, by the Ashman Formation of the Bowser Lake Group.

In Toodoggone (94E) map area, north of the region considered by Tipper and Richards (1976), volcanic rocks of similar age to the Hazelton Group were informally named Toodoggone volcanics by Carter (1972). More recently, Panteleyev (1984), on the basis of isotopic dates ranging from 179 to 204 Ma, correlated those rocks with the Telkwa Formation. He described the Toodoggone volcanics, which lies east of the study area, as a ''subaerial, intermediate, calc-alkaline to alkaline, predominantly pyroclastic assemblage'' and thereby established an additional facies of the Telkwa.

In Spatsizi map area, Gabrielse and Tipper (1984) informally used the Toodoggone name for Lower and Middle Jurassic volcanic rocks. However, because the Cretaceous Sustut Basin separates the volcanic strata in the study area from those in the Toodoggone, correlations are uncertain. Thomson et al. (1986) used the informal term Cold Fish volcanics for Jurassic eruptives in the Spatsizi region and that terminology will be followed in this report.

COLD FISH VOLCANIC AND RELATED SEDIMENTARY ROCKS

Facies and lithologies

The Cold Fish volcanics are a subaerial to shallow marine succession of mafic and felsic lavas, and air-fall and ash-flow tuffs. The subaerial facies, which predominates, is nearly devoid of epiclastic rocks except for lahar. Conversely, the subaqueous volcanics are intercalated with limestone conglomerate, breccia, siltstone and shale (Fig. 2). Although the division between terrestrial and marine is commonly nebulous, fossiliferous limestone locally is stratigraphically continuous with clearly subaerial flows and tuffs. For example, 3.5 km northeast of Nation Peak (Fig. 1), limestone containing abundant pelecypods lies within lavas of uncertain depositional environment overlying welded ignimbrite and highly oxidized (reddened) basic flows. This close stratigraphic and spatial relationship is further indicated by admixtures of limestone and mafic lava observed 9 km northwest, and 5 km east-northeast of Nation Peak.

Figure 2. Massive Cold Fish basalt overlying limestone and shale interbeds, 5 km east-northeast of Nation Peak.

Another facies distinction can be made between sequences comprising abundant mafic lava flows interlayered with rhyolites and clastic rocks, and those in which mafic extrusives are virtually absent. In the latter, thick (20-100 m) flow-banded rhyolite flows and highly welded ignimbrite sheets are predominant and suggestive of an intracaldera setting. Although structural evidence for the morphology is scarce, rhyolitic dykes coincident with block faults were observed 8 km east-southeast and 5 km east-northeast of Nation Peak. Rhyolite-ignimbrite facies are concentrated toward the southeastern end of the study area, from near Mount Will to Spatsizi River. Excellent exposures over 600 m thick are present above Will Creek, 5 km southeast of Mount Will.

Contrasting sequences with higher proportions of basic lava are found in the Joan Lake Anticline and throughout the Jurassic belt northeast of Mount Will. Mafic flows are aphyric to porphyritic, with plagioclase, and in basaltic flows, serpentine-after-olivine pseudomorphs, dominating the phenocryst populations. Bladed plagioclase porphyry, hosting abundant tabular plagioclase phenocrysts 6-12 mm long, is common in the Pliensbachian succession. Pyroxene grains, although common, are nearly everywhere small (<2 mm) and low in relative abundance. Most basic flows are partly amygdaloidal (especially at their tops) and partly dense. Vesicles are variably filled with chlorite, calcite, celadonite, zeolites, quartz and, less commonly epidote, generally suggestive of zeolite grade metamorphism. Subaerial flows, usually 5-15 m thick, exhibit reddened margins and varicoloured autoclastic breccia. They are interbedded with rhyolite, tuffaceous rocks, and less commonly, lahar. Air-fall tuff, identified by good internal stratification, is generally red or green. Welded ignimbrite, somewhat less common, is usually light-grey weathering, poorly sorted and non-stratified. Rhyolite has planar to highly contorted flow-banding, in many places autobrecciated and, in places, weathers rusty due to oxidation of pyrite. Marine extrusions, typically green, are generally brecciated, palagonitized, and interbedded with sedimentary rocks. Well-exposed marine sections are present 9 km northwest and 5 km northeast of Nation Peak. The various elements of this composite, marine to nonmarine facies suggest that the rocks were deposited on the flanks of a gently to moderately sloping, oceanic or coastal volcanic edifice.

Intruding the Cold Fish volcanics, in addition to rhyolite dykes, are mafic dykes, rhyolitic sills and, in at least two places (9 km east of Mount Will and 9 km west of Mount Brock), felsic granitoid plutons. A general lithologic similarity to Cold Fish volcanics and an absence of younger volcanic strata in the region (except for distinctive Tertiary flows of the Stikine Belt) suggest that the fine-grained intrusions are comagmatic with the eruptive rocks. Furthermore, extrusive and intrusive aphanites occupy the same chemical fields (Figs. 3 to 5). Leucocratic granitic rocks east of Mount Will are crosscut by green dykes of intermediate composition, suggesting that they were emplaced prior to cessation of Cold Fish volcanism.

Thomson et al. (1986) examined sedimentary rocks within and adjacent to the Cold Fish volcanics. Based largely on ammonite biostratigraphy and to a lesser extent on lithology, they defined the Spatsizi Group and five constituent formations. Comprising mostly shale, siltstone and waterlain tuff, the group was depicted as a partly coeval, basinward equivalent to the Cold Fish volcanics ranging in age from early Pliensbachian to early Bajocian. Its relationship to the Cold Fish is therefore similar to that between the shaly and volcanic facies of the Nilkitkwa Formation (Tipper and Richards, 1976). Additionally, the tuffaceous and fine-grained clastic character of the Spatsizi generally fits lithologic descriptions given by Tipper and Richards for the Smithers Formation. Another similarity with the Smithers is the nearly conformable relationship with the overlying Ashman Formation of the Bowser Lake Group.

Age determinations of the Cold Fish volcanics, inferred from stratigraphic relations with Spatsizi rocks and related fossiliferous strata within the volcanics, were given by Thomson et al. (1981). They divided the Cold Fish volcanics in the study area into a Toarcian sequence on the northwestern end, a larger Pliensbachian sequence extending from the Toarcian part southeastward to Spatsizi River, and a Bajocian section east of the river. Tentatively, the Bajocian part is now considered to be part of the Stuhini-Takla assemblage for reasons which are given later. Because no striking lithologic differences between the Toarcian and Pliensbachian were observed, the Cold Fish volcanics appears to be without strong time-dependent variations.

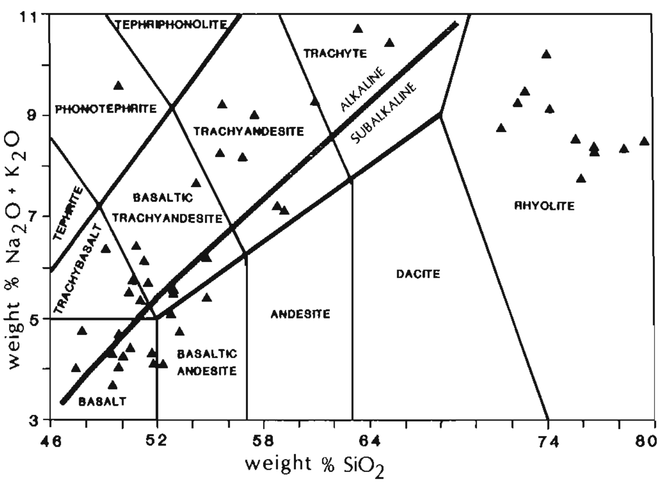


Figure 3. Total alkalies vs. silica classification diagram (Zanettin, 1984). Alkaline/subalkaline curve from Irvine and Baragar (1971). Symbols represent Cold Fish rocks from Nation Peak area.

Chemistry and petrography

Preliminary geochemical analysis of the Pliensbachian volcanics from the Nation Peak and Joan Lake Anticline regions defines a bimodal mafic-felsic suite. From a collection of forty-six lavas, dykes and sills only five have silica contents between 58 % and 71 %. According to the IUGS total alkalies vs. silica classification diagram (Zanettin, 1984; Fig. 3), eleven specimens are rhyolite and the remaining thirty-five define a basalt to trachyte trend. Twenty-two of the latter have silica values less than 54 %. The transitionally alkaline nature of the basalt to trachyte suite is shown by the discriminant curve of Irvine and Baragar (1971). Because K_2O and Na_2O ratios vary greatly, consistent subdivision into sodic and potassic domains is not possible. Rhyolites, on the other hand, cluster well inside the subalkaline field. Their apparent lack of association with the more basic rocks suggests that they may have, at least in part, a separate petrogenetic history.

On a tholeiitic/calc-alkaline discriminant diagram (Fig. 4; modified from Miyashiro, 1974) the samples near-

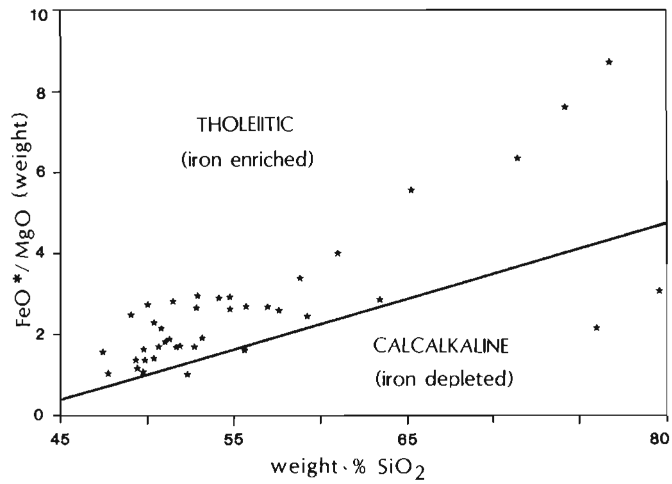


Figure 4. Tholeiitic/calc-alkaline discriminant diagram (Miyashiro, 1974). FeO* = total Fe as FeO (weight). Symbols represent Cold Fish rocks from Nation Peak area.

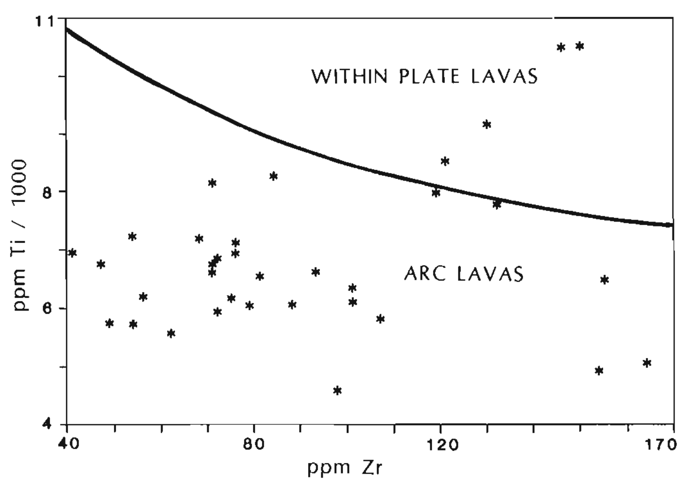


Figure 5. Ti vs. Zr diagram showing intraplate and arc fields (modified from Pearce et al., 1981). Symbols represent Cold Fish basalt-trachyte rocks from Nation Peak area.

ly all fall in the field of relative Fe enrichment. Six rhyolites having extreme enrichment are not shown. However, because the basalt-trachyte suite is marginally alkaline, it cannot be properly classified as tholeiitic and is best described as transitionally tholeiitic to alkaline. The rhyolites can be broadly classified as tholeiitic although two specimens plot on the field of Fe depletion.

The basalt-trachyte suite was further categorized on a Ti vs. Zr diagram (modified from Pearce et al., 1981; Fig. 5). Most samples plot in the arc lavas field suggesting a subduction-related origin.

The basalt-trachyte suite is characterized by a fractionating assemblage of olivine, plagioclase and clinopyroxene. Olivine is consistently pseudomorphed by serpentine (or other mafic phyllosilicates) and opaque oxides (Fig. 7). Plagioclase phenocrysts, variably saussuritized, are present as scattered grains and, less commonly, glomerocrysts. Clinopyroxene, the most stable silicate phase, is locally contact-twinned on (100). Magnetite is present as a phenocryst in some samples.

UPPER TRIASSIC ROCKS

Triassic rocks near Mount Cartmel were mapped by Gabrielse and Tipper (1984) and previous workers (Fig. 1). They comprise a sequence of mafic flows, intermediate to felsic breccia, conglomerate, siltstone, sandstone, and locally, sedimentary melange. The flows are predominantly aphyric although augite porphyry, plagioclase porphyry and hornblende-plagioclase porphyry are present. In the submarine facies, which is dominant, lavas are greenish-grey and intercalated with marine sedimentary rocks. Typically, the latter are finely laminated siliceous siltstones showing ball and pillow load structures. In some places, notably 6 km north of Mount Cartmel, the siltstones host heterolithic pebbles, cobbles and boulders. There, clasts of aphyric and augite porphyry, micritic limestone and granitoids are set in a highly deformed siltstone matrix. Six kilometres north-northeast of Mount Cartmel the deposits are entirely clastic, and rhythmically bedded siltstone coarsens upward and is overlain by an olistostrome hosting carbonate cobbles and boulders, and chert granules. One limestone block exceeds 5 m in diameter. Overlying the melange is a sequence of sandstone, conglomerate and breccia.

East of Spatsizi River a section of felsic and mafic flows, airfall and ashflow tuff and various sedimentary rocks structurally overlie Toarcian strata of the Spatsizi Group. Thomson et al. (1986) interpreted that contact to be stratigraphic and considered the volcanic sequence to be of Bajocian age. Evenchick (1986) re- interpreted the contact as a thrust fault and correlated the volcanics with Pliensbachian eruptive rocks west of Spatsizi River.

The volcano-sedimentary package east of the river is herein tentatively correlated with the Stuhini and Takla groups based on striking lithologic similarities to the Upper Triassic rocks near Mount Cartmel. The most conspicuous unit east of the river is a polymictic conglomerate containing clasts of chert, limestone, and volcanic rocks in a sandy, purple matrix. The chert clasts, granule to cobble size, are red, green, light blue, white and black, and variably rounded but commonly angular. Limestone clasts, mostly pebbles to boulders, include crinoidal and micritic varieties, and are generally more dispersed than the chert fragments. On weathered surfaces they form recessive pockets among more resistant lithoclasts. Volcanic clasts include large (1 cm) augite basalt and hornblende-plagioclase porphyries. The chert-rich matrix also forms sandstone lenses and massive to cross-stratified beds within and below the conglomerate. Locally abundant cobbles of granitic rocks are present (C.A. Evenchick and H. Gabrielse, pers. comm., 1986).

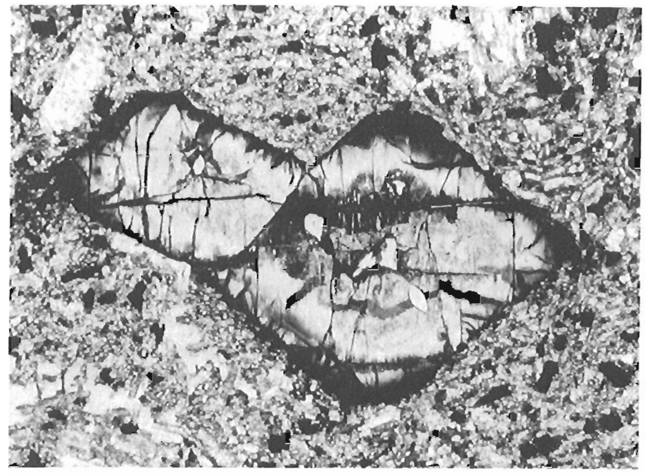


Figure 6. Serpentine-after-olivine pseudomorphs in Cold Fish basalt. Plane light; magnification = 32x.

Figure 7. Chert and limestone conglomerate in (?) Upper Triassic rocks 5 km east of Spatsizi River.

Underlying the conglomeratic unit, at one locality, are interbedded breccias, sandstones and shales of probable marine origin. Above the conglomerate, are mafic, subaerial augite porphyry and aphyric flows which are overlain by rhyolite and welded ignimbrite. Aphyric and augite (4-12 mm) porphyry dykes crosscut all the units. The succession is interpreted as a nearshore marine flysch and breccia deposit conformably overlain by fluvial chert- and limestone-bearing sandstone and conglomerate, capped by mafic and felsic extrusives, and felsic explosive products of proximal subaerial volcanism. Mafic dykes attest to the probable eruption of additional basaltic lava higher in the section. The coincidence of cross-stratified red-beds and the influx of chert and limestone fragments suggests that regional uplift produced concomitant marine regression and exposure of older units which served as source material for high-energy fluvial deposits. The section hosting the melange unit, north of Mount Cartmel, shows a similar history. There, the appearance of fragmental chert and limestone also marks the end to quiescent basinal conditions and an abrupt transition to deposition of coarser material.

Basalt with large augite phenocrysts has not been identified in the Hazelton Group, including the nearby Cold Fish volcanics, but are present in Stuhini Group near Mount Cartmel and Tsaybahe Mountain, 15 km east of the confluence of the Klappan and Stikine rivers. The presence of augite porphyry clasts within the conglomerate, plus augite porphyry dykes and identical flows which intrude and overlie the conglomerate, indicate that Stuhini-type volcanism pre- and post-dated the change in environmental conditions. It is also reasonable, however, to correlate the conglomeratic unit with the polymictic conglomerate in the Sikanni facies of the Lower Jurassic Telkwa Formation. It seems possible, therefore, that either the Sikanni facies is Triassic or that Stuhini-Takla volcanism locally persisted into the Jurassic. Alternatively, the Sikanni facies could be time transgressive, with more northerly deposits recording earlier periods of uplift.

SUMMARY

Upper Triassic and Lower to Middle Jurassic volcanic rocks on Stikinia are known as the Stuhini (or Takla) and Hazelton groups respectively. They are products of two periods of arc volcanism and related basinal deposition separated by a latest Triassic to earliest Jurassic uplift. Within each group, chemical variations probably reflect physical and temporal variations in tectonic settings.

In the study area, the Pliensbachian to Toarcian Cold Fish (informal) division of the Hazelton Group comprises a zeolite-grade, bimodal, basalt-to-trachyte and rhyolite suite. Subaerial facies, typified by welded pyroclastic flows and reddened lavas, are predominant. Marine tuff and flows, interbedded with limestone and shale, are present locally. Rhyolitic facies are concentrated in the region between Mount Will and Spatsizi River. Geochemistry of flows, dykes and sills indicates that the basalt-trachyte component is transitionally tholeiitic to alkaline whereas the rhyolites, clearly subalkaline, are tholeiitic. Basic units show strong arc affinity. Fractionation was apparently dominated by olivine, plagioclase and clinopyroxene.

Upper Triassic rocks near Mount Cartmel comprise submarine and subaerial volcanic and sedimentary rocks including porphyry flows with large augite phenocrysts and chert- and limestone-bearing olistostromes. Rocks east of Spatsizi River contain clastic chert and limestone deposits similar to those in both the Cartmel rocks and the basal, Sikanni facies of the Hazelton Group. Their ambiguous stratigraphic affinity is compounded by the presence of felsic flows and tuff, typical of the Hazelton, and porphyry with large augite phenocrysts suggestive of the Stuhini and Takla groups. Spatial and temporal aspects of inferred post-Stuhini, pre-Hazelton tectonism may be clarified by determination of deposit age and clast provenance.

REFERENCES

Anderson, R.G.
1980: Satellitic stocks, volcanic and sedimentary stratigraphy, and structure around the northern and western margins of the Hotailuh Batholith, north-central British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 37-40.

Carter, N.C.
1972: Toodoggone river area; in Geological Exploration and Mining in British Columbia, 1971, British Columbia Department of Mines and Petroleum Resources, p. 51-55.

Evenchick, C.A.
1986: Structural style of the northeast margin of the Bowser Basin, Spatsizi map area, north-central British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 733- 739.

Gabrielse, H. and Tipper, H.W.
1984: Bedrock geology of Spatsizi map area (104H); Geological Survey of Canada, Open File 1005.

Irvine, T.N. and Baragar, W.R.A.
1971: A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Mihalynuk, M.G. and Ghent, E.D.
1986: Stratigraphy, deformation and low grade metamorphism of the Telkwa Formation near Terrace, British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 721-726.

Miyashiro, A.
1974: Volcanic rock series in island arcs and active continental margins; American Journal of Science, v. 274, p. 321-355.

Monger, J.W.H. and Church, B.N.
1977: Revised stratigraphy of the Takla Group, north-central British Columbia; Canadian Journal of Earth Sciences, v. 14, p. 318-326.

Panteleyev, A.
1984: Stratigraphic position of Toodoggone Volcanics (94 E/2, 3, 6, 11, 12, 13); in Geological Fieldwork, British Columbia Ministry of Energy, Mines and Petroleum Resources, 1983, Paper 1984-1, p. 136-138.

Pearce, J.A., Alabaster, T., Shelton, A.W., and Searle, M.P.
1981: The Oman ophiolite as a Cretaceous arc-basin complex: evidence and implications; Philosophical Transactions of the Royal Society of London, A, v. 300, p. 299-317.

Souther, J.G.
1977: Volcanism and tectonic environments in the Canadian Cordillera — a second look; *in* Volcanic Regimes in Canada, Geological Association of Canada, Special Paper 16, p 3-24.

Thomson, R.C., Smith, P.L., and Tipper, H.W.
1986: Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia; Canadian Journal of Earth Sciences, v. 23, p. 1963-1973.

Tipper, H.W. and Richards, T.A.
1976: Jurassic stratigraphy and history of north-central British Columbia; Geological Survey of Canada, Bulletin 270, 73 p.

Zanettin, B.
1984: Proposed new chemical classification of volcanic rocks; Episodes, v. 7, no. 4, p. 19-20.

Preliminary study of the Work Channel lineament in the Ecstall River area, Coast Plutonic Complex, British Columbia

S.A. Gareau[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Gareau, S.A., Preliminary study of the Work Channel lineament in the Ecstall River area, Coast Plutonic Complex, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 49-55, 1988.

Abstract

The region can be separated into two parts based on lithological, metamorphic and structural differences. Eastern rocks are dominantly metasedimentary and contain sillimanite, whereas the western are mainly igneous rocks metamorphosed to kyanite grade. In both belts, foliation strikes northwest to north and dips steeply east; lineations plunge steeply northwest to north. Lineated rocks and tight folds are present predominantly in the eastern belt.

These two belts may correlate with similar belts north of the Skeena River. The steep foliation and lineation in the study area are analogous to structures found along the Work Channel lineament farther north where the lineament separates the western and central belts of the Coast Plutonic Complex and is interpreted as a wide and steep ductile shear zone.

Résumé

La région peut se répartir en deux zones qui diffèrent du point de vue lithologique, métamorphique et structural. À l'est, les roches sont pour la plupart d'origine métasédimentaire et contiennent de la sillimanite, tandis que la zone de l'ouest est composée de roches ignées dont le degré de métamorphisme correspond maintenant à celui du disthène. Une foliation orientée entre le nord-ouest et le nord et à fort pendage vers l'est, ainsi qu'une linéation fortement inclinée vers le nord-ouest ou le nord, se retrouvent dans les deux zones. La plus grande densité de linéations et de plis étroits se trouve dans la zone de l'est.

Une corrélation peut être faite entre ces deux zones et des zones semblables situées au nord de la rivière Skeena. Les foliations et linéations de la région d'étude rappellent les structures observées le long du linéament de Work Channel situé plus au nord. À cet endroit, le linéament sépare les zones de l'ouest et du centre du complexe plutonique côtier et on considère qu'il doit s'agir d'une large zone de cisaillement ductile.

[1] Ottawa-Carleton Geoscience Centre Department of Earth Sciences, Carleton University Ottawa, Ontario, K1S 5B6

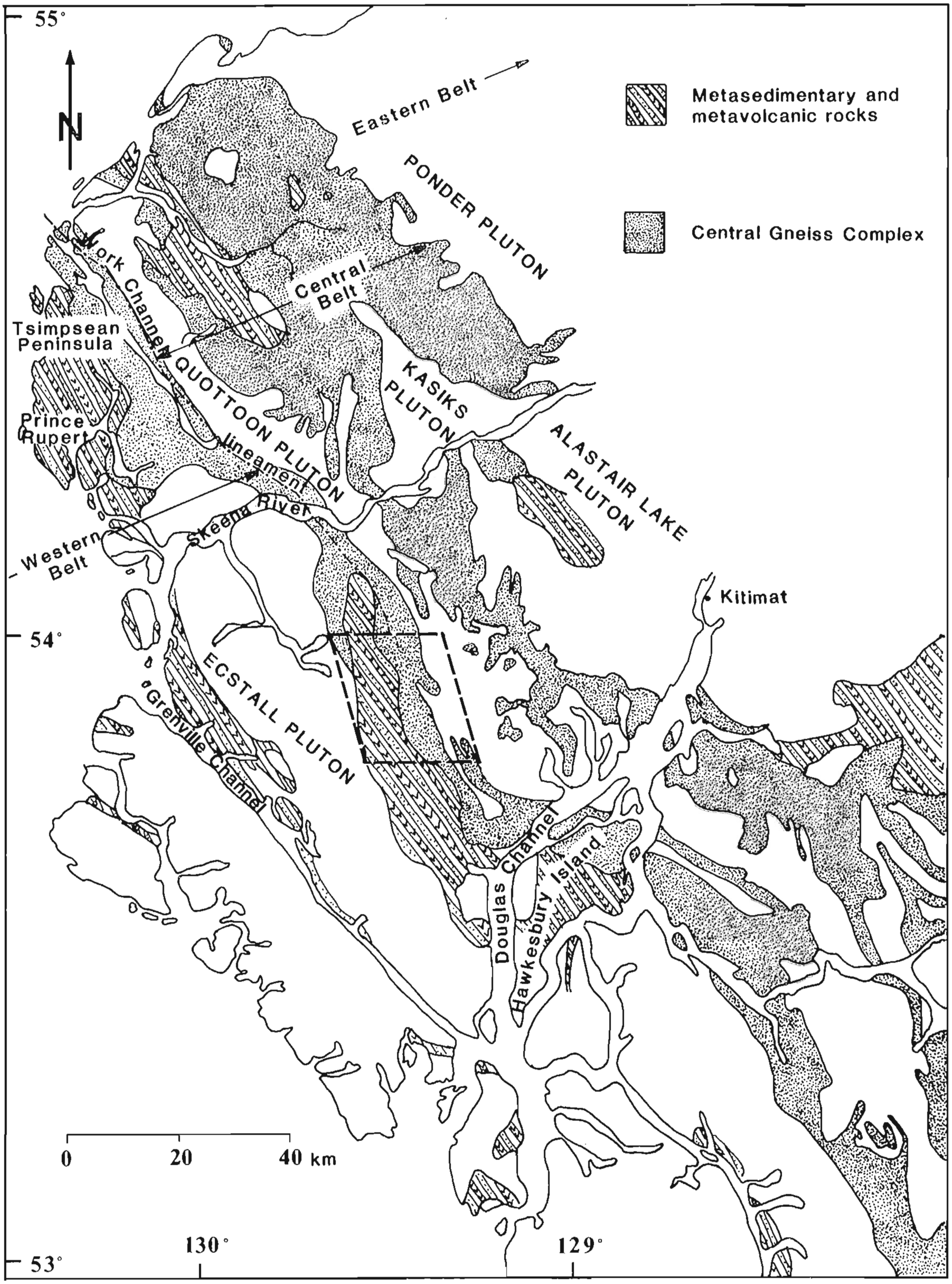


Figure 1. Generalized geological map of part of the Coast Plutonic Complex between latitudes 53 and 55°N. After Hutchison (1982) and Roddick (1970).

INTRODUCTION

The Coast Plutonic Complex at the latitude of Prince Rupert, British Columbia has been divided into three distinct, northwest-trending belts (Fig. 1) that have different histories and are separated by extensive tectonic boundaries (Crawford et al., 1987). The western belt consists mainly of low to high grade, medium to high pressure schist and gneiss. The low-grade rocks on the west side of this belt are correlative with rocks of the Alexander terrane of southeast Alaska to the north (Woodsworth and Orchard, 1985). High grade gneiss and plutonic bodies of the Central Gneiss Complex comprise the central belt. Fossils found in the eastern part of the central belt (Hill, 1985) may correlate with Upper Paleozoic fauna from the Stikine terrane on the east side of the Coast Plutonic Complex. The eastern belt is composed of low-grade to unmetamorphosed Lower Permian to Upper Cretaceous sedimentary and volcanic rocks of the Stikine terrane.

The Work Channel lineament, an extension of the Coast Range Megalineament in Alaska (Brew and Ford, 1978), separates the western and central belts. The lineament is the western limit of post-90 Ma plutonism and Early Eocene mineral cooling dates. It separates high pressure, kyanite-grade rocks on the west from high temperature, moderate pressure sillimanite-bearing rocks on the east (Crawford and Hollister, 1982) and thus is a boundary between regions of contrasting metamorphic styles (Crawford and Hollister, 1982). The lineament was interpreted by Crawford et al. (1987) as a large and steep ductile shear zone in which microstructures indicate upward movement of the eastern block 55 to 65 Ma ago.

Along and north of the Skeena River, rocks in the Work Channel lineament zone are poorly exposed. However, in the Ecstall River area in the Douglas Channel map area (103G) an almost complete cross-section of the zone is exposed (Figs. 1, 2). The purpose of this study is, firstly, to delineate and characterize the lineament in this area of excellent exposure and, secondly, to document the rock types, metamorphic grades, deformational styles and ages across the lineament.

The study is timely because of renewed interest in massive sulphide deposits (e.g. Ecstall, Packsack) in the area; work in the past has resulted in numerous unpublished company reports and two graduate theses (Pagdham, 1958 and Money, 1959).

Figure 2. Typical exposures above timberline in the Ecstall River area. The white synformal bands in the centre are folded and deformed pegmatitic dykes.

LOCAL GEOLOGY

The Ecstall River area consists of a north-trending belt about 10 km wide of metamorphic rocks bounded by the mid-Cretaceous (98 ± 4 Ma; Woodsworth et al., 1983) Ecstall pluton to the west and the Paleogene (58 to 60 Ma; Armstrong and Runkle, 1979) Quottoon tonalite to the east (Fig. 3).

LITHOLOGY

The area is composed of strongly deformed and metamorphosed sedimentary, volcanic and plutonic rocks (Fig. 3). Much of its western part is underlain by a distinctive foliated, felsic, quartz + feldspar ± biotite ± white mica ± garnet granitoid gneiss (Unit 1). Although some stretched inclusions of fine-grained amphibolite (Fig. 4) are present, the rock is generally homogeneous. Always well-foliated, varying degrees of deformation have produced textures ranging from augen gneiss to fine-grained gneiss with coarse white mica growing across the foliation. Concordant quartz veins (1 to 2 cm across) and foliated and folded amphibolite dykes are common in this unit. Epidote-rich pods are rare. The texture and mineralogy of the least deformed parts of this unit suggest that it is an orthogneiss.

Green schist and gneiss (Unit 2) outcrop mainly in two bands in the central part of the region. The predominant rock is a fine-grained chlorite-amphibole schist that is commonly interlayered with a more felsic biotite-quartz semi-schist. Locally this unit contains undeformed to elongated (5:1) siliceous clasts up to 15 cm in length; these rocks are interpreted as volcanic agglomerates. Calcite pods occur locally. Unit 2 may be the dominant lithology in the low country by the Ecstall River, where massive sulphide showings and quartz sericite schist are present. The mafic nature and relict volcanic textures suggest a mafic to intermediate volcanic protolith.

Well-layered metasedimentary rocks (Unit 3; Fig. 5) occur mostly on the eastern side of the area and consist of quartzite interlayered with felsic biotite + hornblende gneiss, fissile mica schist, or black phyllite to meta-argillite. Metapelitic layers are uncommon and largely restricted to the easternmost part of the area.

Discontinuous layers of coarse-crystalline calcite marble occur mainly in units 2 and 3. Foliated and folded amphibolite dykes are abundant in units 1 and 3.

Like Unit 3, Unit 4 also occurs mostly on the eastern side of the region and consists of fine-grained calc-silicate gneiss. The gneiss contains variable amounts of biotite and hornblende; garnet is locally present. Stretched epidote-rich pods and aligned amphiboles define a strong lineation. Outcrops of coarse-grained and nonlineated to weakly lineated hornblende diorite (Unit 5) occur in the central part of the area.

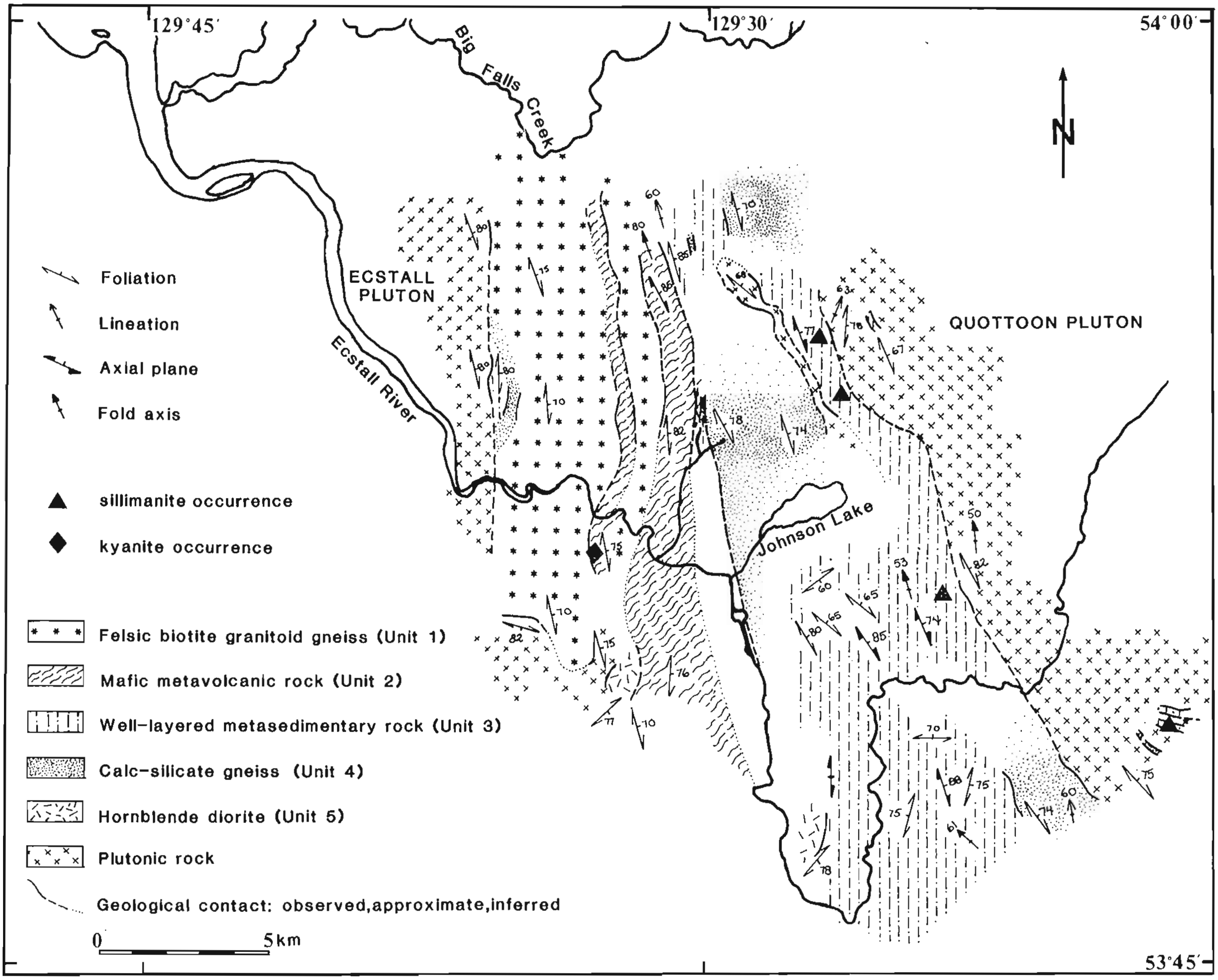


Figure 3. Geological map of the study area.

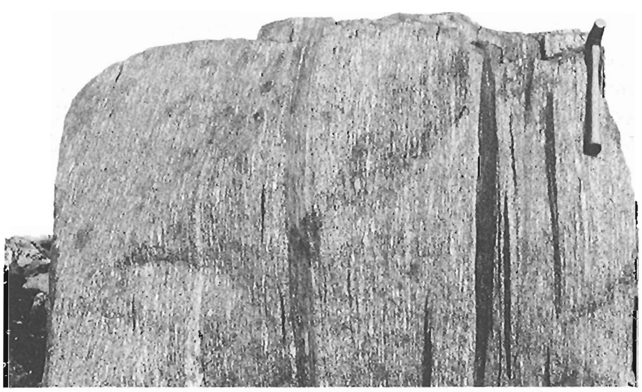


Figure 4. Well foliated felsic granitoid gneiss (Unit 1) containing stretched inclusions of fine-grained amphibolite. The steep dip of the foliation is typical of the area.

Figure 5. Well-layered metasedimentary rocks of Unit 3.

Figure 6. Concordant and deformed, and cross-cutting pegmatite dykes in folded biotite-hornblende gneiss.

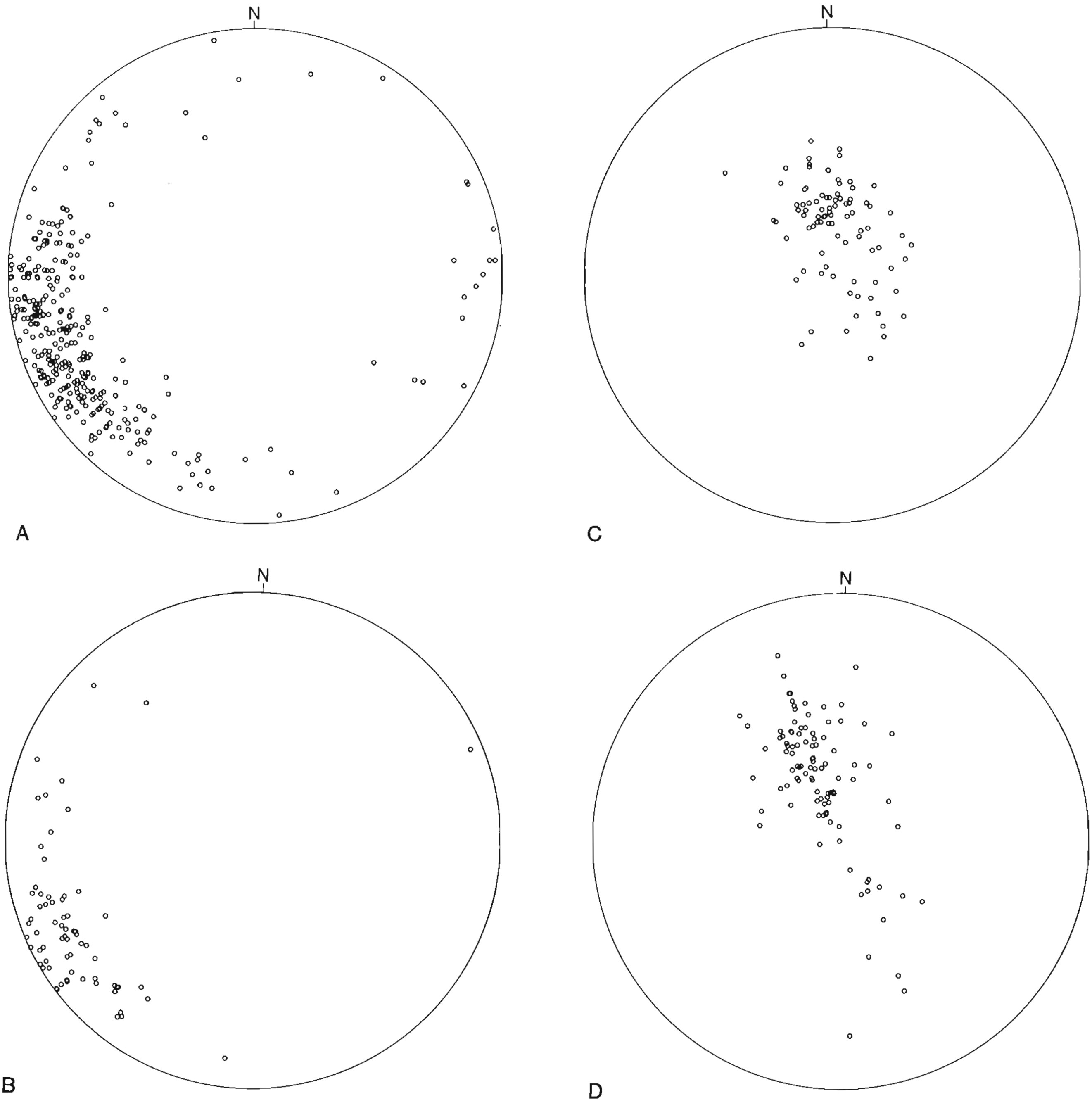


Figure 7. Plots of structural elements from the Ecstall River region. A) poles to 351 foliations; B) poles to 70 axial planes; C) 87 lineations; and D) 101 fold axes.

The Ecstall pluton, which intrudes the metamorphic rocks on the western side of the area, is a medium-grained epidote-hornblende-biotite quartz diorite. Within 1 km of its sharp contact with the country rock the pluton is foliated and contains uncommon, fine-grained bands and coarse leucocratic layers. Away from the contact the pluton is homogeneous and unfoliated.

At the eastern edge of the area, the Quottoon pluton is a strongly foliated and lineated biotite-hornblende tonalite which varies in grain size and mafic content. Its contact with the metamorphic rocks is gradational, with metamorphic layers intermixed with the plutonic rocks for several kilometres across strike. The contact shown in Figure 3 delineates the first appearance of the tonalite. Near the contact the pluton contains variably textured deformed amphibolitic inclusions. Also common are coarse hornblendite dykes, fine-grained hornblende-feldspar dykes, pegmatites and quartz veins. The foliation and lineation, which parallel those of the metamorphic rocks, persist into the intrusion over the area mapped.

Aplite and pegmatite dykes of varying thicknesses and degrees of deformation (Fig. 6) contain plagioclase and quartz with varying amounts of biotite, muscovite and garnet. These dykes are ubiquitous throughout the area, but increase in density close to the contact of the Quottoon pluton.

METAMORPHISM AND STRUCTURE

Pelitic layers on the eastern side of the area contain sillimanite (Fig. 3); at least locally sillimanite is associated with K-feldspar. To the west, kyanite $\pm$ muscovite occur in metapelitic layers within chlorite-rich metavolcanics. Additional detailed mapping and geothermobarometric analyses are needed to characterize the boundary rocks containing these differing aluminosilicate polymorphs.

All the metamorphic rocks are foliated. In most cases the foliation is parallel to compositional layering, strikes northwest to north and dips steeply east (Fig. 7). Alignment of elongate minerals such as amphibole and sillimanite, of fold hinges of crenulations and of stretched epidote pods and siliceous clasts in volcanic breccias define a steep northerly-trending lineation. Mesoscopic tight to isoclinal folds with axial planes striking northwest and dipping steeply to the east and fold axes plunging mainly steeply to the northwest are common. The spread in the plunge of fold axes suggest that they have been rotated during a later deformation event. Folding is particularly obvious in the well-layered metasedimentary rock and the chlorite schist. In one location, the compositional layering of the metasedimentary rock is folded and the well-developed foliation is axial planar (Fig. 8); a sillimanite lineation is parallel to the fold axis. This rock is cut by a folded and boudined sillimanite-bearing quartz vein. Minor folds and variation in the foliation orientation suggest larger scale folding throughout the area. Folding of the felsic granitoid gneiss (Unit 1) is suggested by the presence of folded amphibolite dykes in the metaplutonic rock.

Figure 8. Tight, upright folds in metasediments of Unit 3. The well-developed foliation, shown mainly by aligned biotite, is axial planar.

The cross-cutting to concordant, undeformed to foliated and folded leucocratic aplitic to pegmatitic dykes are syn- to post-tectonic. Numerous quartz veins also range from undeformed to foliated and folded.

DISCUSSION

The area between the Ecstall and Quottoon plutons can be separated into an eastern and a western belt based on major lithological, metamorphic and structural differences. The eastern belt is mainly underlain by metasedimentary rocks, whereas most rocks of igneous origin occur in the western belt. Sillimanite-bearing rocks are restricted to the eastern belt and kyanite-rich rocks to the western belt. The eastern metamorphism is apparently pre- or syn-deformation. The pressure and temperature conditions represented by the kyanite-bearing metapelites and associated chlorite-amphibole assemblages in the western belt are unknown. They may represent high pressure and temperature, prograde metamorphism such as that described by Crawford et al. (1979) farther north. It is unlikely that the chlorite schist is entirely retrograde in origin, as one thin section of chlorite schist contains oriented chlorite defining a schistosity overprinted by coarse nonoriented amphibole, itself partly chloritized. This implies that only part of the chlorite is retrograde and that amphibole crystallization occurred post-tectonically.

All rocks, although some more than others, are strongly deformed. Foliation and lineation are steep; this is reminiscent of the structures along the Work Channel lineament farther north (Crawford and Hollister, 1982). Tight folding is present, predominantly in the eastern belt. Mineral and stretching lineations are also concentrated in eastern rocks. This may partly reflect differences in rock competency and composition but probably also implies different deformation histories for the two belts.

These two distinct belts may correlate with parts of the western and central belts of the Coast Plutonic Complex that were defined in the Prince Rupert area by Crawford et al., 1987. The western rocks are bounded on the west by the mid-Cretaceous Ecstall pluton, whereas the rocks in the eastern part of the region appear to have undergone deformation during emplacement of the Paleogene Quottoon pluton. The change in metamorphic conditions from sillimanite grade in the east to kyanite grade on the west is analogous to the variation observed in the Prince Rupert area. The steep foliation and lineation are similar to the structures along the Work Channel lineament. Additional work is needed to clarify the nature and age of the protoliths, the age of the metamorphic event in each belt and the nature of the thermal and structural boundary between the two belts.

ACKNOWLEDGMENTS

Generous support provided by Glenn Woodsworth is gratefully acknowledged. I also thank Frank Hassard and Peter Manojlovic of Falconbridge Ltd. for their hospitality in the Ecstall camp during the 1987 field season. Kathleen Dixon's cheerful assistance in the field is greatly appreciated, as are the flying skills and resourceful help provided by Dave Newman and Garry Thomsen (Okanagan Helicopters Ltd). The manuscript was reviewed by S.D. Carr, R.R. Parrish and G.J. Woodsworth.

REFERENCES

Armstrong, R.L. and Runkle, D.
1979: Rb-Sr geochronometry of the Ecstall, Kitkiata, and Quottoon plutons and their country rocks, Prince Rupert region, Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 16, p. 387-399.

Brew, D.A. and Ford A.B.
1978: Megalineament in southeastern Alaska marks southwest edge of Coast Range batholithic complex; Canadian Journal of Earth Sciences, v. 15, p. 1763-1772.

Crawford, M.L. and Hollister, L.S.
1982: Contrast of metamorphic and structural histories across the Work Channel lineament, Coast Plutonic Complex, British Columbia; Journal of Geophysical Research, v. 87, p. 3849-3860.

Crawford, M.L., Hollister, L.S. and Woodsworth G.J.
1987: Crustal deformation and regional metamorphism across a terrane boundary, Coast Plutonic Complex, British Columbia; Tectonics, v. 6, p. 343-361.

Crawford, M.L., Kraus, D.W. and Hollister, L.S.
1979: Petrologic and fluid inclusion study of calc-silicate rocks, Prince Rupert, British Columbia; American Journal of Science, v. 279, p. 1135-1159.

Hill, M.L.
1985: Remarkable fossil locality: Crinoid stems from migmatite of the Coast Plutonic Complex, British Columbia; Geology, v. 13, p. 825-826.

Hutchison, W.W.
1982: Geology of the Prince Rupert-Skeena map area, British Columbia; Geological Survey of Canada, Memoir 394, 116 p.

Money, P.L.
1959: Geology of Hawkesbury Island; unpublished M.Sc. thesis, University of British Columbia, 159 p.

Padgham, W.A.
1958: Geology of the Ecstall-Quaal Rivers area, British Columbia; Unpublished M.A.Sc. thesis, University of British Columbia, 202 p.

Roddick, J.A.
1970: Douglas Channel — Hecate Strait map-area, British Columbia; Geological Survey of Canada, Paper 70-41, 56 p.

Woodsworth, G.J. and Orchard, M.J.
1985: Upper Paleozoic to lower Mesozoic strata and their conodonts, western Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 1329-1344.

Woodsworth, G.J., Loveridge, W.D., Parrish, R.R. and Sullivan, R.W.
1983: Uranium-lead dates from the Central Gneiss Complex and Ecstall pluton, Prince Rupert map area, British Columbia; Canadian Journal of Earth Sciences, v. 20, p. 1475-1483.

Metamorphism in and near the northern end of the Shuswap Metamorphic Complex, south-central, British Columbia

D.W.A. McMullin[1] and H.J. Greenwood[1]
Cordilleran and Pacific Geoscience Division, Vancouver

McMullin, D.W.A. and Greenwood, H.J., Metamorphism in and near the northern end of the Shuswap Metamorphic Complex, south-central British Columbia; in *Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 57-64, 1988.*

Abstract

Three areas of recent study show a wide variety of metamorphic features. In the Quesnel Lake area, rocks vary from garnet to sillimanite grade. Some rocks, previously considered to be sub-garnet grade, are staurolite-kyanite grade and show extensive retrogression. Narrow metamorphic zones result from marked changes in lithology.

Rocks in the Clearwater Lake-Azure Lake area are chlorite to garnet and sillimanite grade. There appear to be no intermediate metamorphic zones, possibly as a result of faulting.

In the Deception Mountain-Mica Mountain area rocks of both the Quesnel and Barkerville terranes are present. Quesnel terrane rocks occur in a small synform on the east flank of Mica Mountain. This package consists of ultramafics at the base with quartzite, amphibolite, graphitic to pyritic phyllite, and staurolite schist above. These have been downfolded into kyanite to sillimanite grade, Snowshoe Group, quartzose to pelitic schists.

Résumé

Une étude récente a révélé trois zones ayant des caractéristiques métamorphiques très variées. Dans la zone du lac Quesnel, on trouve des roches de qualité grenat à sillimanite. Certaines roches, autrefois considérées de qualité subgrenat, sont de qualité staurolite-kyanite et présentent une rétrogression poussée. Des zones métamorphiques étroites proviennent de changements lithologiques marqués.

Les roches de la zone de Clearwater Lake-Azure Lake sont de qualité chlorite à grenat et sillimanite. Il ne semble pas y avoir de zones métamorphiques intermédiaires, peut-être par suite de la formation de failles.

Dans la région des monts Deception et Mica, on trouve des roches des deux formations géologiques de Quesnel et de Barkerville. Des roches de la formation de Quesnel gisent dans une petite structure synforme sur le flanc est du mont Mica. Cet ensemble est composé de roches ultramafiques à la base, surmontées de quartzites, d'amphibolites, de phyllites graphitiques à pyritiques et de schistes à staurolite. Celles-ci ont été transformées dans des plis synclinaux en schistes quartzeux à pyritiques du groupe de Snowshoe de qualité kyanite à sillimanite.

[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

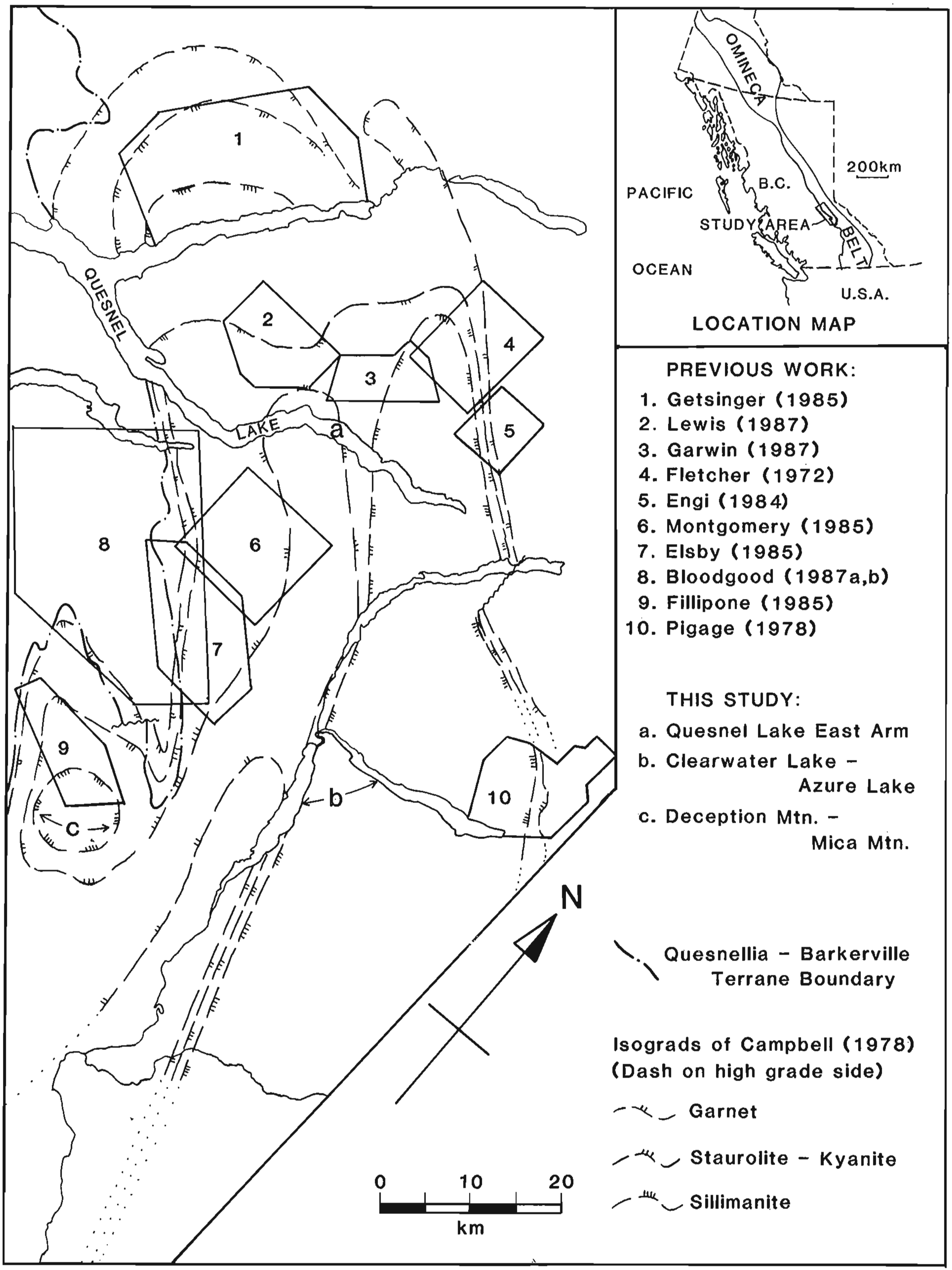


Figure 1. Map of the northern end of the Shuswap Metamorphic Complex (sillimanite grade rocks) and surrounding area.

INTRODUCTION

The northernmost part of the Shuswap Metamorphic Complex (Reesor, 1970; Okulitch, 1984) has been extensively studied in recent years. This includes work by the Geological Survey (e.g. K.V. Campbell and R.B. Campbell, 1970; Campbell, 1978; Struik, 1983) and a significant number of Ph.D. and M.Sc. theses at the University of British Columbia. Recent examples include, Lewis (1987), Garwin (1987), Bloodgood (1987a), Fillipone (1985) and Getsinger (1985). The latter studies have concentrated on the stratigraphy and structure, and to a lesser extent on the metamorphism, of quite small field areas. Figure 1 shows the extent of the area covered by these studies. With these data available it is appropriate to attempt a synthesis of the metamorphism of the entire area.

To date, a suite of 650 additional samples has been collected from throughout the area but with an emphasis on locales outside previous studies. This report concentrates on three areas of recent collection; the east arm of Quesnel Lake area, Clearwater Lake-Azure Lake area and the Deception Mountain-Mica Mountain area.

EAST ARM, QUESNEL LAKE AREA

The east arm of Quesnel Lake has an overall east trend oblique to the general geological trend in the area (Fig. 1, 2). Rocks along the shore, accessible by boat, provided a relatively complete suite ranging from low grade rocks near the Quesnellia-Barkerville terrane boundary to the sillimanite grade rocks of the Shuswap Complex proper.

At the western end of the east arm is the Quesnellia — Barkerville terrane boundary. This is a thrust fault (Eureka thrust, Struik 1986) and is marked by a highly foliated amphibolite (Crooked amphibolite of Struik, 1986). To the east of this, the non-intrusive rocks of the Barkerville terrane consist of a mixed sequence of quartzite, quartzose schist, pelitic schist, marble, calcareous schist and amphibolite. These rocks are considered to belong to the Snowshoe Group (Struik, 1983; Lewis, 1987; Garwin, 1987), a continentally derived package of siliciclastic to calcareous rocks of Hadrynian to Lower Paleozoic age. These have been intruded by the Devonian age (Getsinger, 1985) granodioritic to granitic Quesnel Lake orthogneiss and by various pegmatitic and granitic bodies of Cretaceous age (Struik, 1983).

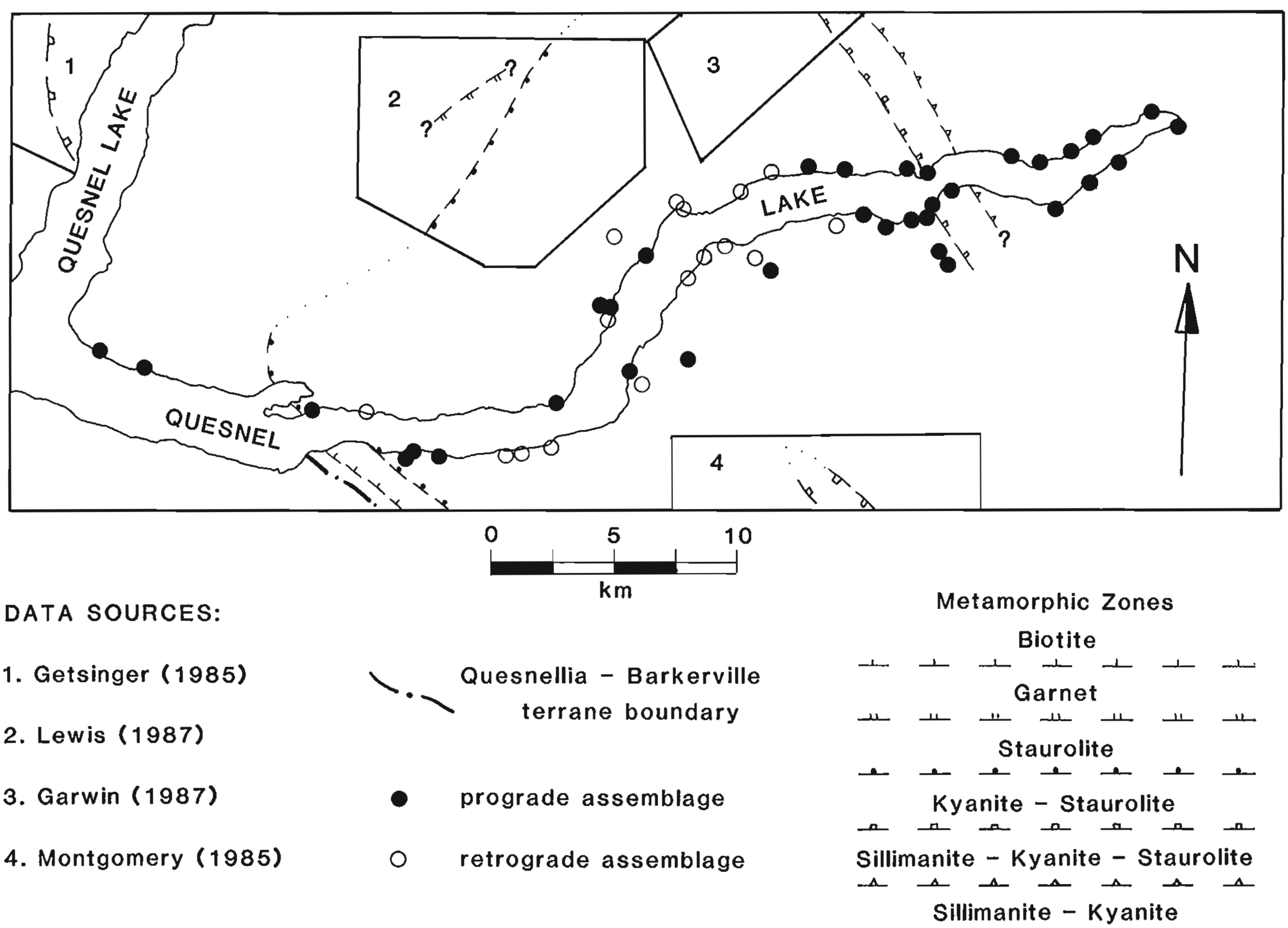


Figure 2. Map of the east arm, Quesnel Lake showing the metamorphic zones, prograde and retrograde assemblages.

Along the east arm of Quesnel Lake the Snowshoe Group is divisible into three broad packages. Near the terrane boundary the rocks are dominantly quartzose to pelitic schists with some amphibolite and have been intruded by the Quesnel Lake gneiss. Halfway along the east arm marbles, calcareous schists and amphibolites are prominent. At the eastern end of the lake, quartzose and pelitic lithologies predominate. This gross change in bulk rock composition has a pronounced effect on the mineral assemblages present and thus any interpretation of the metamorphic conditions which operated.

Prograde metamorphism.

A suite of 400 samples was collected from the area and is currently under study. Preliminary petrographic work agrees with the 'isograds' of Campbell (1978) with one exception. Campbell (1978) indicated that about halfway along the east arm rocks are of garnet grade or less whereas we suggest that the rocks should be represented as being staurolite — kyanite grade. Peak metamorphic assemblages show increasing grade from west to east in the area (Fig. 2).

Garnet zone.

Garnet appears very abruptly just below the terrane boundary. Staurolite and kyanite are present in rocks a few kilometres to the east. This narrow garnet zone is represented (Campbell, 1978; this study) by very closely spaced 'isograds'. Closely spaced isograds are commonly interpreted as indicating a steep thermal gradient during metamorphism. This is not necessarily the case here.

Above the Eureka thrust the lithologies are amphibolite and graphitic, pyritic phyllites. Neither of these lithologies is susceptible to garnet growth at normal garnet grade temperatures. The abrupt appearance of garnet in the Snowshoe Group rocks just below the thrust is thus considered to be due to the abrupt change in bulk rock composition. The narrow garnet zone is therefore not regarded as the result of a steep thermal gradient.

Staurolite and staurolite — kyanite zones.

Separate staurolite and staurolite — kyanite zones are not recognized along the east arm. The staurolite — kyanite zone is extremely wide, stretching from near the terrane boundary to about 10 km west of the eastern end of the lake. Lewis (1987) noted that staurolite appears before kyanite in the Ogden Peak area. However, Lewis also notes that the presence of either of these phases is strongly dependent on lithology. Many of the rocks along the westernmost portion of the east arm are either quartzose pelites or the Quesnel Lake gneiss, neither of which permits the development of highly aluminous phases. Therefore, the absence of a notable staurolite zone in this area is probably also due to lack of appropriate bulk rock compositions. Rocks exposed along the centre section of the east arm show varying degrees of retrogression. This led Campbell (1978) to classify these rocks as garnet grade or lower. This is dealt with in more detail below.

Sillimanite — staurolite — kyanite zone.

Sillimanite appears in rocks about 10 km west of the eastern end of the lake. Samples contain fibrolite and biotite growing in embayed garnet possibly as a result of the reaction

$$\text{gt} + \text{musc} = \text{sill} + \text{bi} + \text{qtz}.$$

Not all garnet is consumed by this reaction and some may be generated by other reactions so that garnet is still present throughout the sillimanite zone(s).

Sillimanite — kyanite zone.

The transition to the sillimanite — kyanite zone results from the breakdown of staurolite by one or both of the reactions

$$6\text{st} + 25\text{qtz} = 46\text{sill} + 8\text{gt} + 12H_2O$$

$$6\text{st} + 8\text{musc} + 17\text{qtz} = 62\text{sill} + 8\text{bi} + 12\text{H}$$

At the easternmost end of the lake, kyanite is absent from all except one of the samples examined indicating the progression of the polymorphic transformation

$$\text{ky} = \text{sill}.$$

The single sample containing kyanite may be from a downfaulted block.

Retrograde assemblages.

About halfway along the east arm the rocks have a very low grade appearance. This led Campbell (1978) to classify them as garnet grade and lower. This lower grade appearance is due to two factors. Firstly, many of the lithologies have a significant calcareous component and thus their compositions are unsuitable for the developement of garnet, staurolite or kyanite. Secondly, the rocks in this area have been subjected to severe retrogression and the pelitic rocks present have very few remaining recognisable porphyroblastic minerals. Figure 2 shows the distribution of these retrograded assemblages. Thin section examination reveals that staurolite and kyanite have been replaced by sericite ± chlorite, garnet by chlorite and biotite by chlorite. The degree of alteration is variable. Kyanite and staurolite are the most severely altered, garnet less so and biotite least. Note that biotite in rocks which do not appear to have contained garnet (calcareous assemblages) is commonly fresh, implying that the garnet breakdown reaction involves the consumption of biotite also. Possible retrograde reactions are:

$3\text{ky} + 3\text{qtz} + 2K^+ + 3H_2O = 2\text{musc} + 2H^+$ (kyanite breakdown; Lewis, 1987),

$\text{st} + 3\text{bi} + 7\text{qtz} + 14H_2O = 3\text{musc} + \text{chl}$ (staurolite breakdown; Hoscheck, 1969),

$4\text{alm} + \text{bi} + 12H_2O = 3\text{chl} + \text{musc} + 3\text{qtz}$ (garnet breakdown; Fillipone, 1985).

Retrogression has been noted by Getsinger (1985), McMullin and Greenwood (1986), Lewis (1987) and by Garwin (1987). In all these cases the rocks affected are in the carbonate-rich section of the stratigraphy. The reason for this is unknown but it is clear that significant quantities of water were either retained or introduced during the waning stage of the metamorphism.

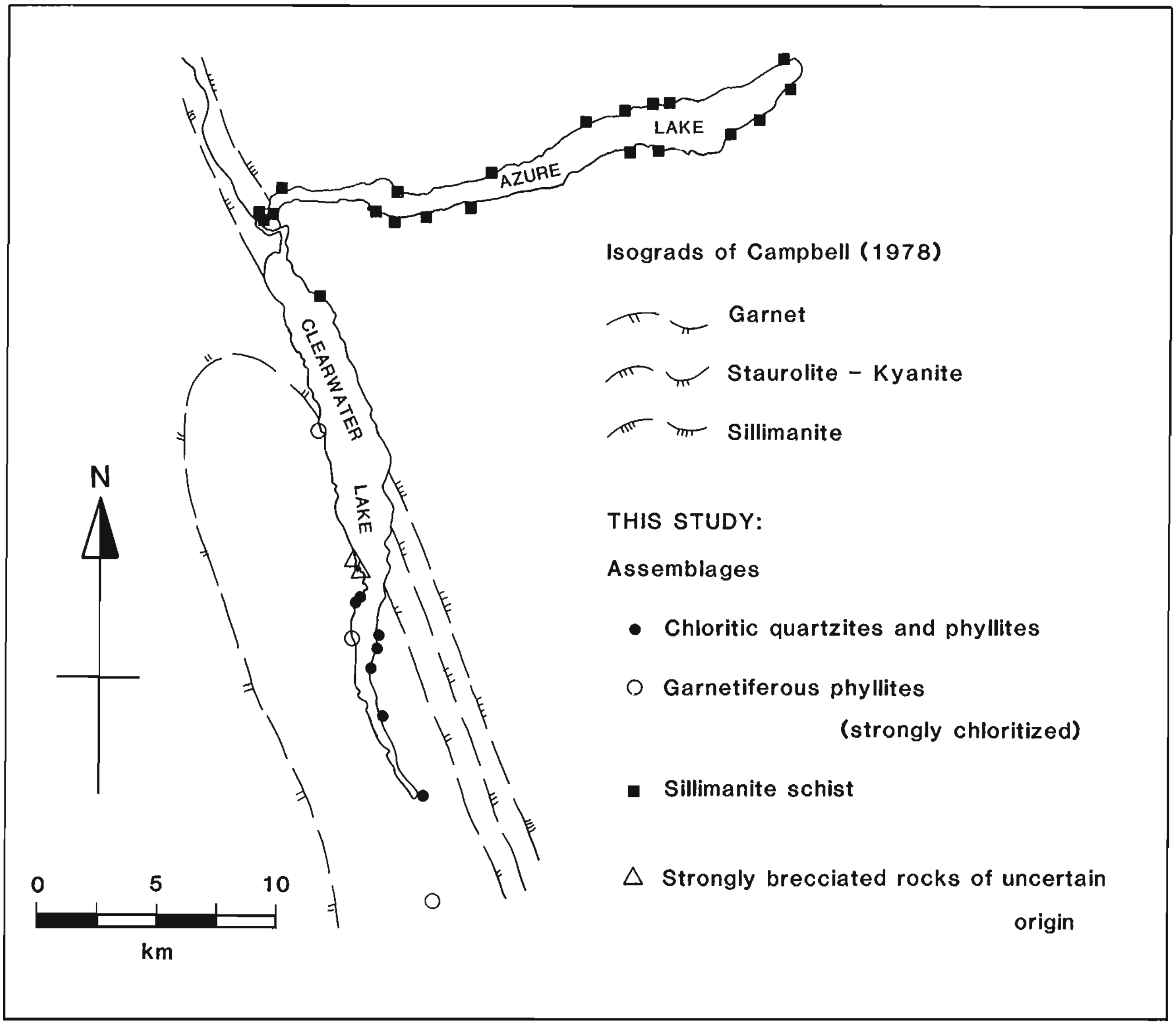


Figure 3. Map of the Clearwater Lake — Azure Lake area showing the metamorphic assemblages seen. Isograds after Campbell (1978).

CLEARWATER LAKE — AZURE LAKE AREA.

The rocks in this area range in grade from chlorite to sillimanite. Figure 3 shows the isograds proposed for the area by Campbell (1978). The rocks along Azure Lake and at the northern end of Clearwater Lake are sillimanite grade quartzose and pelitc schists, calcsilicate and quartzofeldspathic gneiss and amphibolite. The rocks exposed on the southern and western shores of Clearwater Lake appear to be chlorite to garnet grade quartzites and phyllites. The low grade appearance is partly the result of retrogression. Three of the most westerly samples contain strongly retrograded garnet set in a quartz, chlorite and muscovite matrix.

These rocks also appear to have been extensively faulted. Rocks at the southern end of the lake extending tens of kilometres to the south are highly fractured, with metre-sized blocks set in a very fine grained, clayey matrix. The faults appear to have an approximate north-south trend along Clearwater Lake.

The faults in this area are considered to be the reason for the sharp jump in grade across Clearwater Lake. There is no indication of staurolite, staurolite — kyanite, sillimanite — staurolite — kyanite or sillimanite — kyanite zone rocks in the area, though outcrop is sparse along the central part of the eastern shore of Clearwater Lake. To date, kyanite has only been observed in a single sample from the eastern end of Azure Lake where there is evidence of the grade decreasing eastwards (Fig. 1).

Faulting along Clearwater Lake could also explain the sandwich of lowest grade rocks (chloritic schists and quartzites on the southeast) between garnetiferous (albeit chloritized) schists to the west and sillimanite schists to the east.

For these reasons the rocks at the southern end of Clearwater Lake are considered to be a complex mix of slices of retrograded higher grade (garnet at least) rocks and down-dropped blocks of lower grade (chlorite).

DECEPTION MOUNTAIN — MICA MOUNTAIN AREA

Figure 4 shows the isograds of Campbell (1978) for the area. Also shown are the field-observed assemblages determined in this study. This area is of interest for two reasons. Firstly, Campbell (1971) noted the presence of andalusite in rocks on the western flank of Deception Mountain. This is the only reported occurrence of this mineral in the vicinity of the northern part of the Shuswap Complex. The presence of andalusite would imply a period of low pressure metamorphism not observed anywhere else in the northern part of the Shuswap Complex. Secondly, the Deception Mountain — Mica Mountain area lies between the Boss Mountain area to the north, studied by Fillipone (1985), and the Dunford Lake area to the south, studied by Montgomery (1978) and J. Radloff (work in progress).

The rocks of the Deception Mountain area are quartzose to pelitic schists (Snowshoe Group; Fillipone, 1985). They contain kyanite to the west and sillimanite and kyanite to the east (Fig. 4). Although considerable effort was made to find andalusite, none was observed in hand specimen. Detailed petrographic analyses are in progress to determine if it is present on the microscopic scale. Staurolite is not present in the rocks at Deception Mountain, probably as a result of bulk composition constraints. These rocks are considered to be in the staurolite — kyanite and sillimanite — staurolite — kyanite zones described for the Quesnel Lake area.

The rocks on Mica Mountain show a variation in grade from sillimanite (with kyanite) in the west to kyanite in the east. However, there are significant differences in the lithologies compared with the Deception Mountain area. On the

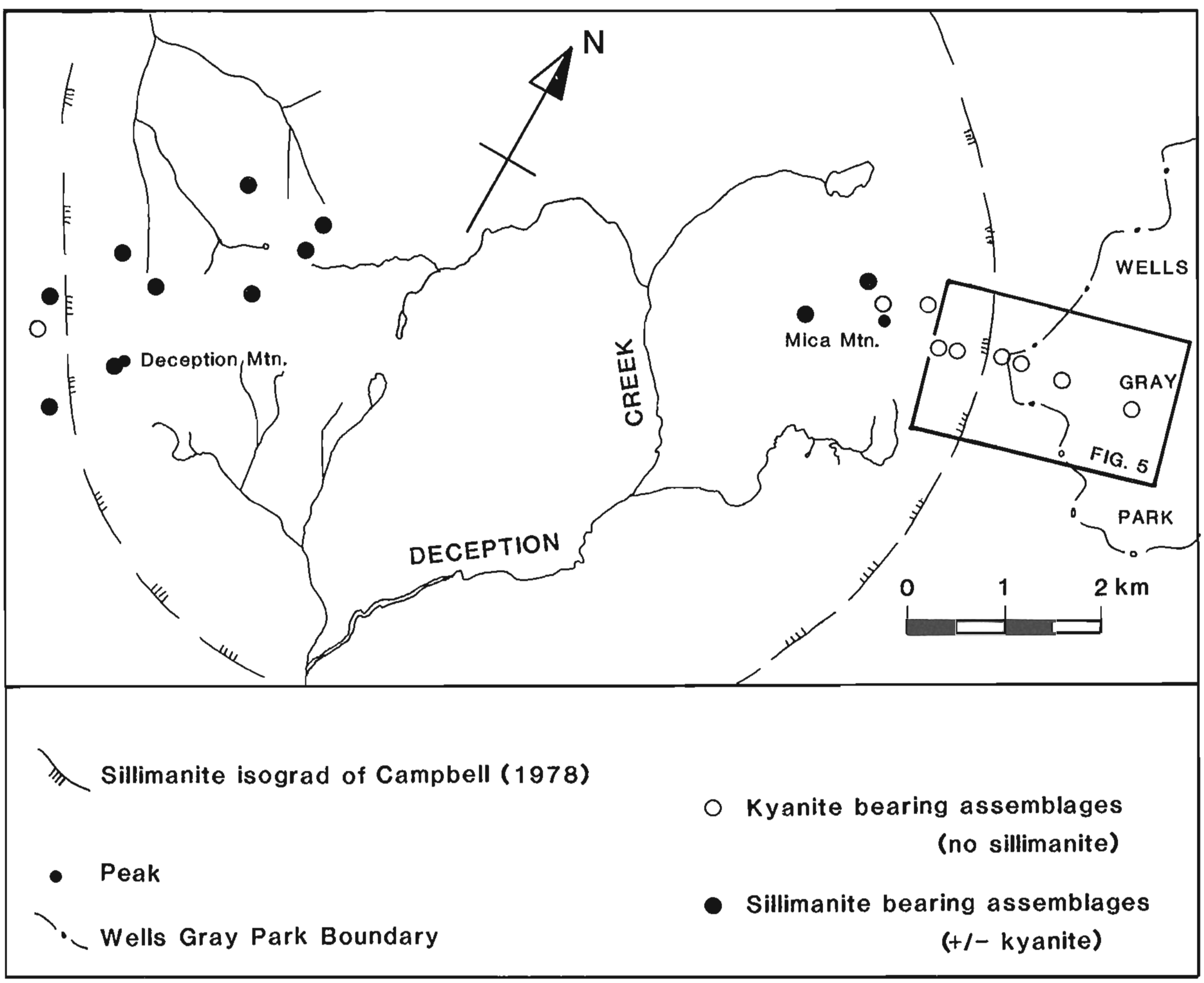


Figure 4. Map of the Deception Mountain — Mica Mountain area showing the mineral assemblages seen. Sillimanite isograd after Campbell (1978).

eastern flank of Mica Mountain a series of rocks of markedly different lithology occurs in what appears to be a synformal structure. Figure 5 is a sketch map and cross-section of this area. On the east and west, the rocks are quartzose and pelitic schists similar to those seen in the Deception Mountain area (Snowshoe Group) and are indicated on the diagram as lithological unit 1. Lithology 2 is an ultramafic rock that occurs in at least four distinct pods 40-50 m long and 30-40 m wide which appear to have tectonized (foliated) margins. Most of the rock consists of anthophyllite and talc though there are occurrences of tremolite — talc assemblages as well as tremolite — phlogopite and chlorite veins. These rocks are suitable for microprobe analyses and should furnish good estimates of the pressure and temperature of metamorphism. These will be used to cross-check the pressures and temperatures determined using pelitic assemblages. Lithology 3, an almost pure, possibly mylonitized quartzite, may be tectonized Snowshoe Group rocks (unit 1). Lithology 4 is a mylonitized amphibolite and is possibly correlative with Crooked amphibolite (Struik, 1986). Lithology 5 is a mixed graphitic to pyritic phyllite and carbonate package. This unit is tentatively correlated with Bloodgood's (1987b) unit 3 of the informal Triassic Black Phyllite. Lithology 6 is a highly porphyroblastic staurolite schist which is tentatively correlated with unit 4 of Bloodgood's (1987b) Triassic Black Phyllite. In the Mica Mountain area, staurolite porphyroblasts, up to 10 cm in length, are unique to this unit which appears to contain little or no kyanite.

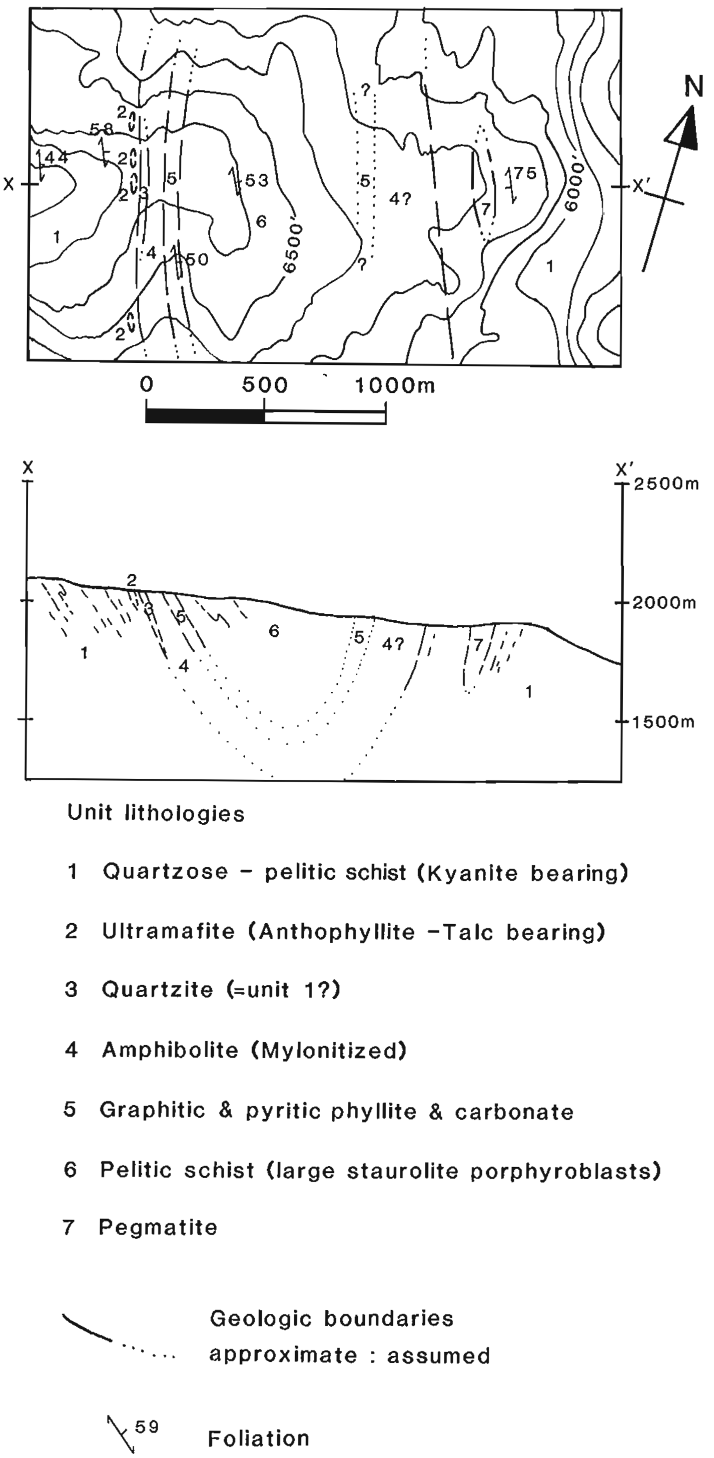


Figure 5. Sketch map and cross-section of the eastern flank of Mica Mountain.

A synformal structure is interpreted from outcrop patterns (Fig. 5), though the rocks are not as well exposed to the east. Units 2 and 3 were not observed on the east. This may be the result of their discontinuous nature. Alternatively, the eastern margin of this structure may be a fault which juxtaposes units 1 and 4.

The correlations made above imply that this package is a small infold of Quesnellia terrane rocks. This minor synform is possibly a parasitic syncline on the eastern flank of the Boss Mountain anticline (Fillipone, 1985), a major, upright, northwest-plunging structure to the west of Mica Mountain. The Boss Mountain anticline and the adjacent Eureka Peak syncline produce the fold pattern of the terrane boundary (Fig. 1).

DISCUSSION

There are two major problems encountered in attempting to synthesize the metamorphic history of an area of this size. Firstly, lithological changes on all scales make it difficult to compare and contrast the metamorphic history of even adjacent subareas. Lithological variation results in the appearance and disappearance of the minerals used to define metamorphic zones. Additionally, solid-solution minerals may form in different rocks under different physical conditions. These two features result in mineral zones that can end abruptly at geological boundaries and, where present, these zones can form under a range of physical conditions. In order to compare widely spaced areas, such as those under consideration, it is necessary to determine temperatures and pressures of metamorphism in a quantitiative manner using geothermometers and geobarometers such as those of Ferry and Spear (1978), and Ghent (1976). Many of these techniques have some significant drawbacks:

1. Standard methods do not necessarily result in the simultaneous determination of pressure and temperature from a single mineral assemblage. Calculated temperatures and pressures may never have been experienced by the rocks.
2. There is commonly disagreement between two methods using different mineral assemblages at the same grade. For example, the Ghent (1976) and GRAIL (Bohlen et al., 1983) geobarometers commonly give significantly different pressures even when applied to the same rock.

3. Different calibrations of the same method (e.g. garnet — biotite thermometer) give different results. This is due to discrepancy between experimental data and the solution models used by different workers (e.g. Ferry and Spear, 1978; Newton and Hazelton, 1981; and Ganguly and Saxena, 1984).

An effort is underway to develop and refine new techniques (McMullin and Greenwood, 1987) which address these concerns.

The second major problem seen in this area is the degree of retrogression undergone by many rocks. This renders the rocks unusable for the determination of pressures and temperatures of peak metamorphism. These rocks are of interest mainly because they show disequilibrium assemblages which can yield information on the metamorphic path. Additionally, some of the assemblages, if carefully chosen and analysed, will be useful for defining the path of retrogression. This has significance in determining the tectonic evolution of the area.

REFERENCES

Bloodgood, M.A.

1987a: Deformational history, stratigraphic correlations and geochemistry of Eastern Quesnel Terrane rocks in the Crooked Lake area, east central British Columbia, Canada; unpublished M.Sc. thesis, University of British Columbia, 165 p.

1987b: Geology of the Triassic Black Phyllite in the Eureka Peak area, central British Columbia; *in* Geological Fieldwork, 1986, British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-1, p.135-142.

Bohlen, S.R., Wall, V.J., and Boettcher, A.L.

1983: Experimental investigations and geological applications of equilibria in the system $FeO-TiO_2-Al_2O_3-SiO_2-H_2O$; American Mineralogist, v. 68, p. 1049-1058.

Campbell, K.V.

1971: Metamorphic petrology and structural geology of the Crooked Lake area, Cariboo Mountains, British Columbia; unpublished Ph.D. thesis, University of Washington, Seattle, 192 p.

Campbell, K.V. and Campbell, R.B.

1970: Quesnel Lake map-area, British Columbia; *in* Report of Activities, Part A, April to October 1969, Geological Survey of Canada, Paper 70-1A, p. 32-35.

Campbell, R.B.

1978: Quesnel Lake (93A) map-area, British Columbia; Geological Survey of Canada, Open File 574 (map).

Elsby, D.C.

1985: Structure and deformation across the Quesnellia — Omineca terrane boundary, Mt. Perseus area, east central British Columbia; unpublished M.Sc thesis, University of British Columbia, 178 p.

Engi, J.E.

1984: Structure and metamorphism north of Quesnel Lake and east of Niagara Creek, Cariboo Mountains, British Columbia; unpublished M.Sc. thesis, University of British Columbia, 137 p.

Ferry, J.M. and Spear, F.S.

1978: Experimental calibration of the partitioning of Fe and Mg between biotite and garnet; Contributions to Mineralogy and Petrology, v. 66, p. 113- 117.

Fillipone, J.A.

1985: Structure and metamorphism at the Intermontane — Omineca boundary near Boss Mountain, east central British Columbia; unpublished M.Sc. thesis, University of British Columbia, 149 p.

Fletcher, C.J.N.

1972: Metamorphism and structure of Penfold Creek area, near Quesnel Lake, British Columbia; unpublished Ph.D. thesis, University of British Columbia, 133 p.

Ganguly, J. and Saxena, S.K.

1984: Mixing properties of aluminosilicate garnets: constraints from natural and experimental data, and applications to geothermo-barometry; American Mineralogist, v. 69, p. 88-97.

Garwin, S.L.

1987: Structure and metamorphism in the Niagara Peak area, western Cariboo Mountains, British Columbia; unpublished M.Sc. thesis, University of British Columbia, 177 p.

Getsinger, J.S.

1985: Geology of the Three Ladies Mountain / Mount Stevenson area, Quesnel Highland, British Columbia; unpublished Ph.D. thesis, University of British Columbia, 239 p.

Ghent, E.D.

1976: Plagioclase-garnet-Al_2SiO_5-quartz: a potential geobarometer-geothermometer; American Mineralogist, v. 61, p. 710-714.

Hoscheck, G.

1969: The stability of staurolite and chloritoid and their significance in metamorphism of pelitic rocks; Contributions to Mineralogy and Petrology, v. 22, p. 208-232.

Lewis, P.D.

1987: Polyphase deformation and metamorphism in the western Cariboo Mountains near Ogden Peak, British Columbia; unpublished M.Sc. thesis, University of British Columbia, 146 p.

McMullin, D.W.A. and Greenwood, H.J.

1986: Metamorphic pressures and temperatures in the Barkerville and Cariboo terranes, Quesnel Lake, British Columbia: preliminary results; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 727-732.

1987: PT-GRADS: Simultaneous P and T calculations with GE0-CALC's PTSYSTEM (abstr); Geological Association of Canada — Mineralogical Association of Canada, Program with Abstracts, v. 12 p. 73.

Montgomery, J.R.

1985: Structural relations of the southern Quesnel Lake gneiss, Isosceles Mountain area, southwest Cariboo Mountains, British Columbia; unpublished M.Sc. thesis, University of British Columbia, 96 p.

Montgomery, S.L.

1978: Structural and metamorphic history of the Dunford Lake map area, Cariboo Mountains, British Columbia; unpublished M.S. thesis, Cornell Univeristy, Ithaca, New York, 170 p.

Newton, R.C. and Hazelton, H.T.

1981: Thermodynamics of the garnet- plagioclase-Al-quartz geobarometer; *in* Thermodynamics and Melts, Newton, R.C., Navrotsky, A., and Wood, B.J. (eds.), New York, Springer-Verlag, p. 131-147.

Okulitch, A.V.

1984: The role of the Shuswap Metamorphic Complex in Cordilleran tectonism: a review; Canadian Journal of Earth Sciences, v. 22, p. 1171-1193.

Pigage, L.C.

1978: Metamorphism and deformation on the northern margin of the Shuswap Metamorphic Complex; unpublished Ph.D. thesis, University of British Columbia, 289 p.

Reesor, J.E.

1970: Some aspects of structural evolution and regional setting in part of the Shuswap Metamorphic Complex; *in* Structure of the Canadian Cordillera, Wheeler, J.O. (ed.), Geological Association of Canada, Special Paper 6, p. 73-86.

Struik, L.C.

1983: Bedrock geology of Quesnel Lake (93A/10) and part of Mitchell Lake (93A/15) map areas, central British Columbia; Geological Survey of Canada, Open File 962.

1986: Imbricated terranes of the Cariboo gold belt with correlation and implications for tectonics in southeastern British Columbia; Canadian Journal of Earth Sciences, v.23, p. 1047-1061.

Geological mapping in Tatshenshini River map area, British Columbia

C.J. Dodds
Cordilleran and Pacific Geoscience Division, Vancouver

Dodds, C.J., Geological mapping in Tatshenshini River map area, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 65-72, 1988.

Abstract

The 114P/10 map area is dominated by Upper Oligocene, granitoid intrusions. Complex, anastomosing faults, intricately bound these, and a variety of chlorite-grade Paleozoic and early Mesozoic marine sediments and volcanics, and Tertiary nonmarine clastics and bimodal volcanics. Much of the faulting and associated deformation is Cenozoic, and could largely be strike-slip-fault related. The 114P/12 map area is dominated by Jura-Cretaceous granitic rocks, with chlorite-grade lower Paleozoic carbonates and Upper Triassic marine calcareous fine clastics and basic volcanics, and rare lower Paleozoic or older amphibolite, schist and gneiss. These rocks are cut by strike-slip and high-angle faults, and locally display kink-banding, and isoclinal and open folds. Deformation is less intense than in the 114P/10 area.

The most significant mineral prospect is the Windy Craggy massive sulphide (Cu,Co,Zn,Au) deposit. Other smaller deposits include: Ba, polymetallic massive sulphides; Cu,Ag,Bi skarns; Ag,Pb,Zn,Cu,Cd and Au quartz-carbonate veins; bedded gypsum-anhydrite; and placer Au.

Résumé

La région de la carte 114P/10 est dominée par des intrusions de granitoïdes de l'Oligocène supérieur. Celles-ci sont étroitement délimitées par des failles anastomosées complexes et par une variété de sédiments et de roches volcaniques marins de qualité chlorite du Paléozoïque et du Mésozoïque inférieur et par des roches clastiques et volcaniques bimodales non marines du Tertiaire. La plupart des failles et des déformations associées sont du Cénozoïque et pourraient être fortement liées à des failles de cisaillement en direction. La zone de la carte 114P/12 est dominée par des roches granitiques du Jura-Crétacé, avec des carbonates du Paléozoïque inférieur et des roches clastiques fines calcaires marines et des roches volcaniques basiques du Triassique supérieur de qualité chlorite et un peu d'amphibolites, de schistes et de gneiss du Paléozoïque inférieur ou d'une époque plus ancienne. Ces roches sont coupées par des failles de glissement en direction et à fort pendage, et elles comportent par endroits des structures zonées brisées et des plis insoclines et ouverts. La déformation est moins intense que dans la région 114P/10.

La plus importante minéralisation est le gisement (Cu, Co, Zn, Au) sulfuré massif de Windy Craggy. D'autres gisements plus petits contiennent: des sulfures massifs polymétalliques à Ba; des skarns à Cu, Ag et Bi; des veines de quartz-carbonate à Ag, Pb, Zn, Cu, Cd et Au; de l'anhydrite à gypse litée; et de l'or de placer.

INTRODUCTION

During 1987, a short field season was spent in Tatshenshini River (114P) map area, northwesternmost British Columbia. Much of the work was concentrated in 114P/10 and/12 areas, and expanded on previous small-scale mapping in the area.

Visits, coupled with exchange of information and ideas, were made with mining exploration companies active in Tatshenshini River map area.

PREVIOUS AND PROPOSED GEOLOGICAL MAPPING

Field work during 1987 initiated a program to map selected areas at 1:50 000 scale in parts of Yakutat (114O), Tatshenshini River (114P) and Skagway (104M) map areas. This program will be coupled with a regional geological synthesis of these and certain immediately adjoining map areas at 1:250 000 scale. It follows the termination of field work involved in Operation Saint Elias (Campbell and Eisbacher, 1974; Campbell and Dodds, 1975, 1978, 1979; Eisbacher, 1975; Read and Monger, 1975, 1976; Read, 1976; Souther and Stanciu, 1975). Prior to Operation Saint Elias, more than 70 percent of the region was essentially unstudied (Sharp, 1943; Watson, 1948; Kindle, 1953; Sharp and Rigsby, 1956; Wheeler, 1963; Muller, 1967). That project, which was undertaken by the Geological Survey of Canada, completed the mainly reconnaissance-scale geological mapping of the Saint Elias Mountains within Yukon and British Columbia (Campbell and Dodds, 1982a,b,c, 1983a,b).

Aspects of geological mapping

During August 1987, approximately three weeks were spent in 1:50 000 scale geological mapping in the Nadahini Creek (114P/10) and Tats Lake (114P/12) sheets (Fig. 1). It expanded on previous, unpublished mapping at this scale by the writer in these and various other parts of Tatshenshini River (114P) (particularly in 114P/9, 11, 13, 14, 15), during 1978, 1979, 1981, 1983, and 1986. About two weeks were spent in 114P/10, while staying at Stryker/Freeport Resources Limited base camp, in the Rainy Hollow area. The remaining time was alloted to work in 114P/12, which was done from the Geddes Resources Limited camp at Tats air strip.

Only the salient geological features are depicted in Figure 1. Nadahini Creek (114P/10) map area lies entirely within, while Tats Lake (114P/12) is mostly within the Alexander terrane of Berg et al. (1978). The allocthonous Alexander terrane in 114P is bounded by the Duke River Fault and part of the Denali Fault System to the northeast, and by the Hubbard Fault to the southwest.

Nadahini Creek (114P/10) map area

Previous geological mapping in this map area was done by Watson (1948), Campbell and Dodds (1979, 1983a).

The believed oldest rocks (unit lPv) occurring in this map area outcrop along the middle section of O'Connor River and upper part of Michael Creek. They are probably, in part at least, of Late Cambrian to earliest Ordovician age. The strata comprise rusty dark grey-green[1], basic volcanics and volcaniclastics, with minor intercalated limestone and argillite-siltstone.

Overlying these rocks is a sequence of tan argillite-siltstone, which locally contains a plentiful, well preserved, early Middle Ordovician graptolite fauna (B.S. Norford, pers. comm., 1987). These are followed, apparently conformably, by a thick[2] succession of first interbedded blue-grey laminated carbonate, ochre-buff calcareous mudstone, and tan siltstone, and then rapidly alternating, thin to more thickly bedded, rusty-tan siltstone and vivid reddish-ochre calcareous mudstone. Possibly interdigitating with and overlying the latter sediments, are thicker bedded, blue-grey limestones. Collectively these predominantly calcareous clastics and carbonates constitute unit lPs, and are believed to be largely of Ordovician to Silurian age. They outcrop south of Fault Creek, on the southwest side of O'Connor River, and on either side of Michael Creek. By far the best sequences, however, occur immediately to the west and east of the headwaters of the Michael Creek.

Strata of unit μPs incorporate Lower Devonian (?) greywacke siltstone; latest Lower Devonian calcareous, dark blue-grey phyllite-argillite; Middle Devonian shallow-marine, discontinuous, blue grey limestone and minor intercalated dark blue-grey calcareous argillite; and Upper Devonian and Carboniferous (?), dark grey, siliceous argillite. These mainly Devonian rocks outcrop on the northwest side of Samuel Glacier pluton, and in the vicinity of the headwaters of both the O'Connor and Klehini rivers. They are strongly suspected to unconformably overlie lower Paleozoic strata. Also locally included (known at the headwaters of the O'Connor River) in unit μPs are conodont-bearing Upper Triassic dark calcareous argillite-siltstone and dark grey micritic limestone. The O'Conner gypsum deposits, lumped with rocks of this unit, may well be of Late Triassic age. Although unproven, Upper Triassic strata probably unconformably overlie the upper Paleozoic sequences.

Fairly thick accumulations of Eocene (?) nonmarine clastics (unit Es) are present between Michael Creek and uppermost Klehini River, and to the west of the headwaters of O'Connor River. They comprise brownish- to greenish-grey sandstone, conglomerate, siltstone, shale and coaly shale, which locally carry fairly plentiful plant debris. Clasts from the conglomerates are predominantly granitoid, limestone, basic volcanics, and black chert, and could be very locally derived. These sediments probably represent fluvial and lacustrine clastics, which may have been deposited within fault-bounded basins (pull-aparts?), and which have been tightly folded by later, strike-slip fault-related deformation.

Thick sequences of basaltic, andesitic, and rhyolitic flows and pyroclastics of probable, but so far undated, Tertiary age are present to the north of the middle part of O'Connor River and on the west side of Michael Creek. These rocks (unit Tv) are abundantly intruded by basic and acid dykes (probably feeders). They probably represent a bimodal suite of volcanics, a result of extension related to strike-slip faulting during Tertiary time.

Intrusives are areally the most abundant rock types in the Nadahini Creek map area. Of these, Oligocene granitoid

[1] Colours in rock descriptions, throughout this paper, refer to weathered surfaces only.
[2] Thicknesses of all stratigraphic units in this report are poorly known, due to structural complexity.

rocks (unit Og) are by far the most dominant. They constitute the Samuel Glacier pluton, parts of the Tkope and Three Guardsmen batholiths, and a segment of the Mt. McDonnell pluton. Collectively these intrusive rocks form the Tkope plutonic suite (Dodds and Campbell, in press,), which from assorted K-Ar, Rb-Sr and fission track isotopic age determinations (Jacobson et al., 1980; Dodds and Campbell, in press) range in age from 24 to 31 Ma. These composite, elongate, calc-alkaline (?), granitoid bodies are epizonal, and have contact metamorphosed their host rocks. They comprise mostly creamy grey, homogenous, medium grained, hornblende, biotite leuco-granite; less light to darker grey, heterogeneous, hornblende, biotite granodiorite, and dark green-grey gabbro-diorite; and rare microgabbro and pink granophyre. Included within the composite Three Guardsmen batholithic complex (extent unkown) are plutons of the uppermost Lower Cretaceous (106-117 Ma) Kluane Ranges plutonic suite (Dodds and Campbell, in press; MacKevett et al., 1974). The Mt. McDonnell pluton could also be a composite of Oligocene and older intrusions. The Oligocene granitoid bodies may have been intruded during Late Paleogene strike-slip faulted-related extension. However, the plutons themselves have been locally intensely brittlely shattered by post-emplacement, probably strike-slip fault-related deformation.

Unsubdivided, variably sized dykes, sills, small plutons and complexes, composed of gabbro, diorite, diabase and basalt-andesite, are widespread in this map area. Field evidence indicates Cambrian-Ordovician, mid- to late-Paleozoic, Permian-Triassic, Early Cretaceous, Cretaceous-Tertiary, Oligocene and Miocene ages for them. Acid dykes, sills and small plutons of Late Oligocene and Miocene age are also present in the area, but they are as abundant as similar age basic subvolcanics. Some ultramafic dykes-sills are known to occur in the vicinity of Nadahini Mountain (Watson, 1948).

Within the 114P/10 map area, strata of Paleozoic and lowermost Mesozoic age, are by and large regionally metamorphosed to no higher than chlorite grade. Sediments and volcanics of various Tertiary ages appear to have undergone only burial or low-subgreenschist-grade regional metamorphism. The metamorphic history of the area is very poorly understood. However, field evidence from elsewhere in the Saint Elias Mountains, suggests the probability of at least one major regional metamorphic event between latest Triassic and earliest Cretaceous time.

Most of the rocks within the Nadahini Creek map area have undergone moderate to complex deformation, but only the salient structural aspects are shown in Figure 1. Abundant complex anastomosing networks of northward- to northwestward-trending, linear to curvilinear, steeply dipping faults dominate these structures. Two of the main faults present within the map area occur along the Parton and Klehini river valleys, and along the O'Connor River and the valley immediately east of Michael Creek. The movement sense on these two faults is believed to be oblique dextral strike-slip and high-angle reverse. Within the anastomosing fault strands, strata and plutonic rocks are disposed in variably sized lenses in which the stratigraphy and plutonic phases are relatively coherent. Fault zones contain gauge and breccia, and immediately adjacent rocks are brittlely deformed. The intense, largely high-level deformation appears to diminish to the southwest of O'Connor River and Michael Creek. The Paleozoic to lowermost Mesozoic strata in the latter area, locally exhibit upright to slightly overturned similar and chevron style folds. Field evidence from elsewhere in the Saint Elias Mountains, indicates that this deformation may partly be of uppermost Triassic to lowermost Cretaceous age, and consequently it would roughly be synchronous with the regional metamorphic event.

To the east of Michael Creek, clastic sediments of probable Eocene age display tight, upright, long amplitude, northwest-trending, en echelon, cylindrical folds. A penetrative axial plane cleavage is present and well rounded conglomeratic clasts are locally highly flattened. Extension, apparently related to this folding event, has resulted in the emplacement of bimodal gash fills, dykes, and sills. Rhyolite and crowded feldspar porphyry subvolcanics have been dated as Late Oligocene (Christopher et al., 1972; Dodds and Campbell, in press). However, comparable intrusives elsewhere in the Saint Elias Mountains are known to be Miocene or younger (?) (Dodds and Campbell, in press). Consequently, this deformation is post-Eocene, and probably Late Oligocene or younger. However, much more conclusive evidence for relatively major, post Late Oligocene, high-level deformation, comes from the locally intense shattering and fault-dislocation of K-Ar dated (Dodds and Campbell, in press) intrusive bodies such as the Samuel Glacier and Mt. McDonnell plutons and the Three Guardsmen batholith. The majority of uppermost Mesozoic through Tertiary deformation may be high-level and strike-slip-fault related. The close proximity of the major intracontinental dextral transcurrent Denali Fault System is ample evidence for this (among others, Eisbacher, 1976; Clague, 1979).

Mineral prospects[3] within in the Nadahini Creek map area include the following.

Hum Bird showings: quartz-filled shears associated with a fault zone in altered, sporadically silicified and mildly brecciated, Devonian(?) limestone carrying various galena, sphalerite, chalcopyrite, tetrahedrite (with Ag), and native silver.

Sam/Main and North Glacier showings: unspecified details (Au, Ag, Cu, Zn).

Nadahini Mountain: veinlets in two sills (15 and 30 m thick) consist of highly serpentinized peridotite, serpentine, talc carbonate and carry up to one inch long poor quality cross-fibre asbestos.

Lunar/Mag: Pb, Zn, Ag, values obtained from upper Paleozoic metasediments close to granodiorite-quartz diorite intrusion.

Pam: Cu, Zn in granitic to quartz monzonitic intrusions.

O'Connor Gypsum, Snow Group: bedded replacement deposit of gypsum and anhydrite adjacent to upper Paleozoic (Devonian?) limestone, Upper Triassic (?) calcareous sediments, and purple conglomerate of uncertain age.

Kim, Aunt Jemima: small scattered occurrences of quartz stringers carrying sphalerite; disseminated replacement in unit μPs.

[3] Data on mineral prosects in this paper is mostly from the British Columbia Ministry of Energy, Mines and Petroleum Resources, Mineral Inventory map and file, 1986.

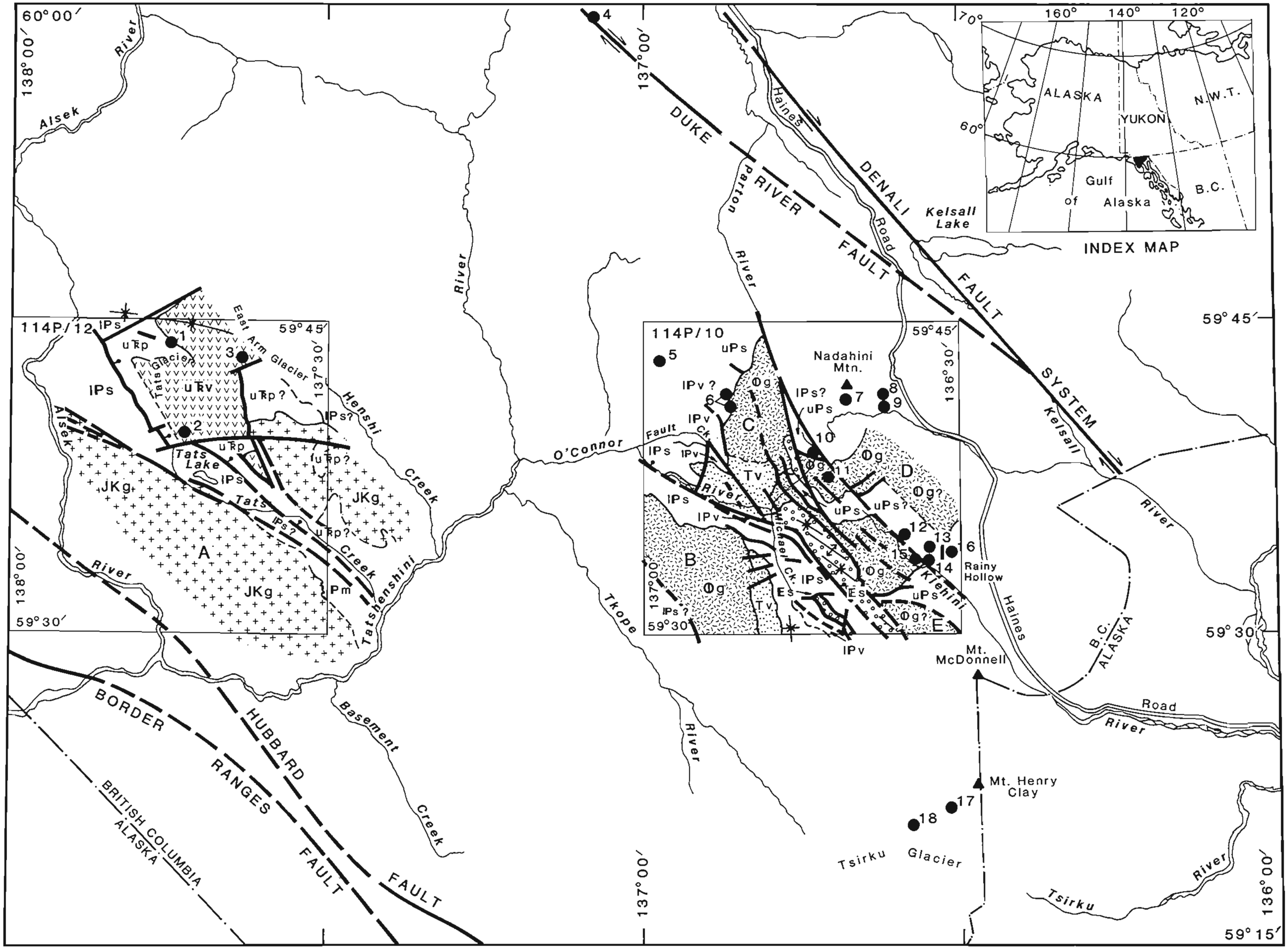


Figure 1. Salient aspects of the geology in the 114P/10 and 114P/12 sheets, Tatshenshini River (114P) map area, and selected mineral prospects.

LEGEND

TERTIARY

Tv bimodal flows and pyroclastics.

OLIGOCENE (24-31 Ma)

Og granite; less granodiorite, diorite.

(?) EOCENE

Es conglomerate, sandstone; minor shale.

UPPER JURASSIC TO LOWERMOST CRETACEOUS (130-160 Ma)

JKg tonalite; granodiorite; minor diorite.

UPPER TRIASSIC

uTRv basic pillow lava; rare sediments.

uTRp calcareous fine clastics; less carbonate; rare basic volcanics.

DEVONIAN TO UPPER TRIASSIC

uPs calcareous, siliceous fine clastics, limestone; local basic volcanics, quartzite.

(?) LATE CAMBRIAN TO SILURIAN

lPs laminated carbonate-calcareous mudstone; less limestone and fine clastics.

lPv basic flows and volcaniclastics; minor carbonate, argillite and mafic intrusions.

(?) LOWER PALEOZOIC AND (?) OLDER

lPm amphibolite, marble, less schist and gneiss; abundant granitoid sills/dykes.

geological boundary (defined, approximate).
high-angle fault (defined, approximate).
strike-slip fault (dextral).
reverse fault (downthrown side).
anticline, syncline.

A Noisy Range batholith.
B Tkope batholith.
C Samuel Glacier pluton.
D Three Guardsmen batholith.
E Mt. McDonnell pluton.

● **SELECTED MINERAL PROSPECTS**

1.	WINDY CRAGGY	(Cu,Co,Zn,Au)
2.	TATS	(Cu,Ag,Au)
3.	RIME (MUS)	(Cu,Au,Ag)
4.	SQUAW CREEK	(placer Au)
5.	HUM BIRD	(Ag,Pb,Zn,Cu,Cd)
6.	SAM SHOWINGS	(Au,Ag,Cu,Zn)
7.	NADAHINI MTN.	(asbestos)
8.	LUNAR	(Ag,Pb,Zn)
9.	PAM	(Cu,Zn)
10.	O'CONNOR (SNOW)	(gyp.,anhyd.)
11.	KIM, AUNT JEMIMA	(Zn)
12.	MAID OF ERIN	(Cu,Ag,Bi)
	BORNITE, CLAY	(Cu,Pb,Zn)
13.	STATE OF MONTANA	(Cu,Ag,Bi)
	WINDSOR	(Fe,Cu)
14.	VICTORIA	(Ag,Pb,Zn)
	WAR EAGLE	(Fe,Cu)
15.	HIBERNIAN	(Cu,Pb,Zn)
16.	ADAMS	(Ag,Pb,Zn)
17.	LOW HERBERT	(Cu,Pb,Au,Ag,Ba)
18.	GRIZZLY HEIGHTS	(Au,Ag)

Maid of Erin, Carmichael, Pretoria: irregular replacement deposits in various skarn types within quartzites, marble and argillite of unit μPs; mineralization is principally of bornite, chalcocite, chalcopyrite, sphalerite, magnetite, and wittichenite; a small producer.

State of Montana, New England: irregular garnet-bearing skarn band within marble and quartzite of unit μPs; chief mineralization comprises several small lenses carrying mostly bornite and chalcocite, local sphalerite, and wittichenite (in bornite); a small producer.

Victoria: irregular skarn bodies, in marble flanked by quartzite of unit μPs; the two main showings consist mostly of sphalerite and galena in a gangue of garnet, wollastonite, and calcite.

Adams: skarn in marble between argillite and quartzite of unit μPs, which are intruded by feldspar porphyry sills and dykes; lenses and bands of galena and sphalerite occur within the skarn.

Windsor: iron-rich body (size, shape and setting unspecified) containing some chalcopyrite and sphalerite.

Bornite, Cay, Cat: skarn in rocks of unit μPs carrying bornite, chalcocite, chalcopyrite, galena, and sphalerite.

War Eagle: small iron gossan of altered pyrrhotite or pyrite in rocks of unit μPs.

Hibernian: skarn in marble and argillite of unit μPs carrying pyrrhotite, chalcopyrite, sphalerite, galena and a gangue of garnet, actinolite, quartz and calcite.

TATS LAKE (114P/12) MAP AREA

Widely scattered work was done in this map area during 1987. It expanded on earlier geological mapping by Campbell and Dodds (1979, 1983a), MacIntyre (1983, 1984), and Gammon and Chandler (1986). Only the major aspects of the geology have been sketched in Figure 1. Most of the map area lies within the Alexander terrane. The extreme southwest corner may incorporate part of Wrangellia (W1) (Campbell and Dodds, 1983a,b,c), which is bounded by the Hubbard Fault to the northeast and the Border Ranges Fault to the southwest.

The presumed oldest rocks present within the map area occur along the western side of lower Tats Creek. These rocks (unit lPm) comprise a sequence of dark greyish green amphibolite, marble and impure marble, rusty greenish and greyish brown hornblende-biotite schist, and hornblende-biotite gneiss and granitoid gneiss. These amphibolite grade metamorphic rocks are of uncertain age, but they could possibly be as old as earliest Paleozoic or even Precambrian.

Thick sequences of mid-greenschist grade, laminated blue-grey limestone and buff-ochre calcareous mudstone-siltstone with partings of silvery grey phyllitic schist are present to the west of Tats Glacier, east of Tats Lake, and probably along the west side of the lower part of Tats Creek. Sparse conodonts indicate these rocks to be Ordovician in age (M.J. Orchard, pers. comm., 1985). Locally both overlying and interdigitating with the laminated carbonates are thick to massively bedded light- to medium-grey limestones, and rare darker blue-grey calcareous argillite. These latter limestones are believed to be mostly of Silurian age, but locally may include Devonian. Collectively these carbonate dominant rocks form unit lPs. Without doubt, they are correlatable with rocks of the same unit in the vicinity of Michael Creek. However, their relationship with rocks of unit lPm is not known.

An apparently thick sequence of highly deformed, thinly interbedded, medium- to buff-grey calcareous mudstone-siltstone, dark grey micritic limestone and black graphitic calcareous argillite (unit μTrp), outcrop to the north and west of Tats Glacier, at the Rime showing and probably to the southeast of the latter. Included within this unit are minor greenish-grey gabbro-diabase sills and rare basic massive and pillow lavas. Conodonts obtained from these dominantly fine clastic strata, are mainly of Early Norian age (M.J. Orchard, pers. comm., 1985). Brief work in 1987 revealed that these sediments are also present just to the northeast of Tats Lake and probably along the east side of the middle section of Tats Creek. Relationships between the Upper Triassic strata and underlying rocks, have not been observed. For the most part, they are faulted against older rocks.

Interfingering with and overlying sediments of unit μTrp, are very thick successions of low-greenschist grade, dark greenish-grey basaltic to andesitic pillow lava and fewer massive flows; local interbedded dark grey limy argillite-siltstone-carbonate and basic intrusives; minor limestone, tuff, and agglomerate; and rare gypsum. These volcanic dominated rocks constitute unit μTrv, and very sparse conodont collections from carbonate interbeds indicate that they are of Early Norian or younger age (M.J. Orchard, pers. comm., 1985). They are the youngest strata so far observed by the writer in the Tats Lake map area.

Previous reconnaissance-scale mapping (Campbell and Dodds, 1983a) suggests that about 50 per cent of the map area is underlain by granitoid plutonic rocks. The bulk of these rocks constitute the Noisy Ranges batholith. This large, elongate, epizonal body, has been grouped with the Upper Jurassic to lowermost Cretaceous, calc-alkaline, Saint Elias plutonic suite. This was based on a reasonably concordant paired, K-Ar age date from biotite 136 $\pm$ 5 Ma and hornblende 141 $\pm$ 8 Ma, and on similarities in lithology, chemistry and setting of this batholith to other intrusions of that suite (Dodds and Campbell, in press). The batholith appears, from cursory study, to be composed largely of weakly foliated, fairly homogeneous, coarse medium grained, light- to mid-greenish-grey, biotite hornblende tonalite, with rare diorite close to its northeast margin. Much of that margin appears faulted, but a traverse in the southeasternmost corner of the map area revealed a very sharp, finely chilled, somewhat discordant contact with undeformed, hornfelsed rocks of unit lPm. However, most of the batholith examined immediately west and northwest of Tats Lake has underdone post-emplacement, high-level, brittle deformation. This has resulted in a complex array of conjugate minor faults and shear zones, together with the emplacement of pink feldspar pegmatitic and aplitic gash-fills and dykes (some composite), which locally have since been intensely sheared or finely comminuted.

The unnamed granitoid pluton to the east of Tats Creek is essentially unstudied. Two observations suggest that it discordantly intruded and contact metamorphosed sediments of possible Late Triassic age. The northwest edge of the body appears to be composed of homogeneous, fine medium grained, light grey, hornblende biotite granodiorite. It is tentatively grouped with the Saint Elias plutonic suite.

The structural geology of Tats Lake map area is less complex than that of the Nadahini Creek sheet. Mapping during 1987 revealed a large, possibly strike-slip fault zone extending from the Alsek River to the northwest of Tats Lake to the lowermost part of Tats Creek. It also confirmed the projection to the lower part of Tats Creek of the high-angle reverse fault that juxtaposes laminated carbonates of unit lPs against calcareous clastics of unit μTrp. The previously outlined synclinal structure to the north of Windy-Craggy continues farther to the west into rocks of unit lPs, but it is unknown whether it pre- or post-dates the relatively small, northeast-trending fault which down-dropped unit μTrp against lPs. This west-northwest-trending, en echelon(?) fold and the westerly-trending, oblique sinistral-strike-slip(?) fault to the north of Tats Lake, may have arisen from dextral-strike-slip(?) faulting along the Tats Creek valley. The local gash-vein and dyke emplacement, the subsequent shearing of these and the developement of the abundant, small conjugate fault and shear sets in parts of the Noisy Range batholith could also be in response to possible strike-slip faulting along Tats Creek. The age of faulting in the Tats Lake map area is as yet poorly constrained. However, during Mesozoic and Tertiary time, large-scale displacements, some of a dextral-strike-slip nature, have occurred along the major Fairweather (among others, Plafker, et al., 1978; Carlson et al., 1985), Border Ranges (MacKevett and Plafker, 1974; Plafker and Campbell, 1979) and Hubbard (Plafker and Campbell, 1979; Campbell and Dodds, 1982b; 1983a,b) faults, which are located not far to the west. The faulting and related deformation within the Tats Lake sheet, could in part have arisen from large-scale displacements on those major faults.

Fold styles exhibited by strata within the 114P/12 map area are quite variable. Rocks of unit lPm just beyond the southeasternmost edge of the map sheet, appear to be monotonously northwest-striking and steeply northeast-dipping. Similarly striking and dipping, low grade metasediments of unit lPs east of Tats Lake, display kink-bands in shallow, southwestward-dipping, conjugate joints. Rocks of unit lPs are also disposed in shallow-amplitude, fairly upright, minor folds on the steeply northward-dipping, southern limb of the syncline to the northwest of Windy Craggy. South of the Rime showing, sediments of unit μTrp occur in tight, long-limbed, upright, isoclinal folds, while to the west of lower Tats Glacier they are strongly kink-banded. Adjacent to the volcanics of unit μTrv at Windy Craggy, these Upper Triassic sediments are locally moderately to intensely deformed into small-scale, variably plunging, disharmonic, isoclinal folds, and into relatively open, larger-scale folds. Volcanic strata of unit μTrv south of Windy Craggy, are mostly northwest-striking and steeply northeastward or southeastward dipping. The age(s) of this folding is not known. However, some of the folding may have resulted from the late Mesozoic to Tertiary strike-slip fault-related deformation that is already well documented in the 114P/10 map area, and in the Saint Elias Mountains region as a whole.

The main mineral prospects in the Tats Lake 114P/12 map area include the following.

Windy Craggy: a potentially very large, strata-bound massive sulphide deposit is within complexly folded, fine-grained clastics, carbonates, and minor basic volcanics and subvolcanic intrusives of unit μTrp, close to the contact of these rocks with extensive basaltic-andesitic pillow lava of unit μTrv, collectively mostly of Norian age; mineralization comprises pyrite, chalcopyrite, pyrrhotite, and sphalerite, and contains Co and Au values (MacIntyre, 1983; 1984; Gammon and Chandler, 1986).

Tats: the showing comprises chalcopyrite-pyrrhotite-bearing massive sulphides, with Au and Ag values, and occurs in amygdaloidal basic volcanics of unit μTrv (MacIntyre, 1984).

Rime (Mus): the main showing (X) occurs in tightly folded, Early Norian (M.J. Orchard, pers. comm., 1985) limy argillites, associated with massive amygdaloidal dacitic flows; mineralization consists of a thin zone of banded pyrrhotite, chalcopyrite, and calcite, and contains Au and Ag values (MacIntyre, 1984).

PROPERTY VISITS

While staying at the Stryker/Freeport Resources Limited base camp, very brief visits were made to the Low Herbert and Grizzly Heights showings in the Mount Henry Clay area. Drilling programs were undertaken at both prospects by Stryker/Freeport Resources Limited during 1987.

The Low Herbert showing comprises a 100 m thick and 700 m long, yellow-orange gossan zone within a sequence of sheared, sericite-talc and chlorite-talc-altered acid tuff or flows (MacIntyre and Schroeter, 1985). These are overlain by basic pillow lava. The age of the host rocks is uncertain, but may be Late Triassic or late Paleozoic. Mineralization consists of bands of disseminated, fine-grained pyrite, less chalcopyrite, barite, and sphalerite.

The Grizzly Heights showing is close to the contact between calcareous argillite-siltstone and buffish-grey, more massively bedded limestone. Overlying these sediments are extensive basic tuffs and lava flows. Poorly preserved silicified coral and conodont collections from the carbonates appear to be of Devonian age (M.J. Orchard, pers. comm., 1986). Au values have been obtained from quartz-carbonate conjugate, gash-veins and breccia fills, probably arising from minor faulting. Boulders of massive pyrrhotite and pyrite and of bedded galena, sphalerite and barite, were found on the south-facing slopes above the Tsirku Glacier in the vicinity of Grizzly Heights.

A short visit was made to Squaw Creek Holdings (placer Au). A 74.5 oz. gold nugget was discovered there during July 1987.

During the stay at Geddes Resources Limited base camp at Tats air strip, visits were made to the Windy Craggy deposit and its immediate surroundings. Geddes Resources Limited is currently engaged in driving an adit to the deposit. During August 1987, they conducted a drilling program on the Tats showing, and on the north face of Windy Craggy Mountain.

Data and ideas were shared during a visit with the project geologist of St. Joe Canada Inc. During August 1987, that company in joint venture with Newmont Mines Limited undertook a drilling program from the ice surface, to explore a geophysical anomaly outlined under East Arm Glacier.

An informative day was spent in the Skagway 104M/15 map area with Mitch Mihalynuk of the British Columbia Geological Survey (BCGS), reviewing geological ideas 'on the outcrop'. The BCGS is commencing a 1:50 000 scale mapping program along the eastern edge of the Skagway (104M) map area.

ACKNOWLEDGMENTS

Very capable field assistance was given by Phil Benham in 1986 and by Shane Dennison in 1987. Pilots Dennis Cassidy (Tundra Helicopters Ltd.) and James Clancy (Airlift Corp.) provided safe and efficient helicopter support during 1986-87 and 1987. The writer particularly wishes to thank Doug Perkins and Bill Clark of Stryker/Freeport Resources Limited, and Mary Webster and Doug Little of Geddes Resources Limited for generous logistical support, the use of facilities at their base camps, and the free exchange of ideas and data during 1986-87 and 1987. Thanks also are conveyed to Heinz Eckervogt of Squaw Creek Holdings for the property visit, to Jim Brisco and Dave Kennedy of St. Joe Canada Inc. for ready sharing of ideas and data, and to Christine Davis for draughting services.

REFERENCES

Berg, H.C., Jones, D.L., and Coney, P.J.
1978: Map showing pre-Cenozoic tectonostratigraphic terranes of southeastern Alaska and adjacent areas; United States Geological Survey, Open File Report 78-1085, 2 sheets.

Campbell, R.B. and Dodds, C.J.
1975: Operation Saint Elias, Yukon Territory: *in* Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 51-53.
1978: Operation Saint Elias, Yukon Territory; *in* Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 35-41.
1979: Operation Saint Elias, British Columbia: *in* Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 17-20.
1982a: Geology of S.W. Kluane Lake map area (115G and F (E1/2), Yukon Territory; Geological Survey of Canada, Open File 829.
1982b: Geology of Mount St. Elias map area (115B and C (E1/2)), Yukon Territory part; Geological Survey of Canada, Open File 830.
1982c: Geology of S.W. Dezadeash map area (115A), Yukon Territory; Geological Survey of Canada, Open File 831.
1983a: Geology of Tatshenshini River map area (114P), British Columbia; Geological Survey of Canada, Open File 926.
1983b: Geology of Yakutat map area (114O), British Columbia; Geological Survey of Canada, Open File 927.
1983c: Terranes and major faults of the Saint Elias Mountains, Yukon Territory, British Columbia, and Alaska; Geological Association of Canada, Annual Meeting Victoria, Program with Abstracts, p. A10.

Campbell, R.B. and Eisbacher, G.H.
1974: Operation Saint Elias, Yukon Territory; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 74-1A, p. 11-12.

Carlson, P.R., Plafker, G., and Bruns, T.R.
1985: Map and selected seismic profiles of the seaward extension of the Fairweather Fault, eastern Gulf of Alaska; United States Geological Survey, Map MF-1722, 2 sheets.

Christopher, P.A., White, W.H., and Harakal, J.E.
1972: K-Ar dating of the 'Cork' (Burwash Creek) Cu-Mo Prospect, Burwash Landing area, Yukon Territory; Canadian Journal of Earth Sciences, v. 9, p. 918-921.

Clague, J.J.
1979: The Denali Fault System in southwest Yukon Territory — A geologic hazard?; *in* Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 169-178.

Dodds, C.J. and Campbell, R.B.
— Potassium-Argon ages of mainly intrusive rocks in the Saint Elias Mountains, Yukon and British Columbia; Geological Survey of Canada, Paper.

Eisbacher, G.H.
1975: Operation Saint Elias, Yukon Territory: Dezadeash Group and Amphitheatre Formation; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 61-62.
1976: Sedimentology of the Dezadeash flysch and its implications for strike-slip faulting along the Denali Fault, Yukon Territory and Alaska; Canadian Journal of Earth Sciences, v. 13, p. 1495-1513.

Gammon, J.B. and Chandler, T.E.
1986: Exploration of the Windy Craggy massive sulphide deposit, British Columbia; *in* Geology in the real world — the Kingsley Dunham volume, The Institution of Mining and Metallurgy, p. 131-141.

Jacobson, B., Parrish, R.R., and Armstrong, R.L.
1980: Geochronology and petrology of the Tkope River batholith in the Saint Elias Mountains, northwestern British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 80-1B, p. 195-206.

Kindle, E.D.
1953: Dezadeash map area, Yukon Territory; Geological Survey of Canada, Memoir 268, 68p.

MacIntyre, D.G.
1983: A comparison of stratiform massive sulphide deposits of the Gataga District with the Midway and Windy-Craggy deposits, northern British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1982, Paper 1983-1, p. 149-170.
1984: Geology of the Alsek-Tatshenshini rivers area (114P); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1983, Paper 1984-1, p. 173-184.

MacIntyre, D.G. and Schroeter, T.G.
1985: Mineral occurrences in the Mount Henry Clay area (114P/7,8); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1984, Paper 1985-1, p. 365-379.

MacKevett, E.M., Jr., and Plafker, G.
1974: The Border Ranges Fault in south-central Alaska; U.S. Geological Survey, Journal of Research, v. 2, no. 3, p. 323-329.

MacKevett, E.M., Jr., Robertson, E.C., and Winkler, G.R.
1974: Geology of the Skagway B3 and B4 quadrangles, southeastern Alaska; United States Geological Survey, Professional Paper 832, 33p.

Muller, J.E.
1967: Kluane Lake map area, Yukon Territory; Geological Survey of Canada, Memoir 340, 137p.

Plafker, G. and Campbell, R.B.
1979: The Border Ranges Fault in the Saint Elias Mountains; in Johnson, K.M., and Williams, J.R. et., The United States Geological Survey in Alaska; Accomplishments during 1978; United States Geological Circular 804-B, p. B102-B104.

Plafker, G., Hudson, T., Bruns, T., and Rubin, M.
1978: Late Quaternary offsets along the Fairweather Fault and crustal plate interactions in southern Alaska; Canadian Journal of Earth Sciences, v. 15, p. 805-816.

Read, P.B.
1976: Operation Saint Elias, Yukon Territory: pre-Cenozoic volcanic assemblages in the Kluane Ranges; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 187-193.

Read, P.B. and Monger, J.W.H.
1975: Operation Saint Elias, Yukon Territory: the Mush Lake Group and Permo-Triassic rocks in the Kluane Ranges; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 55-59.
1976: Pre-Cenozoic volcanic assemblages of the Kluane and Alsek ranges, southwestern Yukon Territory; Geological Survey of Canada, Open File 381, 96p.

Sharp, R.P.
1943: Geology of the Wolf (now Steele) Creek area, Saint Elias Ranges (now Mountains); Geological Society of America, Bulletin, v. 54, p. 625-650.

Sharp, R.P. and Rigsby, G.P.
1956: Some rocks of the central Saint Elias Mountains, Yukon Territory, Canada; American Journal of Science, v. 254, p. 110-122.

Souther, J.G. and Stanciu, C.
1975: Operation Saint Elias, Yukon Territory: Tertiary volcanics; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 63-70.

Watson, K. DeP.
1948: The Squaw Creek-Rainy Hollow area, British Columbia; British Columbia Department of Mines, Bulletin 25, 74p.

Wheeler, J.O.
1963: Kaskawulsh (Mount St. Elias, east half), Yukon Territory; Geological Survey of Canada, Map 1134A.

Geology of southwestern Dawson map area, Yukon Territory

J.K. Mortensen
Lithosphere and Canadian Shield Division

Mortensen, J.K., Geology of southwestern Dawson map area, Yukon Territory; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 73-78, 1988.

Abstract

Mapping has provided a clearer understanding of the tectonic framework of the Yukon-Tanana terrane in western Yukon and of its styles of mineralization. Sedimentary and volcanic rocks and granitoids, in part middle and upper Paleozoic, experienced strong ductile shearing at moderate metamorphic grades, and were imbricated by regional scale thrusts. Greenstone, ultramafic rocks and weakly deformed Early Mesozoic sediments were structurally interleaved with the metamorphic rocks along these thrust. Late Cretaceous and Early Tertiary volcanic and sedimentary rocks that unconformably overlie the imbricated metamorphic rocks, are locally tightly folded and faulted, particularly adjacent to the Tintina fault zone.

Mineralization includes asbestos in serpentinite, stratabound, possibly syngenetic base metal occurrences in metasediments and metavolcanics, W-Mo porphyries and skarns associated with Late Cretaceous and Tertiary intrusives, galena-arsenopyrite-quartz and cinnabar-barite-quartz veins cutting metamorphic rocks, and galena-sphalerite-tetrahedrite (± stibnite) veins and disseminations in quartz-carbonate altered ultramafics.

Résumé

Des levés nous ont permis de mieux comprendre le cadre tectonique du terrane du Yukon et de Tanana dans l'ouest du Yukon, ainsi que les styles de minéralisation qui le caractérisent. Les roches volcaniques et sédimentaires et les roches granitoïdes, en partie du Paléozoïque moyen et supérieur, ont subi un fort cisaillement ductile à des degrés modérés d'intensité métamorphique, et ont ensuite été imbriquées les unes dans les autres par des failles chevauchantes, à l'échelle régionale. Des roches vertes, des roches ultramafiques et des sédiments faiblement déformés du Mésozoïque inférieur se sont trouvées intercalées dans les roches métamorphiques le long de ces chevauchements. Les roches volcaniques et sédimentaires du Crétacé supérieur et du Tertiaire inférieur qui recouvrent en discordance les roches métamorphiques imbriquées, montrent localement des plis serrés et un grand nombre de failles, en particulier à proximité de la zone faillée Tintina.

Parmi les minéralisations, citons la présence d'amiante dans les serpentinites, des venues stratiformes et peut-être syngénétiques de métaux communs dans des roches métasédimentaires et métavolcaniques, des porphyres et skarns enrichis en W-Mo, associés à des roches intrusives du Crétacé supérieur et du Tertiaire, des filons de galène, arsénopyrite et quartz et filons de cinabre, barytine et quartz qui recoupent des roches métamorphiques, et des filons de galène, sphalérite et tétraédrite (±stibnite) et des disséminations dans des roches ultramafiques altérées en quartz et carbonates.

INTRODUCTION

The Dawson map area (NTS 116 B, C) is underlain by rock units belonging to two separate tectonic assemblages, which are separated by the Tintina fault zone (Green, 1972). Underlying about 80 per cent of the map area northeast of the fault zone are strata that are mapped as continuous with those of the Selwyn Fold Belt. The southwestern part of the map area, however, is mainly underlain by strongly deformed and metamorphosed rocks variously called the Yukon Crystalline Terrane (e.g. Tempelman-Kluit, 1976), the Yukon Cataclastic Complex (Tempelman-Kluit, 1979), the Yukon-Tanana terrane (Monger and Berg, 1984), and/or the Kootenay terrane (Wheeler, 1987). The term Yukon- Tanana terrane has been retained in this contribution.

The northeastern portion of the Dawson map area has been re- mapped by R. Thompson, C. Roots and P. Mustard. In this study, fifteen weeks were spent by the writer in 1986 and 1987 re-mapping the southwestern part of the map area, which lies within the unglaciated part of the Yukon Plateau. Exposure is very limited, occurring mainly along road cuts and major stream and river valleys, and as sporadic outcrops on ridge crests. The Yukon and Sixtymile Rivers, Top-of-the-World highway and Clinton Creek mine access road (Fig. 1) provide lines of semi-continuous exposure across the area. An extensive network of secondary roads and bulldozer trails, mostly constructed during mineral exploration and placer mining activity over the past two decades, permit access to many of the intervening areas. Despite the poor exposure, lithologic units can often be traced with considerable confidence by mapping the distribution of rock types in colluvium, subcrop and, in some instances, stream gravels.

Sampling for microfossil and isotopic age determinations was carried out during the course of the mapping. The results of the study thus far provide a clearer understanding of the tectonic framework of the Yukon-Tanana terrane in western Yukon, and on the nature and geological setting of base and precious metal and asbestos occurrences in the area.

In this paper, the main lithologic assemblages, and their observed and inferred relationships to one another are briefly described. Also included are brief discussions of the structural geology of the area, and styles of mineralization present.

LITHOLOGICAL ASSEMBLAGES

Bedrock in the map area can be divided into a number of regionally mappable assemblages, based on lithology and, to some extent, on metamorphic grade and degree of deformation. These assemblages are:

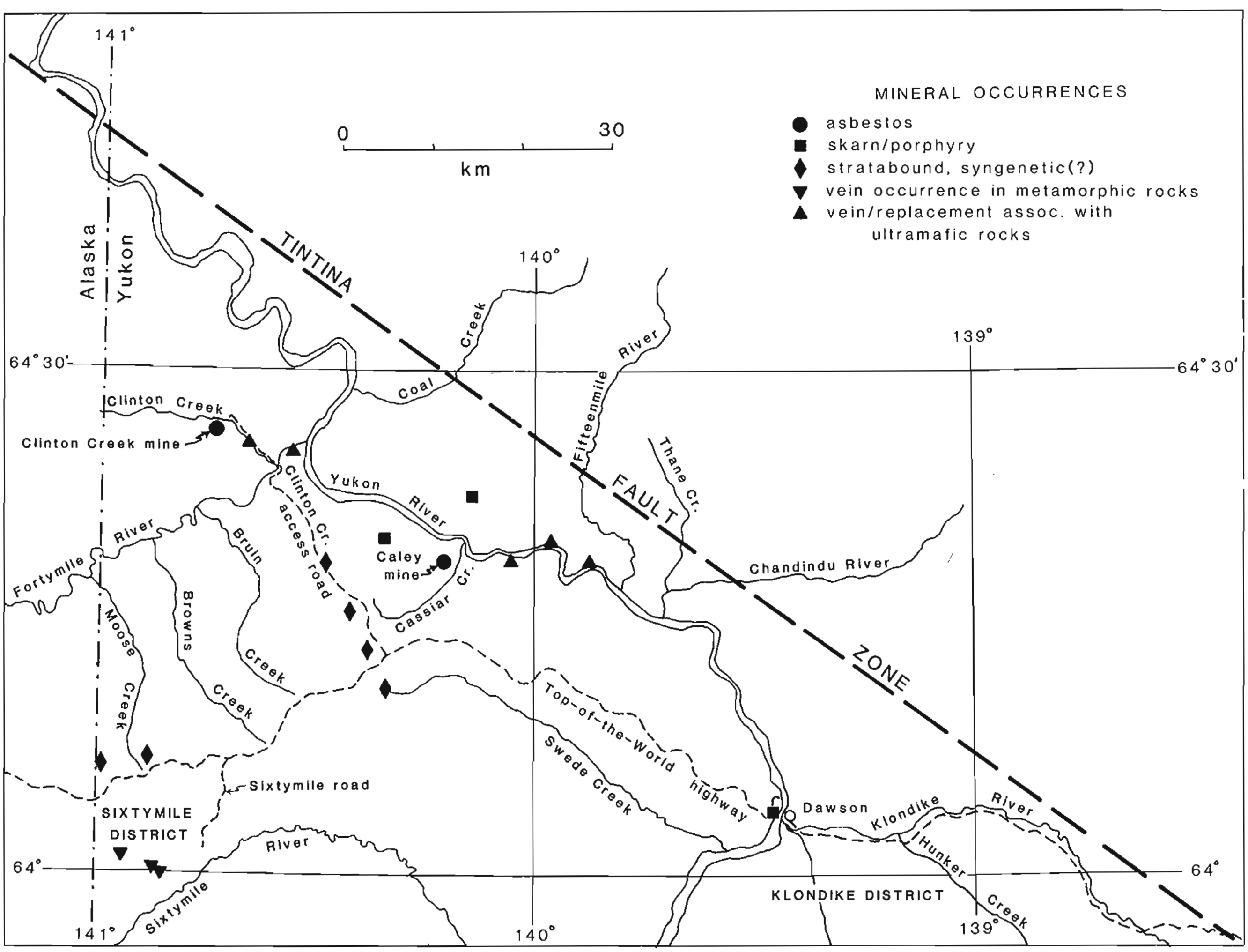


Figure 1. Location map for southwestern Dawson map area showing selected mineral occurrences.

1) penetratively deformed, typically well foliated, medium grade metasedimentary and meta-igneous rocks;
2) massive to weakly foliated greenstone and ultramafic rocks and their altered equivalents;
3) weakly deformed and metamorphosed sediments and volcanic rocks;
4) unaltered olivine basalts;
5) a variety of undeformed mafic to felsic intrusions.

Penetratively deformed metamorphic rocks

This assemblage, which underlies most of the study area, was originally divided by Green (1972) into three main units; Unit A, comprising metamorphic rocks of sedimentary origin; Unit B, consisting mainly of muscovite, quartz-muscovite and chlorite schists, and Unit D, granitic gneiss. These units correlate with McConnell's (1905) Nasina series, Klondike schist, and Pelly gneiss, respectively. This threefold subdivision of the metamorphic rocks remains useful at a regional scale; however, where exposure and traverse density permit, a considerably more detailed lithologic breakdown has been possible.

Rocks mapped by Green (1972) as Unit A consist predominantly of medium to dark grey and grey-brown, fine-grained, carbonaceous quartz-muscovite ($\pm$chlorite, biotite) schist. Thinly banded, pale to dark grey, fine-grained quartzite and micaceous quartzite is also abundant. Massive to moderately foliated, fine- to coarse-grained marble occurs as bands within the carbonaceous schists. Some bands are up to 100 m in thickness and can be traced in outcrop and float for over 10 km. A variety of other rock types are also present within the schists. These include stretched pebble conglomerate, which occurs in a number of localities in the southern and western part of the map area, and foliated quartz grits that have been observed along the Yukon River between Fifteenmile River and Cassiar Creek (Fig. 1).

Although narrow bands of medium to dark green chloritic schist and amphibolite occur within the carbonaceous metasedimentary package throughout the map area, these lithologies become abundant near the Yukon-Alaska boundary. Well foliated to nearly massive amphibolite with minor interbanded carbonaceous schists are well exposed along the middle parts of Moose Creek and Browns Creek (Fig. 1). In some places, a well preserved relict igneous texture suggests derivation from mafic to intermediate composition intrusions. The amphibolites pass structurally upwards, downwards and laterally into carbonaceous schists, quartzites and marbles.

Non-carbonaceous muscovitic and chloritic schists (Unit B of Green, 1972, or ''Klondike schist'') occur in two main areas, in the northern part of the Klondike District and the northern part of the Sixtymile District (Fig. 1). They also outcrop sporadically along the Yukon River downstream from Dawson. Detailed mapping in the Klondike by the writer and by Debicki (1984) has lead to the subdivision of the ''Klondike schist'' into chlorite-rich and muscovite- rich members thought to have been derived from mafic and felsic volcanic or volcaniclastic rocks, respectively. Also present in the Klondike are strongly foliated quartz and feldspar augen schist (metaporphyry) and fine-grained quartzose metasediments.

''Klondike schist'' in the Sixtymile District is more homogeneous in composition, consisting almost entirely of pale to medium green, well foliated, quartz-muscovite-chlorite schist with nearly ubiquitous quartz and rare feldspar augen to 4 mm in diameter. In some localities, the augen are subhedral to euhedral, suggesting that the rocks were derived from quartz and feldspar porphyries.

Most earlier workers (e.g. McConnell, 1905; Cockfield, 1921) ascribed an igneous protolith to the ''Klondike schist'' of the Klondike and Sixtymile districts; however, Green (1972) argued that the unit was entirely metasedimentary. Although textural and bulk compositional evidence supports an igneous protolith for much of the unit, a substantial metasedimentary component cannot be ruled out.

Much of the area north and west of the Klondike District mapped by Green (1972) as Unit B is compositionally distinct from ''Klondike schist'' in its type area. These rocks are well exposed both along the Yukon River for about 30 km downstream from Dawson, and along the Top-of-the-World highway west of the Yukon River. They consist largely of tan to locally pale green weathering fine grained quartzite, and quartz-muscovite-chlorite schist. Narrow interbands of medium to dark green chlorite schist and metagabbro, and rusty weathering muscovite schist are present locally, but are volumetrically minor. This sequence is distinguished from Unit A (''Nasina series'') by the virtual absence of carbonaceous rocks. Well-banded schists and gneisses along Yukon River between Cassiar Creek and Fortymile River (Fig. 1) may be higher metamorphic grade equivalents of these units.

Well foliated to nearly massive granitic gneisses (Unit D of Green, 1972) underlie a large area along the Sixtymile River (Fig. 1). These gneisses form the northern part of the Fiftymile Batholith (Tempelman-Kluit and Wanless, 1980). The rocks consist mainly of quartz, feldspar and biotite, locally with up to 10 % hornblende, with bulk (modal) compositions ranging from quartz diorite to granodiorite. A pronounced banding, defined both by variations in grain size and by minor variations in composition, is common and is particularly strongly developed near contacts with adjacent rocks.

Granitic gneisses occur in several other localities in the map area. A band of quartz-feldspar-hornblende-biotite gneiss approximately 2.5 km wide crosses Moose Creek 6 km from its head. A large exposure of granitic gneiss was also observed on lower Miller Creek and on the Yukon River 19 km downstream from Coal Creek (Fig. 1).

Preliminary U-Pb zircon ages have been obtained for two samples of meta- igneous rock from the penetratively deformed assemblage in the study area. Zircon from a narrow band of strongly foliated and mylonitized quartz-feldspar augen schist (metaporphyry) within carbonaceous ''Nasina series'' schist and quartzite along the Clinton Creek mine access road (Fig. 1) yields a mid- Permian crystallization age. Zircon from feldspar augen schist within ''Klondike schist'' near the head of Moose Creek (Fig. 1) is also mid-Permian in age. The granitic gneisses have not yet been dated in the study area; however, a Late Devonian-Early Mississippian U-Pb zircon age was obtained from the same body about 22 km south of the map area (Mortensen, 1986). Attempts to recover conodonts from some of the marble units in the area have as yet proven unsuccessful (M. Orchard, personal communication).

Greenstones and ultramafic rocks

Massive to sheared greenstone and altered ultramafic rocks are a widespread but volumetrically minor component in the map area. The greenstones are most abundant near Dawson, along the Yukon River between Dawson and Cassiar Creek, and along Clinton Creek (Fig. 1). They include medium to dark green weathering, fine-grained, epidote- rich metavolcanic rocks as well as altered diabase, and minor altered gabbro. In some localities in the metavolcanic rocks, a vague layering is present, probably reflecting a tuffaceous origin. In several large outcrops along the Yukon River, a coarse fragmental texture is preserved, and at one locality calcite-filled amygdules and faint lobate structures suggestive of pillows have been observed. The greenstones are generally unfoliated, except where they have experienced brittle shearing adjacent to fault zones, and the alteration mineral assemblages do not appear to be related to a regional deformation event.

Serpentinite occurs in association with greenstone and as isolated bodies. Serpentinite ranges from massive to very strongly sheared (''fish-scale texture'') along anastomosing, subparallel brittle shear planes. In some of the massive varieties, shreds of primary orthopyroxene are preserved, suggesting derivation from harzburgite. Chrysotile cross- and slip-fibre veins are common, and reach economic grades and tonnages at the Clinton Creek and Caley mines (Fig. 1).

The serpentinites have been further altered to a variety of other rock types. Partial to complete replacement by ferroan carbonate, quartz (often chalcedonic) and bright green, Cr-bearing mica is common, particularly near the margins of serpentinite bodies. The resulting rock is typically massive and rusty tan to orange weathering. Carbonate replacing asbestos fibre has been noted in several localities. Excellent examples of this rock type occur both in the Clinton Creek mine open pit and along the main mine access road along Clinton Creek (Fig. 1). Other rock types apparently derived from the serpentinites include massive to well-foliated talc and talc-carbonate schist and fine-to coarse-grained actinolite gneiss.

Weakly deformed sedimentary and volcanic rocks

Three lithologically distinct sequences of weakly deformed and metamorphosed sedimentary and volcanic rocks occur in the area. Recessive weathering, medium to dark grey and grey-brown, thin bedded shale, siltsone, argillaceous limestone and minor sandstone underlies a large area along Clinton Creek from its mouth to the Yukon-Alaska boundary. Scattered outcrops of this sequence also occur along lower Fortymile River and north of the Yukon River just downstream from Fifteenmile River (Fig. 1). The rocks are generally unfoliated, but locally a slaty cleavage or phyllitic parting is developed parallel to axial planes of tight mesoscopic folds. This unit was only seen in tectonic contact with adjacent rocks, and internal brittle shearing and brecciation is very common. A single conodont fragment, thought to be of Middle or Late Triassic age, was recovered from an exposure at the Clinton Creek mine (Abbott, 1983).

A large area within the Sixtymile District and along ridge crests to the north and east are underlain by a sequence of volcanic flows and breccias with minor intercalated sediments. This sequence overlies multiply deformed metamorphic rocks with marked angular unconformity. The volcanic rocks are typically porphyritic, with nearly ubiquitous plagioclase, less abundant pyroxene, and rare hornblende phenocrysts. The lavas in the Sixtymile District have been studied by Glasmacher (1984), who determined that they are predominantly andesites, but include rare dacite and basaltic andesite. Subvolcanic dykes and plugs are also present. The volcanic rocks are commonly altered to clay mineral, carbonate and chlorite assemblages.

Sediments associated with the volcanic rocks consist predominantly of weakly cemented coarse sandstone and pebble and cobble conglomerate. White to dark grey quartzite, siliceous schist, and white vein quartz make up nearly all of the clasts present. Minor siltstone, rare coal horizons, and fine-grained tuff beds that weather to bright orange and dark red hues also occur locally. The coarse-grained sediments form a nearly continuous band at the base of the volcanic sequence, but also occur interlayered with the volcanics at higher stratigraphic levels.

The outcrop pattern of the volcanic-sedimentary package has been complicated by post-depositional folding and faulting, and although a total thickness is difficult to estimate accurately, it probably exceeds 400 m.

No fossil or isotopic ages have been obtained as yet from this sequence within the map area. The rocks are probably Cretaceous and/or Tertiary in age, based on correlations with well-dated, lithologically similar sequences 30 km south of the study area (Lowey, 1983, 1984; Lowey et al., 1986).

Shale, arkosic and micaceous sandstone and poorly sorted conglomerate, locally containing minor lignite, occur in a band from 1.5 to 7 km wide along the trace of the Tintina Fault Zone (Green, 1972, Hughes and Long, 1980). These rocks were not examined but a similar sequence occurs along the Yukon River 5 km above Chandindu River (Fig. 1) where immature fine to coarse clastic rocks unconformably overlie grey quartz- mica schist, quartzite and massive greenstone breccias. Overlying the sediments are bedded tuffs and massive volcanic flows of mafic to intermediate composition.

Eocene plant fossils have been recovered from coal-bearing portions of the sedimentary package within Tintina fault zone at Cliff Creek, Coal Creek and Thane Creek (Fig. 1) (Green, 1972; Hughes and Long, 1980).

Olivine basalt

Unaltered olivine basalt of Tertiary or Quaternary age occurs in several localities in the study area. These rocks contain olivine phenocrysts, olivine and pyroxene xenocrysts, and rounded peridotite nodules to 5 cm in diameter. A small body of basalt on the Sixtymile road (Fig. 1) includes both massive and highly scoriaceous varieties, both of which contain abundant xenoliths of the underlying schists and Cretaceous-Tertiary sediments. Olivine basalt also occurs as locally derived boulders to 1 m diameter in the headwaters of Moose Creek about 15 km northwest of the Sixtymile occurrence, and as a small body capping massive greenstone 2.5 km west of the mouth of Clinton Creek (Fig. 1). The final locality where the basalts have been observed is on the west side of the Yukon River, 5.5 km upstream from Fortymile River. Here an apparently valley-filling accumulation about 100 m thick of massive to horizontally bedded debris flow material consisting mainly of olivine basalt is capped by 25 m of spectacularly columnar-jointed basalt.

Intrusive rocks

Undeformed intrusive rocks form narrow dykes, sills and small plugs, as well as large plutons. Two distinct compositions are represented by the smaller bodies. One consists of dark brown weathering diabase and plagioclase-phyric basalt, while the other is a tan to rusty tan weathering, quartz-feldspar porphyry. Both occur sporadically throughout the map area, but only appear to be abundant in the northern Klondike District and along the Yukon River below Dawson. A large body of smoky quartz-feldspar porphyry underlies much of the ridge between Hunker Creek and the Klondike River (Fig. 1). Subparallel mafic and quartz-feldspar porphyry dykes that strike from 120 to 160 and dip steeply southwesterly to vertical are well exposed along the Yukon River between Dawson and Fifteenmile River (Fig. 1). Here quartz-feldspar porphyry dykes are seen cross-cutting mafic dykes, demonstrating that the felsic dykes are at least in part younger than the mafic ones. K-Ar whole-rock ages of 59.4 Ma and 56.1 Ma have been obtained for a quartz-feldspar porphyry stock south of Cassiar Creek (Tempelman-Kluit, 1981; I. Paterson, personal communication, 1986) and in northern Klondike District (R. Debicki, personal communication, 1984), respectively. The mafic dykes have not yet been dated isotopically.

Large plutons of equigranular, fine- to medium-grained hornblende-biotite granodiorite occur east of the Yukon River below Cassiar Creek and west of the Yukon River about 10 km upstrean from the Yukon-Alaska border (Fig. 1). Wide hornfels zones surround these bodies. Several other compositionally similar plugs and small stocks are also present. A K-Ar biotite age of 64.9 Ma has been obtained from a small granodioritic intrusion 8 km west of the Clinton Creek mine (Htoon, 1981). Hornblende from a small granodiorite plug on Hunker Creek in the northern Klondike District just south of the map area (Fig. 1) yielded a K-Ar age of 63.6 Ma (R. Debicki, personal communication, 1984). Biotite from a small biotite-pyroxene monzonite body northwest of Cassiar Creek that may be related to the granodiorite suite was dated at 92 Ma by K-Ar (I. Paterson, personal communication, 1986). Some question therefore still remains about the age of this suite.

DEFORMATION AND METAMORPHISM

Although scarcity of outcrop precludes a detailed structural analysis, a generalized sequence of deformation and metamorphism can be recognized. The earliest fabric identified is the penetrative, layer-parallel recrystallization foliation that characterizes the medium grade metamorphic rocks of the "Nasina series", "Klondike schist" and other unnamed metamorphic units in the area. This foliation is generally shallow to moderately dipping. In rock units derived from relatively coarse grained protoliths (such as the granitic gneisses and augen schists) mylonitic fabrics are preserved. Fold hinges associated with the early fabric are extremely rare. This early deformation (F1) was associated with metamorphism at chlorite to biotite grade throughout much of the map area; however, the metamorphic grade increases to the southwest and west, and most of the metamorphic rocks southwest of Swede and Bruin creeks (Fig. 1) are at garnet grade. It is probable that mylonitic textures related to F1 were originally present throughout the metamorphic sequence, but have been largely annealed during subsequent metamorphism. Large amounts of ductile shearing and transposition of lithologic contacts into parallelism with the F1 schistosity is therefore implied, and stratigraphic reconstructions within the metamorphic sequence must be attempted with great caution.

Greenstone and altered ultramafic rocks are clearly in thrust contact with adjacent metamorphic and sedimentary rocks in a number of localities in the map area, and by analogy to structural interpretations elsewhere in the Yukon-Tanana terrane (e.g. Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Foster et al., 1985), are interpreted to be confined to zones of thrust faulting. The weakly deformed Triassic(?) sediments occur with the greenstones and ultramafic rocks and also appear to be entirely bounded by thrust faults. An implication of this interpretation is that the metamorphic sequence has been imbricated by a series of thrust faults of regional extent. Although the inferred thrust faults are generally subparallel to the F1 schistosity, this schistosity is not present in the greenstones, ultramafic rocks or Triassic(?) sediments, and these units have not experienced as high metamorphic grade as is indicated by F1 mineral assemblages in surrounding metamorphic rocks. Thrust faulting therefore must postdate the F1 event.

At least one, and often two crenulation cleavages are present in the metamorphic rocks and locally in the greenstones, ultramafic rocks and Triassic(?) sediments. In some of the mica-rich portions of the "Klondike schist", these cleavages are very strongly developed, and the F1 schistosity and compositional layering is largely obscured. The cleavages are generally parallel to axial planes of small scale minor folds. It is uncertain whether the folds and fabrics are closely related to one another and were generated during progressive deformation, or whether several discrete deformation events are represented. Consistent patterns of superposition between two separate sets of folds and crenulation fabrics can be recognized in places; however, these relationships (and the orientation of the fabrics involved) are not continous throughout the map area. Since some of the minor folds deform the thrust faults, the folding must at least in part postdate thrusting. It is possible that the deformation and thrust faulting are related events.

Bedding in volcanic and sedimentary rocks in the Sixtymile District that contain neither the F1 nor subsequent crenulation fabrics have locally been deformed by small scale, northeast-southwest trending upright folds, and display dips of up to 56. The presence of large scale, northeast-southwest trending normal faults has also been inferred from map patterns shown by the volcanic-sedimentary sequence in this area, and from aerial photograph interpretation. Some of the folding may be related to drag along these faults.

Clastic sediments in the Tintina fault zone and interlayered sediments and volcanic rocks along Yukon River west of the fault zone are folded, faulted and often steeply dipping. This is not surprising in view of the close proximity to the Tintina fault zone, which is thought to be a major transcurrent fault along which at least 450 km of dextral offset has occurred in Late Cretaceous-Early Tertiary time (e.g. Tempelman-Kluit et al., 1976). Although strong topographic lineaments are present elsewhere in the map area (e.g. along Swede Creek, Fig. 1), little evidence was found for large scale steep faulting.

ECONOMIC GEOLOGY

A great variety of styles of mineralization occur in the map area. The locations of some of the main occurrences are shown on Figure 1. Nearly 1 million tonnes of asbestos fibre was recovered from serpentinite bodies at the Clinton Creek and Caley mines (Fig. 1). W-Mo porphyry mineralization within quartz-porphyry and W- and base metal-bearing skarns associated with a granodiorite pluton occur on both sides of the Yukon River below Cassiar Creek. Cu-Pb-Ag skarn mineralization occurs on the Yukon River opposite Dawson. Several small, stratabound, possibly syngenetic base metal (± barite) occurrences are hosted by carbonaceous schist and quartzite at the head of Swede Creek and along the Clinton Creek mine access road, and within ''Klondike schist'' near the headwaters of Moose Creek and Browns Creek (Fig. 1).

Galena- and arsenopyrite-bearing quartz veins and cinnabar-bearing quartz-barite veins cut metamorphic rocks in the bed of Miller Creek in the Sixtymile District. Pyrite, galena and sphalerite occur with quartz in veins and as breccia matrix within clay-altered and sericitized andesites in Sixtymile River valley at the mouth of Miller Creek.

An unusual type of mineralization occurs within quartz-carbonate altered ultramafic rocks 7 km below the mouth of Fifteenmile River (Silver City occurrence), along lower Fortymile River (Fortymile occurrence) and near the Clinton Creek mine site. It consists of galena, sphalerite and tetrahedrite (± stibnite) in quartz-ferroan carbonate veins and as fine disseminations in altered wall rock. Ag assays of up to several thousand grams per tonne have been obtained from the Silver City occurrence.

Although several of the mineral occurrences in the map area contain minor amounts of gold, the origin of most placer gold in the Klondike, Sixtymile and Fortymile placer gold districts remains largely unresolved. Also of interest is the placer gold, some quite coarse, that has been recovered from Moose Creek and the middle part of Browns Creek, for which no lode source is known.

ACKNOWLEDGMENTS

Peter Tyedmers provided capable and enthusiastic assistance during the 1987 field season. I thank Dirk Tempelman-Kluit for arranging helicopter support for the 1987 mapping program. Randy Parrish reviewed the manuscript and suggested a number of useful changes.

REFERENCES

Abbott, J.G.
1983: Origin of the Clinton Creek asbestos deposit; *in* Yukon Exploration and Geology 1982, Indian and Northern Affairs Canada, Whitehorse, p. 18-25.

Cockfield, W.E.
1921: Sixty Mile and Ladue Rivers area, Yukon; Geological Survey of Canada, Memoir 123, 60 p.

Debicki, R.
1984: Bedrock geology and mineralization of the Klondike area (west), 115 O/14, 15, 116 B/2, 3; Indian and Northern Affairs Canada, Open File map with marginal notes.

Foster, H.L., Cushing, G.W. and Keith, T.E.C.
1985: Early Mesozoic tectonic history of the Boundary area, east-central Alaska; Geophysical Research Letters, v. 12, p. 553- 556.

Glasmacher, U.
1984: Geology, petrography, and mineralization in the Sixty Mile River area, Yukon Territory, Canada (translated from German); unpublished diploma thesis, Technical University Aachen, Federal Republic of Germany.

Green, L.H.
1972: Geology of Nash Creek, Larsen Creek, and Dawson map- areas, Yukon Territory; Geological Survey of Canada, Memoir 364, 157 p.

Htoon, M.
1981: Isotopic age determinations of some metamorphic and igneous rocks from the Clinton Creek area, Yukon; *in* Yukon Geology and Exploration 1979-80, Indian and Northern Affairs Canada, Whitehorse, p. 65-67.

Hughes, J.D. and Long, D.G.F.
1980: Geology and coal resource potential of Early Tertiary strata along Tintina Trench, Yukon Territory; Geological Survey of Canada, Paper 79-32, 21 p.

Lowey, G.W.
1983: Report of 1982 field work in Early Tertiary clastics, west-central Yukon; *in* Yukon Exploration and Geology 1982, Indian and Northern Affairs Canada, Whitehorse, p. 34-37.
1984: The stratigraphy and sedimentology of siliciclastic rocks, west-central Yukon, and their tectonic implications; unpublished Ph.D. dissertation, University of Calgary, 310 p.

Lowey, G.W., Sinclair, W.D., and Hills, L.V.
1986: Additional K-Ar isotopic dates for the Carmacks Group (Upper Cretaceous), west-central Yukon; Canadian Journal of Earth Sciences, v. 23, p. 1857-1859.

McConnell, R.G.
1905: Report on the Klondike gold fields; Geological Survey of Canada, Annual Report, v. 14, p. B1-B17.

Monger, J.W.H. and Berg, H.C.
1984: Lithotectonic terrane map of western Canada and southeastern Alaska; U.S. Geological Survey, Open File 84-0523-B, p. B1-B31.

Mortensen, J.K.
1986: U-Pb ages of granitic orthogneiss in the Yukon-Tanana terrane in west-central Yukon: Selwyn Gneiss and Fiftymile Batholith revisited; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1A, p. 141-146.

Mortensen, J.K. and Jilson, G.A.
1985: Evolution of the Yukon-Tanana terrane: evidence from southeastern Yukon Territory; Geology, v. 13, p. 806-810.

Tempelman-Kluit, D.J.
1976: The Yukon crystalline terrane: enigma in the Canadian Cordillera; Geological Society of America, Bulletin, v. 87, p. 1343-1357.
1979: Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision; Geological Survey of Canada, Paper 79-14, 27 p.
1981: Pluto mining claims; *in* Yukon Geology and Exploration 1979-80, Indian and Northern Affairs Canada, Whitehorse, p. 288-289.

Tempelman-Kluit, D.J., Gordey, S.P., and Read, B.C.
1976: Stratigraphic and structural studies in the Pelly Mountains, Yukon Territory; *in* Current Research, Part A; Geological Survey of Canada Paper 76-1A, p. 97-106.

Tempelman-Kluit, D.J. and Wanless, R.K.
1980: Zircon ages for the Pelly Gneiss and Klotassin granodiorite in western Yukon; Canadian Journal of Earth Sciences, v. 17, p. 297-306.

Wheeler, J.O.
1987: Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Open File 1565.

Holocene sediments at McNaughton Lake, British Columbia

John J. Clague
Terrain Sciences Division, Vancouver

Clague, J.J., Holocene sediments at McNaughton Lake, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 79-83, 1988.

Abstract

A trench excavated across the floor of McNaughtonLake, British Columbia, in 1985 exposed a complexsuccession of Holocene sediments, mainly marl and peat, resting on glaciofluvial gravel deposited at the end of the Late Wisconsinan Fraser Glaciation Lateral facies changes and channelling in the Holocene succession may be a product of water level changes in the basin during the last 10 ka, although other explanations are possible.

Chronological control on Holocene sediments at McNaughton Lake is provided by six radiocarbon dates on bryophytes, shell, and wood, ranging from about 5700 to 9600 BP. Dates on bryophytes and shell may be too old due to old carbon effects; those on wood represent maximum ages for the enclosing sediments.

Résumé

Une tranchée creusée dans le fond du lac McNaughton en Colombie-Britannique, en 1985, a mis en évidence une succession complexe de sédiments holocènes, surtout composée de marnes et de tourbes, et reposant sur des graviers fluvio-glaciaires qui se sont déposés à la fin de la glaciation de Fraser, du Wisconsinien supérieur. Il est possible que les variations latérales de faciès et les cannelures que l'on observe dans la succession holocène soient le résultat des variations du niveau de l'eau dans le bassin au cours des 10 000 dernières années, mais d'autres explications sont possibles.

On a déterminé la chronologie des sédiments holocènes du lac McNaughton en effectuant six datations par le radiocarbone sur des bryophytes, des coquilles et du bois; l'âge déterminé se situe entre 5700 et 9600 BP. Les dates obtenues pour les bryophytes et les coquilles sont peut-être trop anciennes, dues à l'influence du carbone ancien; les dates obtenues pour le bois représentent les âges maximaux des sédiments encaissants.

INTRODUCTION

'McNaughton Lake', a small lake in Highland Valley, British Columbia (50°29.5'N, 121°02.5'W), was drained in early 1985 to allow expansion of an open-pit mine operated by Valley Copper Ltd. (Fig. 1, 2). During this operation, a wide trench up to about 10 m deep was excavated across the floor of the lake near its west end. Prior to collapsing in the summer of 1985, the walls of this trench provided excellent exposures of the Holocene fill in the basin (Fig. 3, 4).

On two occasions, during April and May 1985, I visited the site in order to examine the deposits exposed in the trench walls. During these visits, I documented the stratigraphy and facies relationships of the basin fill and collected samples for radiocarbon dating. This paper briefly summarizes the results of this work.

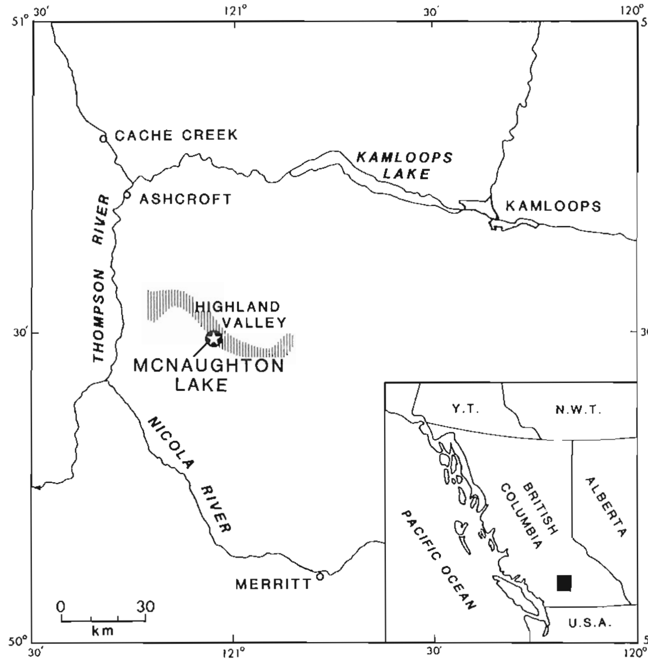


Figure 1. Location map.

STRATIGRAPHY AND FACIES RELATIONSHIPS

The lowest unit exposed in the McNaughton Lake trench is glaciofluvial pebble-cobble gravel of late Pleistocene age. This unit directly underlies the rolling and terraced floor of Highland Valley surrounding McNaughton Lake. It thins towards the sides of the valley where it can be seen to overlie till. The latter mantles bedrock on the walls of the valley and is particularly well exposed in the Valley Copper open pit south of the study site.

In the McNaughton Lake trench, glaciofluvial gravel is overlain by a Holocene succession comprising up to 6.5 m of shell-rich calcareous mud (marl), wood and moss peat, and minor sand which dip gently towards the centre of the basin. In detail, the following units are recognized (from bottom to top):

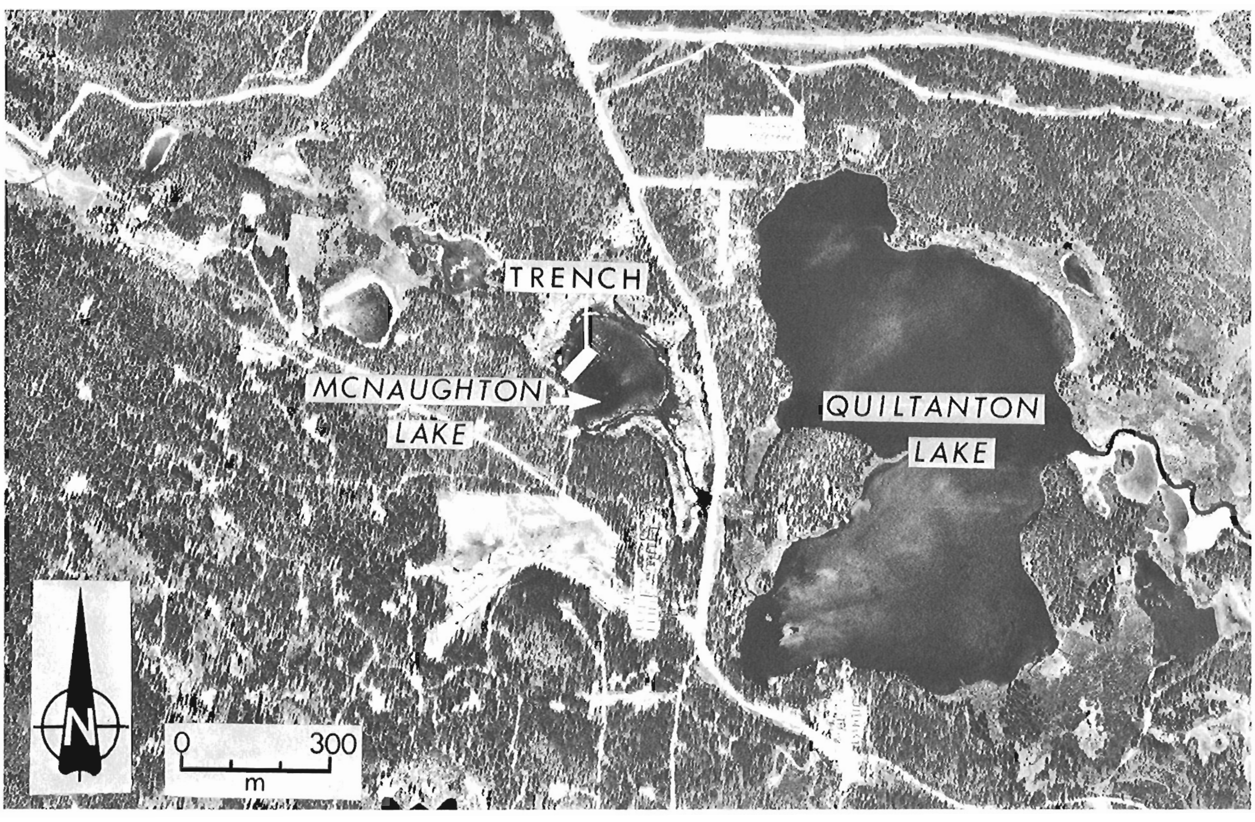


Figure 2. Airphoto of the study area showing the location of the trench excavated across the floor of McNaughton lake. This photo was taken in 1969, before the lake was drained. BC7122-261.

(1) Interfingering marl and sand (maximum exposed thickness = 1 m). The sand, which contains blocks of marl, appears to be restricted to the shallow (outer) part of the lake basin (Fig. 4).

(2) Subhorizontally stratified marl (maximum thickness = 3 m). Thin discontinuous beds of bryophytes occur within the marl about 1 m below the top of the unit.

(3) Interbedded peat and marl (maximum thickness = 4 m). The dominant material in this unit is detrital woody peat. Peat overlies unit 2 marl along the entire length of the trench. In most places, the contact between the two appears to be conformable; however, near the margin of the basin, peat fills a steep-sided channel cut into the marl (Fig. 3, 4). This channel is located off the mouth of an ephemeral stream that flows into the lake from the west. The lower part of unit 3 adjacent to this channel consists of moss peat, up to 50 cm thick, with thin discontinuous lenses of marl; bryophytes in this layer are in growth position. Farther towards the centre of the basin, the moss peat pinches out, and a wedge of marl appears between two beds of woody peat. This marl thickens in a down-dip direction towards the northeast. It conformably overlies the lower bounding peat bed, but is truncated at a low angle (ca. 5°) by the upper peat bed. A discontinuous layer of light grey, sandy tephra up to 5 cm thick occurs within this marl and also is truncated by the upper peat. Stringers of bryophytes are present locally near the top of the marl.

(4) Subhorizontally stratified marl (maximum thickness = 2.0 m). Stratification is defined by colour differences within the marl (light gray to yellowish brown). Unit 4 thickens towards the centre of the basin.

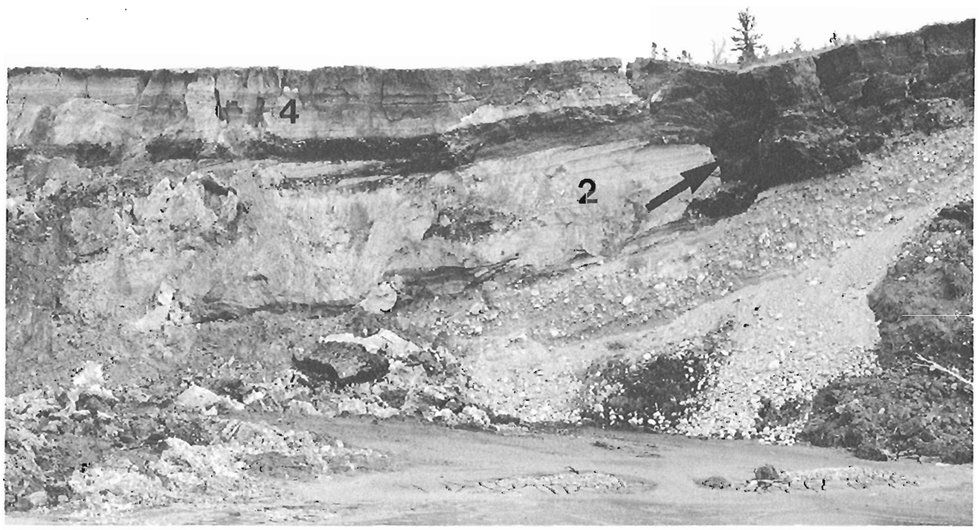


Figure 3. Photograph of the south end of the McNaughton Lake trench, May 1985. Numbered units are described in the text. Note the peat-filled channel cutting through units 1 and 2 (arrow). Compare with Figure 4.

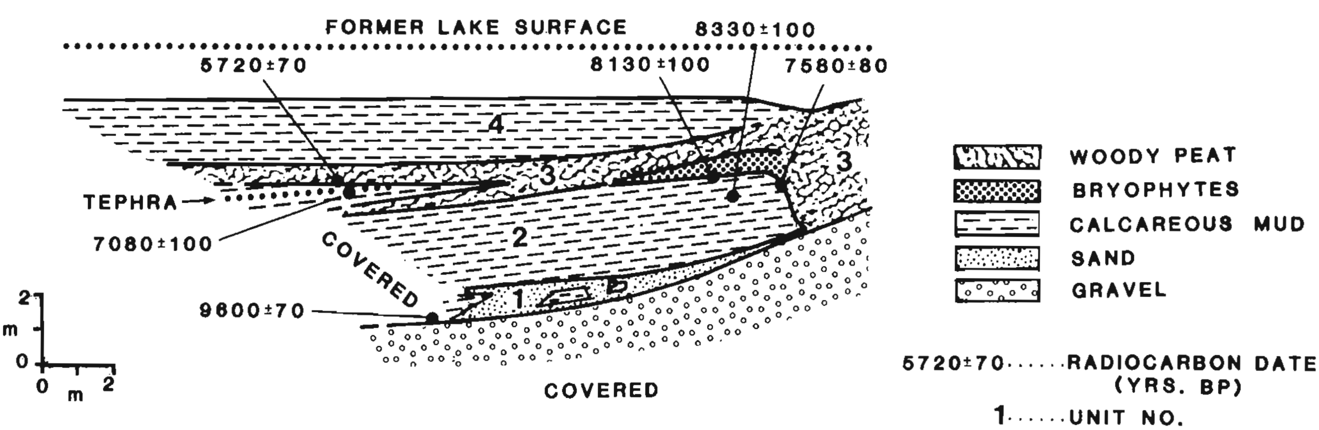


Figure 4. Line drawing of the south end of the McNaughton Lake trench. Compare with Figure 3.

RADIOCARBON AGE DETERMINATIONS

Six radiocarbon dates have been obtained on McNaughton Lake sediments (Table 1, Fig. 4). A single valve of the gastropod *Planorbella* (*Helisoma*) sp. from the lowest 5 cm of marl in unit 1 yielded an AMS (accelerator mass spectrometry) date of 9600±70 BP (TO-215). A thin bryophyte layer within unit 2, 1 m below the base of unit 3, was dated at 8330±100 BP (GSC-4046). Bryophytes from the base of the thick moss bed in unit 2 yielded a date of 8130±100 BP (GSC-4061). This is slightly older than a date on a piece of wood from the same stratigraphic position at the margin of the peat-filled channel (7580±80 BP, GSC-4050). A bryophyte stringer within the marl wedge in unit 3 gave a date of 7080 100 BP (GSC-4054). Finally, a piece of wood from the base of the peat layer overlying this marl wedge was dated by AMS at 5720±70 BP (TO-568); this sample was 2 cm above the tephra.

TEPHRA IDENTIFICATION

Elemental compositions of 16 glass-encased titano-magnetite grains from the tephra in unit 3 were determined with an electron microprobe and compared with reference titano-magnetites from the three common Holocene tephras in southern British Columbia (Mazama, 6800 BP; St. Helens Yn, 3400 BP; Bridge River, 2400 BP; Westgate *et al.*, 1970). Visual comparison and discriminant function analysis of the compositional data indicate that the tephra at McNaughton Lake is either Bridge River or Mazama. More than half of the analyzed grains most closely resemble reference Bridge River titano-magnetites, but about one-third show a closer affinity to the Mazama reference sample. The uncertainty regarding the exact identification of the McNaughton Lake tephra stems, in part, from the fact that the compositional fields of Bridge River and Mazama titano-magnetites are similar (King *et al.*, 1982; Beaudoin and King, 1986).

The relatively coarse texture of the McNaughton Lake tephra is perhaps more compatible with it being Bridge River than Mazama. On the other hand, the radiocarbon dates from unit 3 suggest that the tephra is Mazama (Table 1, Fig. 4). Unfortunately, some of these radiocarbon dates may be too old (see Discussion), thus the problem of identification of the McNaughton Lake tephra remains unresolved.

DISCUSSION

Paleoecological studies of the McNaughton Lake sediments have not yet been conducted, thus only a few general comments on Holocene paleoenvironments can be made at this time. McNaughton Lake probably came into existence about 10 000-11 000 BP, during or shortly after deglaciation of Highland Valley. The lake formed in a natural depression on Late Wisconsinan glaciofluvial sediments. The first organic sedimentation in the lake is recorded by marl of unit 1, dated ca. 9600 BP. While this marl was accumulating, sand was eroded from glaciofluvial sediments at the margins of the basin and transported across the lake floor. Blocks of marl were incorporated into the sand and rafted downslope. The sand, however, did not reach the centre of the basin (at least along the line of the trench).

Sand deposition in McNaughton Lake ended in the early Holocene. By 8000 BP (or later if the radiocarbon dates are too old), about 3 m of marl (unit 2) had accumulated in the deepest part of the basin. Subsequently, a 3-m deep channel was cut through this marl. A thick mat of bryophytes formed at the margin of this channel, and the channel itself was infilled with woody plant material (unit 3, in part). Plant debris also accumulated on the floor of the lake north of the channel.

Channel cutting and peat deposition may be the result of low water levels in the McNaughton Lake basin in middle Holocene time. Alternatively, they may signal an increase in the discharge of an inflowing stream or a shift in the course of such a stream. Whatever the explanation, deposition of peat was supplanted by renewed deposition of marl (unit 4) during middle or late Holocene time.

The establishment of a chronology for these events has proven to be frustratingly difficult. The reliability of at least some of the McNaughton Lake radiocarbon dates is uncertain. It is possible that 'old' carbon from lake or surface waters

Table 1. Radiocarbon age determinations

Age (yr BP)[1]	$\delta C^0/_{00}$	Lab. no.[2]	Dated material	Enclosing material	Depth (m)[3]	Collector
5720±70		TO-568	wood[4]	peat	2.0	J.J. Clague
7080±100	−36.1	GSC-4054	bryophytes	marl	2.4	J.J. Clague
7580±80	−22.9	GSC-4050	wood[5]	marl, peat	2.9	J.J. Clague
8130±100	−31.3	GSC-4061	bryophytes	marl, peat	2.8	J.J. Clague
8330±100	−32.0	GSC-4046	bryophytes	marl	3.1	J.J. Clague
9600±70		TO-215	shell[6]	marl	6.5	J.J Clague, R.W. Mathewes

[1] Errors for GSC dates represent 95% confidence limits; errors for TO dates represent 68% confidence limits.
[2] GSC- Geological Survey of Canada; TO — University of Toronto, IsoTrace Laboratory.
[3] Depth below former lake floor.
[4] Salix sp.
[5] *Pinus ponderosa/contorta;* GSC Wood Identification Report 85-24 by H. Jetté.
[6] *Planorbella (Helisoma)* sp.; identified by J.M. Topping (National Museum of Natural Sciences).

was incorporated into living bryophytes and freshwater invertebrates, making the McNaughton Lake moss and shell dates too old (see, for example, Clague, 1982; MacDonald et al., 1987). The wood dates are unlikely to suffer from this problem. However, these dates must be considered maxima for the age of enclosing sediments, because the dated wood is detrital (i.e., it has been transported).

CONCLUDING REMARKS

The results of this study have important implications for other studies of Holocene lacustrine sediments.

First, McNaughton Lake sediments display pronounced lateral facies variations. Variations of similar complexity probably characterize many Holocene lacustrine fills in British Columbia. Sedimentological and paleoecological studies of such fills require an understanding of the facies variability and three-dimensional geometry of the constituent sediments. Seismic profiles or a dense array of cores commonly are required for this purpose; one or two cores in isolation may yield a misleading picture of sedimentation in the basin.

Second, radiocarbon dates from lacustrine sequences must be interpreted cautiously. Detrital organic matter may be significantly older than the sediments that enclose it. In addition, aquatic organisms may yield anomalous radiocarbon dates due to old-carbon effects. These and other problems often can be overcome if a variety of materials are dated at different levels in a sedimentary sequence. It is hazardous to base a chronology on one or two radiocarbon dates from a core.

ACKNOWLEDGMENTS

W.J. McMillan (B.C. Ministry of Energy, Mines and Petroleum Resources) notified me in early 1985 that McNaughton Lake had been drained and trenched. Kevin Newman (Valley Copper Ltd.) allowed me to enter company property to study the McNaughton Lake sequence; he also provided onsite ground transportation. Roger H. King (University of Western Ontario) analyzed the McNaughton Lake tephra.

REFERENCES

Beaudoin, A.G. and King, R.H.
1986: Using discriminant function analysis to identify Holocene tephras based on magnetite composition: a case study from the Sunwapta Pass area, Jasper National Park; Canadian Journal of Earth Sciences, v. 23, p. 804-812.

Clague, J.J.
1982: Minimum age of deglaciation of upper Elk Valley, British Columbia: Discussion; Canadian Journal of Earth Sciences, v. 19, p. 1099-1100.

King, R.H., Kingston, M.S., and Barnett, R.L.
1982: A numerical approach toward the classification of magnetites from tephra in southern Alberta; Canadian Journal of Earth Sciences, v. 19, p. 2012-2019.

MacDonald, G.M., Beukens, R.P., Kieser, W.E., and Vitt, D.H.
1987: Comparative radiocarbon dating of terrrestrial plant macrofossils and aquatic moss from the "ice-free corridor" of western Canada; Geology, v. 15, p. 837-840.

Westgate, J.A., Smith, D.G.W., and Tomlinson, M.
1970: Late Quaternary tephra layers in southwestern Canada; in Early Man and Environments in Northwest North America, ed. R.A. Smith and J.W. Smith; University of Calgary, Archaeological Association, Calgary, Alberta, p. 13-33.

Organic petrology and depositional environment of a coal-bearing section from Blakeburn open cast mine in Tulameen, British Columbia

F. Goodarzi and E. Van Der Flier-Keller[1]
Institute of Sedimentary and Petroleum Geology, Calgary

Goodarzi, F. and Van Der Flier-Keller, E, Organic petrology and depositional environment of a coal-bearing section from Blakeburn open cast mine in Tulameen, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 85-90, 1988.

Abstract

Samples from the coal-bearing section at Blakeburn mine, Tulameen, British Columbia, were studied using reflected light microscopy. The boron contents of coal and some partings were also determined. Petrologically, the coal is similar to that from the Hat Creek coal deposit of British Columbia in that vitrinite is the dominant maceral group; inertinite macerals make up only a small part of the total composition. Evidence of three depositional cycles was observed, each representing a particular sedimentological and petrological environment of deposition. The coal in cycles I and II was deposited in a freshwater environment with an almost uniform rate of subsidence, whereas the coal in cycle III was formed in a freshwater environment subject to erratic subsidence.

Résumé

On a étudié des échantillons provenant de la section carbonifère de la mine de Blakeburn à Tulameen en Colombie-Britannique, en employant la microscopie en lumière réfléchie. On a aussi déterminé la teneur en bore du charbon et de certaines strates. Pétrologiquement, le charbon est semblable à celui du gisement houiller de Hat Creek en Colombie-Britannique, parce que la vitrinite est le groupe macéral dominant; les macéraux du type de l'inertinite ne constituent qu'une petite partie de la composition totale. On a observé des détails prouvant l'existence de trois cycles sédimentaires, dont chacun représentait un milieu sédimentologique et pétrologique particulier. Dans les cycles I et II, le charbon s'est déposé en eaux douces avec une vitesse presque uniforme de subsidence, tandis que dans le cycle III, le charbon s'est formé dans un milieu d'eaux douces soumis à une subsidence irrégulière.

[1] Department of Geography, University of Victoria, Victoria, British Columbia.

INTRODUCTION

Western Canadian coals can be divided into a. Mountain and Inner Foothills coals (Kootenay Group, Gates and Gething formations); b. Outer Foothills and Alberta Plains coals (Saunders, Belly River and Edmonton groups); c. Intermontane coals from British Columbia (various formations); and d. Saskatchewan coals (Ravenscrag Formation) (Darragh and Goodarzi, 1985).

The intermontane coals of British Columbia include some of the thickest low rank coal deposits in the world (Goodarzi, 1985; Goodarzi and Gentzis, 1987). Published petrological studies of these coals include those of Williams and Ross (1979); Goodarzi (1985); Marchioni (1985); Goodarzi (1987a); and Goodarzi and Gentzis (1987).

A systematic study of the organic petrology of these intermontane coals is currently being undertaken at the Institute of Sedimentary and Petroleum Geology. The intermontane coals are divided into northern and southern deposits. The southern interior coals include the Bowron River, Cariboo/Hat Creek, Merritt, Similkameen (Princeton-Tulameen) and Nicola coalfields.

The present study deals with coals from Blakeburn opencast mine (Mullin's strip mine), which is part of the Tulameen coalfield (Fig. 1). Underground mining in the area took place from 1919 to 1940, and opencast mining from 1954 to 1957.

Previous studies of these coals have included petrographic studies by Donaldson (1973) and Williams and Ross (1979), which indicated that vitrinite is the dominant maceral followed by liptinite, and also that these coals are poor in inertinite.

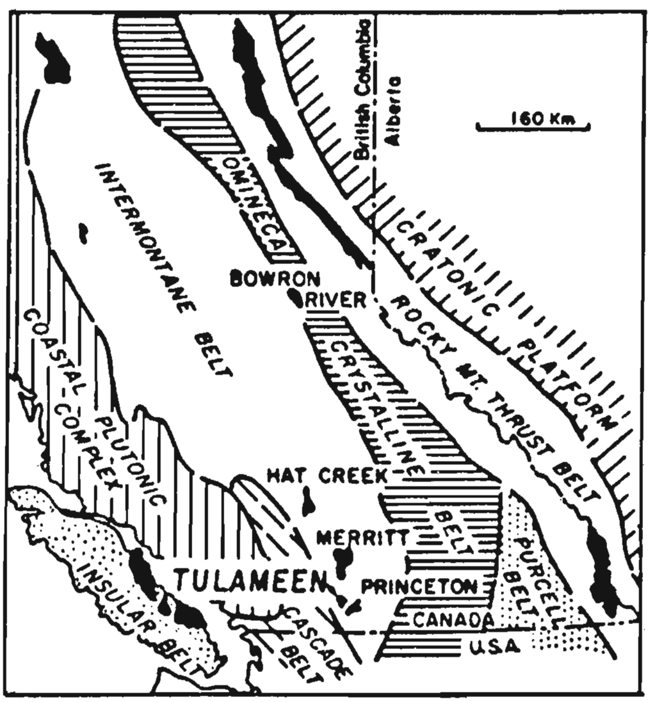


Figure 1. Locations of Eocene coal-bearing remnant basins (black), and their relationships to physiographic/geological belts of the Canadian Cordillera. (After Williams and Ross, 1979).

Geology

The Tulameen coal deposit is situated in one of several coal-bearing Eocene remnant basins occurring in the Intermontane Belt in southwestern British Columbia (Fig. 1). The deposit is located approximately 20 km northwest of Princeton, immediately west of Coalmont ($49_0 31'$N, $120^{\circ}41'$W). The Tulameen basin, which is elliptical in shape, contains Eocene Princeton Group volcanics and sedimentary rocks unconformably overlying Nicola Group volcanics of Triassic age (Figs. 2, 3) (Evans, 1977; Williams and Ross, 1979). Figure 3 shows the general stratigraphy in the Princeton-Tulameen area. The Allenby Formation (maximum thickness 800 m) consists of a coal- bearing member up to 30 m thick, underlain and overlain by shales and sandstones, and intercalated with volcanic material. The succession thickens from north to south (Evans, 1977; Williams and Ross, 1979) and is unconformably overlain by a basaltic cap of Miocene age.

The dominant structure in the basin is a broad, southeast-plunging, asymmetrical syncline (Evans, 1977; Church and Brasnett, 1983). In addition, there are a large number of high-angle faults offsetting the basin margin; some probably extend across the entire basin. The strata dip approximately 32_0 northeast in the vicinity of Blakeburn and range up to 60° and 70_0 (northeast or southwest) elsewhere in the basin.

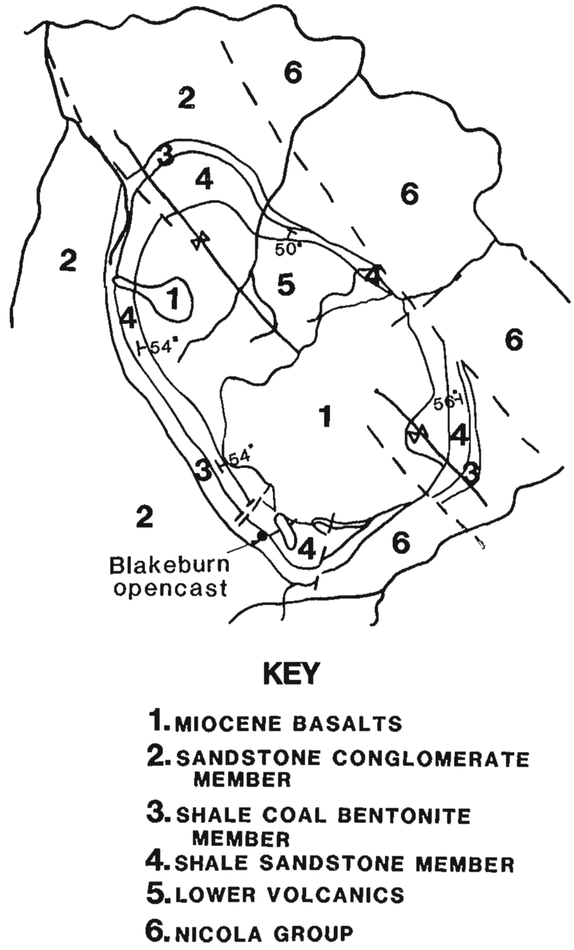


Figure 2. Geology of the Tulameen coal basin (modified from Evans, 1977).

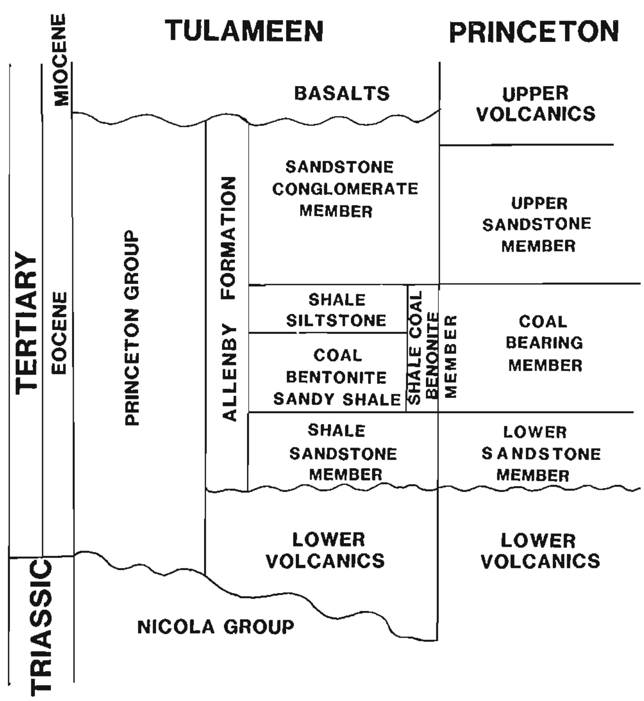


Figure 3. Generalized stratigraphy of the Tulameen and Princeton coalfields (modified from Williams and Ross, 1979; Evans, 1977).

The coal-bearing section at Blakeburn, which is situated toward the southwest margin of the basin (Fig. 2), is exceptionally thick (approximately 17 m). Up to 25 percent of the section consists of partings, which range from several millimetres to tens of centimetres in thickness, and include siltstones, shales, carbonaceous shales and tonsteins. The exposure at Mullins strip mine (Fig. 2) consists of an original section and an upper fault repeat of this section. Figure 4 shows only the lower section. The lateral extent of the exposed coal face of the lower section is approximately 150 m along the strike of the strata, and the partings are generally continuous throughout this length. However, thickness of individual layers may vary laterally. The lateral extent of the partings, particularly the tonsteins, indicates a quiet, lacustrine depositional environment.

Experimental

Channel samples of coals and partings from the coal-bearing section were collected. A coal sample represents a coal unit confined between two partings.

The rank of coal was determined by measuring the random reflectance in oil (n = 1.518) with a Zeiss MPM II microscope fitted with a Zonax microcomputer and printer, under standard conditions, following the procedure outlined in the International Handbook of Coal Petrology (1971). Boron content was determined using a sodium hydroxide fusion procedure, followed by inductively coupled plasma emission spectrometry (Pollock, 1975).

Organic petrology

The petrological variation in the Blakeburn coals is mainly within the vitrinite group of macerals. The high vitrinite content in these coals has been reported by Donaldson (1973), and Williams and Ross (1979). Liptinite macerals consist of resinite, cutinite and sporinite, and resinite is the dominant constituent in this group (Donaldson, 1973; Williams and Ross, 1979). The inertinite content is very low. A limited number of microlithotype analyses from a 1.7 m thick section of the coal seam indicates that vitrite and clarite are the dominant microlithotypes (Donaldson, 1973).

Goodarzi (1985) distinguished coal and sedimentary partings in Hat Creek No. 1 Coal Deposit on the basis of mineral matter or ash content: defining coal as having F 20 percent mineral content; and carbominerite with f20 percent mineral matter (data in volume percent).

The coal-bearing section in Blakeburn mine may be divided three major cycles, each representing a particular sedimentological and organic petrological environment of deposition (Fig. 4). Each cycle begins with coal and terminates either with a parting or with a mineral enriched layer.

Cycle I is 3.50 m thick and covers the lower part of the section. It consists of a 1.70 m thick coal seam at the base, a 0.50 m thick tonstein and carbominerite in the middle, and 1.30 m of coal and carbominerite on the top.

Cycle II is 9.65 m thick and consists mainly of coal with some thin partings of clastic sediments and tonstein (Fig. 4).

Cycle III is 2.40 m thick and consists mainly of carbominerite with three coal layers 5 to 27 cm thick (Fig. 4).

DISCUSSION

The petrographic characteristics of Blakeburn coals; for example, the high vitrinite and low inertinite contents, and the occurrence of resinite as the major maceral of the liptinite group, are similar to those described for Hat Creek No. 1 and No. 2 deposits (Goodarzi, 1985; Goodarzi and Gentzis, 1987), indicating a similar plant input and environment of deposition. Both the Hat Creek and Tulameen coal deposits are Eocene in age. A very humid, lacustrine environment is proposed for the Hat Creek coal deposits based on their petrology, which consists mainly of vitrinite macerals and an almost total absence of inertinite, with the exception of some occurrences of sclerotinite (Goodarzi, 1985; Goodarzi and Gentzis, 1987).

Vitrinite in Blakeburn coals consists of telocollinite and desmocollinite (Fig. 5) with telocollinite being the major component. This composition is similar to the Hat Creek coals, in which humotelinite (precursor of telocollinite) is the dominant maceral (Goodarzi, 1985). Different lithotypes can be deduced from maceral compositions and the associations of the macerals. These lithotypes are defined as bright, banded bright, and dull (Goodarzi, 1985; Goodarzi and Gentzis, 1987). The lithotypes in the coals studied are mainly bright and bright banded (Fig. 5), indicating that these coals were formed predominantly from trees in a forest swamp (Tasch, 1960; Goodarzi, 1985; Diessel, 1986).

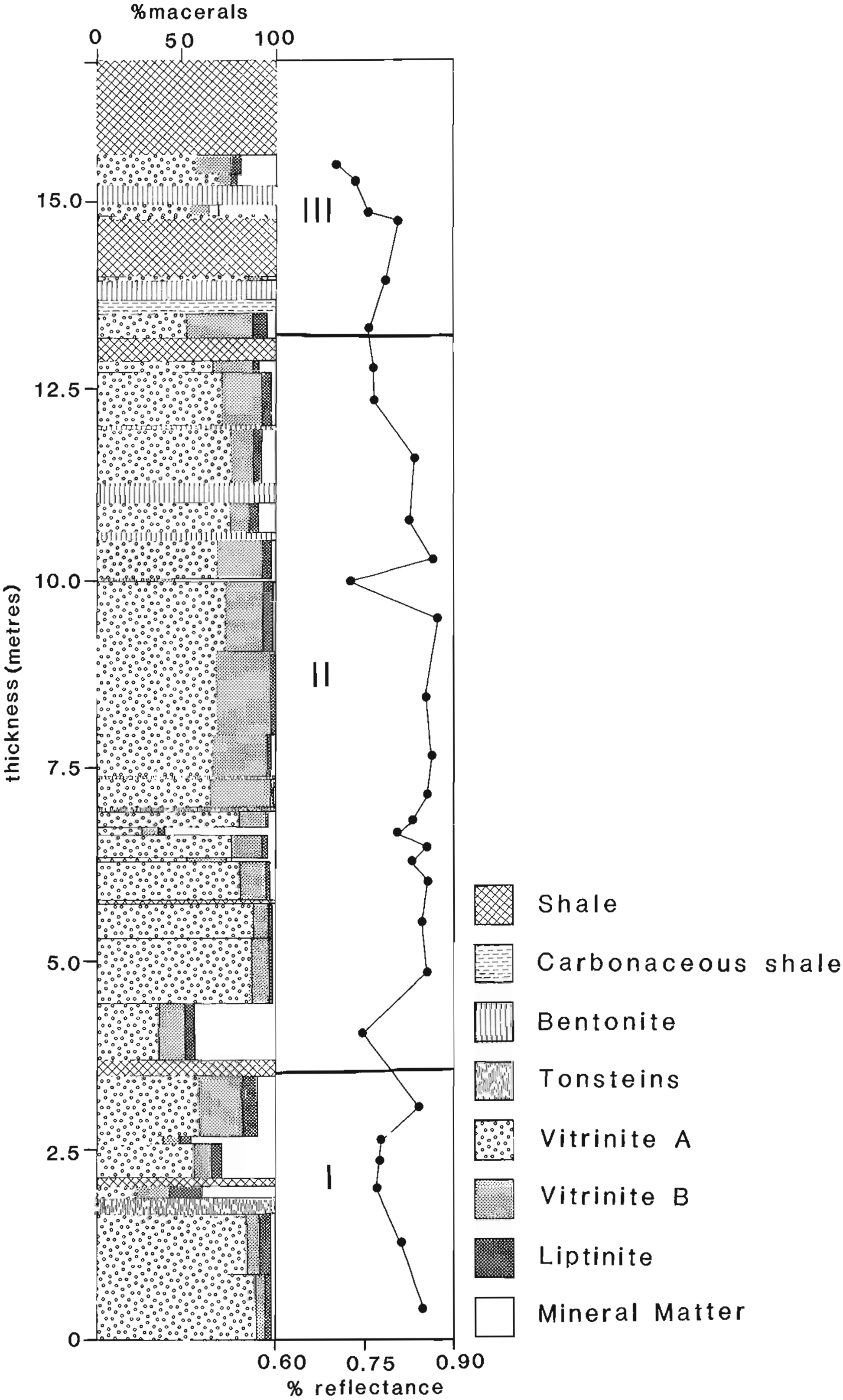


Figure 4. Maceral data and reflectance profile of the Blakeburn coal-bearing section.

Reflectance of vitrinite ($\%R_{oil}$) increases from 0.72 at the top to 0.82 percent over the 17 m interval to the base of the section. These data are shown in Figure 4. In comparison to the reflectance of vitrinite in the more pure coal intervals, the reflectance of vitrinite (Kerogen Type III, Brooks, 1981) in the sedimentary partings is lower in the Blakeburn samples, in agreement with Goodarzi's (1987a) results.

The coal-bearing strata in Cycle I were formed in an environment in which the rate of subsidence of the basin was irregular. Initially the balance between the rate of subsidence and input of plant material was maintained, resulting in formation of the basal coal seam; there was an inbalance in the middle of this cycle (Fig. 4). A balance in plant input versus subsidence was again established briefly near the top of the Cycle (Fig. 4); however, the rate of subsidence became greater at the very top of the cycle resulting in the formation of carbonaceous shales (Fig. 4). The coal in Cycle II formed in an environment in which the rate of subsidence was regular (Fig. 4), resulting in the formation of an almost uninterrupted peat sequence with five volcanoclastic bands indicating frequent volcanic activity. The rate of subsidence was rapid in Cycle III (Fig. 4), resulting in the formation of a sedimentary sequence with the lowest organic content in the coal-bearing section.

Figure 6 shows the boron distribution in the section, and the low boron content (F50 ppm) for coals in Cycles I and II suggests that they were deposited in a freshwater environment (Swaine, 1962, 1971, 1983; Goodarzi, in press). A freshwater environment of deposition is also indicated for Cycle III, which consists mainly of carbonaceous shale and has a boron content of 20-80 ppm. The high boron content of these high-ash units is consistent with the results of Swaine (1983), who pointed out that dirt bands from coal seams deposited in a freshwater environment have higher boron contents (4-170 ppm).

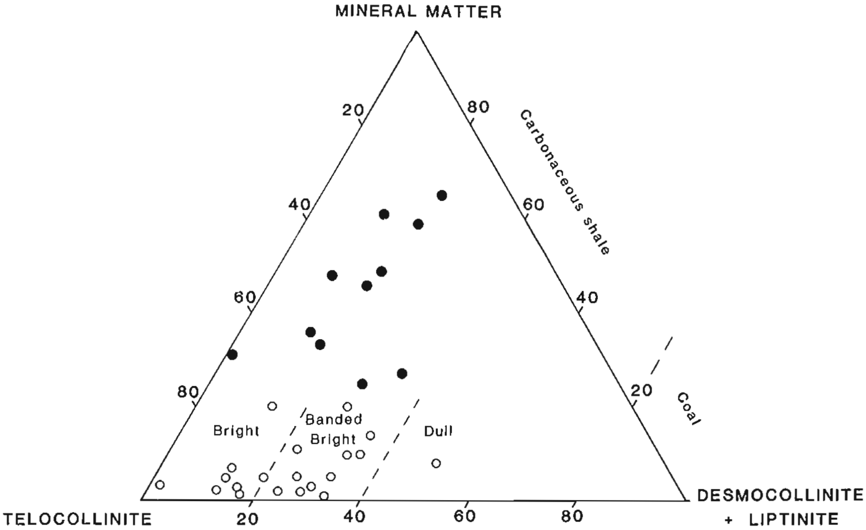


Figure 5. Ternary diagram of maceral composition for the coal of the Blakeburn coal-bearing section: coal (○), carbominerite (●).

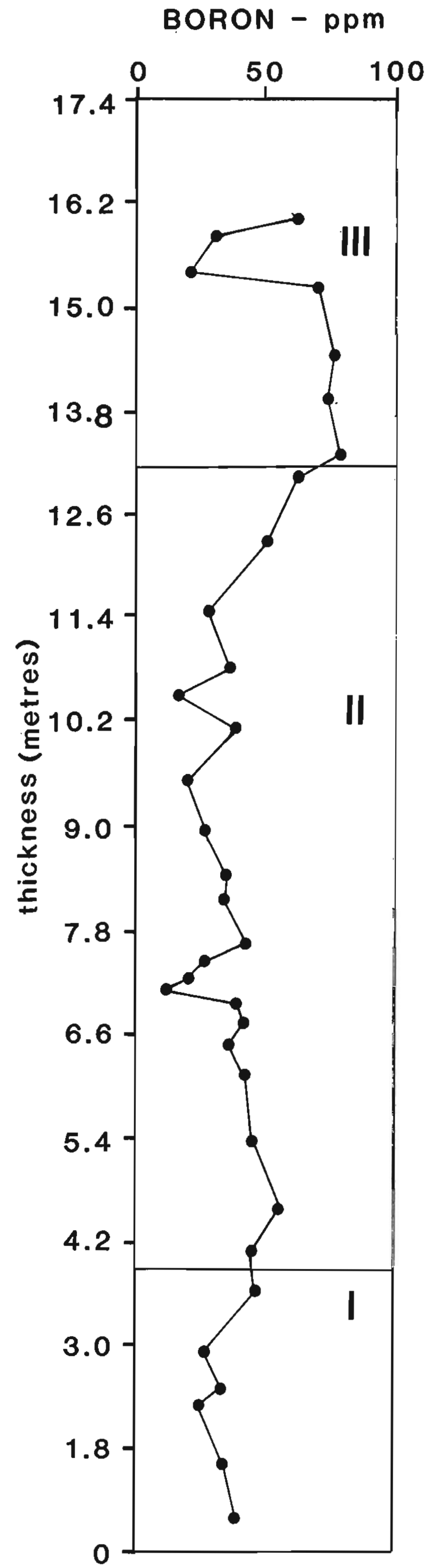


Figure 6. Boron concentrations of the coals and partings in the Blakeburn coal-bearing section.

SUMMARY

Boron content analysis indicates that coals from Blakeburn mine were deposited in a freshwater environment. The relationship between vitrinite macerals and mineral matter is a good indicator of paleoenvironmental changes. A high proportion of telocollinite indicates dryer conditions, and a high proportion of humocollinite and liptinite with relatively low inertinite, indicates wet conditions.

There are similarities between these coals and coals from the Hat Creek deposits; namely, the low inertinite content of both coals, indicative of a relatively humid, peat-forming environment.

In comparison with the reflectance of vitrinite in coal, the reflectance of vitrinite in interbedded clastic sediments is lower. The coal-bearing section consists of three depositional cycles:

Cycle I. Relatively regular and slow peat accumulation and an almost uniform rate of subsidence for most of the cycle, with a period of irregular subsidence toward the end.

Cycle II. Regular, slow peat accumulation interrupted by frequent volcanic activity.

Cycle III. Irregular deposition produced by erratic subsidence, resulting in a sequence with the lowest organic content of the three.

REFERENCES

Brooks, J.
1981: Organic maturation of sedimentary organic matter and petroleum exploration. A review; *in* Organic maturation studies and fossil fuel exploration, J. Brooks (ed.); Academic Press, New York, p. 1-38.

Camsell, C.
1913: Geology and mineral deposits, Tulameen district, British Columbia; Geological Survey of Canada, Department of Mines, Memoir 26.

Church, B.N. and Brasnett, D.
1983: Geology and gravity survey of the Tulameen coal basin, Province of British Columbia; Ministry of Energy, Mines and Petroleum Resources, Paper 1983-1, p. 47-54.

Darragh, A. and Goodarzi, F.
1985: Canadian coals — their distribution and potential; Journal of Coal Quality, v. 5, no. 1, p. 35-39.

Dilles, S.J. and Hill, P.A.
1984: Vertical distribution of copper and zinc in coal zones A, B, C, and D, Hat Creek, British Columbia; Economic Geology, v. 79, p. 1936-1940.

Diessel, C.F.K.
1986: On the correlation between coal facies and depositional environment; *in* Advances in the study of the Sydney Basin, Proceedings of Twelfth Symposium, Publication No. 246, Department of Geology, University of New South Wales, p. 19-22.

Donaldson, J.R.
1973: The petrography of the coal from the Blakeburn strip mine in the Tulameen coal area, British Columbia; Geological Survey of Canada, Paper 72-39, p. 11.

Evans, S.H.
1978: Tulameen coal basin (92H/7); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1977, p. 83-85.

Goodarzi, F.
1985: Organic petrology of Hat Creek Deposit No. 2, British Columbia; International Journal of Coal Geology, v. 5, p. 377-396.
1987a: Comparison of reflectance data from various macerals from subbituminous coals; Journal of Petroleum Geology, v. 10, no. 2, p. 219-226.

Goodarzi, F.
1987b: Trace element concentrations in Canadian Coals II, Byron Creek Collieries, British Columbia; Fuel, v. 66, p. 250-254.
— Concentration of elements in lacustrine coals from Zone A, Hat Creek Deposit No. 1, British Columbia; International Journal of Coal Geology, in press.

Goodarzi, F. and Gentzis, T.
1987: Depositional setting, determined by organic petrography of the Middle Eocene Hat Creek No. 2 coal deposit, British Columbia, Canada; Bulletin of Canadian Petroleum Geologists, v. 35, no. 2, p. 197-211.

Hill, L.V.
1965: Palynology and age of early Tertiary basins, interior British Columbia; unpublished Ph.D. thesis, University of Alberta, 188 p.

International Committee for Coal Petrology
1971: International Handbook of Coal Petrology, 2nd Edition, 1963, supplement to 2nd Edition, 1971; Centre Nationale de la Recherche Scientifique, Paris.

Marchioni, D.
1985: Reflectance studies in brown coals — An example from the Hat Creek deposit of British Columbia; Compte rendue, 9th International Congress on Carboniferous Stratigraphy and Geology, Illinois, 1979, v. 4, p. 590-599.

Pollock, E.N.
1975: Trace impurities in coal by wet chemical methods; *in* Trace Elements in Fuel, S.P. Babu (ed.); American Chemical Society, Special Paper 1, v. 141, p. 23-24.

Robertson, W.F.
1901: Collins Gulch coal; British Columbia report of Minister of Mines, p. 1177-1178.

Shaw, W.S.
1952: The Tulameen coalfield, British Columbia; Geological Survey of Canada, Paper 52-19, 13 p.

Swaine, D.J.
1962: Boron in New South Wales Permian coals; Australian Journal of Earth Sciences, v. 26, no. 6, p. 265-266.
1971: Boron in coals of the Bowen Basin as an environmental indicator; Geological Survey of Queensland, Report No. 62.
1983: Geological aspects of trace elements in coal; *in* The Significance of Trace Elements in Solving Petrogenetic Problems and Controversies, S.S. Augustithis (ed.); Theophrastus Publication, Athens, Greece, p. 521-532.

Tasch, K.H.
1960: Die Moglichkeiten der Flozgleichstellung unter Zuhilfenahme von Flozbildungsdiagrammen; Bergbau — Rundschau., v. 12, p. 152-157.

Teichmuller, R. and Teichmuller, M.
1982: Fundamentals of coal petrography; in Coal Petrology, E. Stach et al. (eds.); Gebruder Borntraeger, Berlin-Stuttgart, p. 5-82.

Williams, V.E. and Ross, C.A.
1979: Depositional setting and coal petrology of Tulameen coalfield, south-central British Columbia; American Association of Petroleum Geologists, v. 63, no. 11, p. 2058-2069.

Structural style and stratigraphy in northeast Bowser and Sustut basins, north-central British Columbia

C.A. Evenchick
Cordilleran and Pacific Geoscience Division, Vancouver

Evenchick, C.A., Structural style and stratigraphy in northeast Bowser and Sustut basins, north-central British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 91-95, 1988.

Abstract

The distribution of lithofacies, including anthracite coal, that developed in the mid-Jurassic to Cretaceous(?) Bowser Basin is controlled by: 1) the initial location of deposition within a sequence that grades upwards from marine at the bottom to nonmarine at the top; 2) tight folds and thrust faults, and 3) is offset by large-scale near vertical dip-slip faults.

Résumé

La distribution des lithofaciès, y compris du charbon anthracitique, qui se sont formés dans le bassin de Bowser du Jurassique moyen au Crétacé(?) a été régie par: 1) le site initial de sédimentation à l'intérieur d'une séquence qui passe de conditions marines à sa base à des conditions continentales à son sommet; 2) des plis étroits et failles chevauchantes; et 3) elle est décalée par des failles normales de grande échelle, presque verticales.

INTRODUCTION

In 1987, mapping at 1:50 000 scale in Spatsizi map area (Fig. 1) was extended to the northwest, southeast, and south of the area covered in 1985 and 1986 (Evenchick, 1986, 1987). Field work focused on establishing mappable units in the Bowser Lake Group, on the structural style in the Bowser Lake and Sustut groups, and the structural relationships between map units at the common boundary of the two groups.

Strata of the Bowser Basin consist of Middle Jurassic to lower (?) Cretaceous marine and nonmarine clastic sediments named the Bowser Lake Group. The Bowser Lake Group was deposited on a lower Jurassic basement of Cold Fish volcanics, and sediments of the Spatsizi Group (Thomson et al., 1986). Strata of the Sustut Basin consist of Cretaceous nonmarine clastic rocks named the Sustut Group (Eisbacher, 1974). It unconformably overlies the Bowser Lake and Spatsizi groups, and the Cold Fish volcanics. All rock units, with the exception of the upper part of the Sustut Group, have been deformed by northeast-verging folds and thrust faults that have accommodated major northeasterly contraction. Steep dip-slip faults offset all stratigraphic units and contractional structures. Data constraining the timing of deformation are outlined by Evenchick (1987).

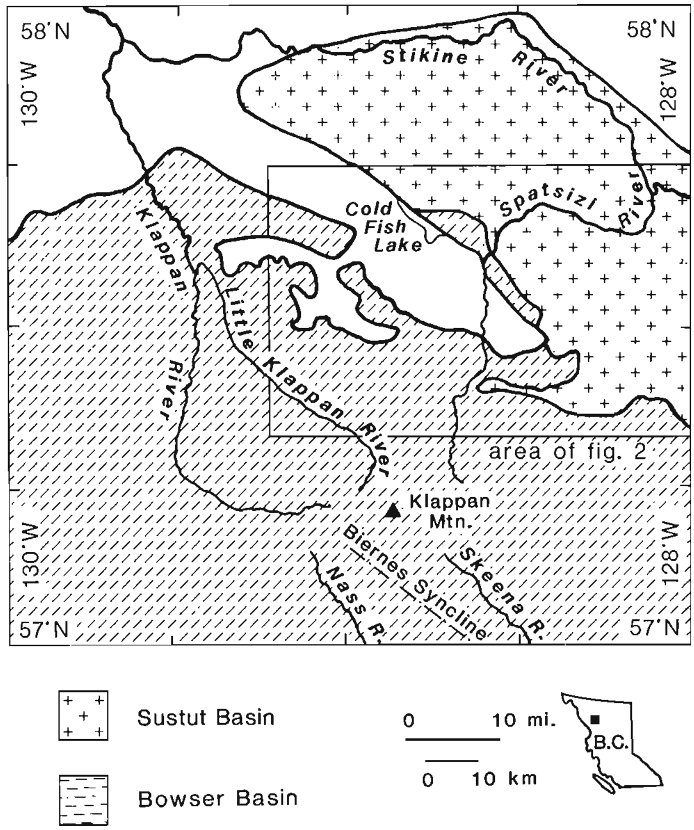


Figure 1. Regional geological and geographic features in Spatsizi map area, and the location of the study area.

STRATIGRAPHY

Spatsizi Group

The Spatsizi Group consists of lower Pliensbachian to upper Bajocian sediments that are interpreted as basinal equivalents of the lower Jurassic Cold Fish volcanics (Smith et al., 1984; Thomson et al. 1986). The group was formally defined by Thomson et al. (1986) based on work on the flanks of the Joan Lake anticline (Fig. 2 and 3 east of Tsetia Creek).

Strata north of Tsetia Creek that are not present in the area mapped by Thomson et al. (1986) include a 15 m thick horizon of massive chert-pebble conglomerate with interbeds of siliceous siltstone. Radiolarian chert is the most common clast type, with lesser volcanic and siltstone clasts. The siltstone both within and above the conglomerate is similar to the Quock Formation of the Spatsizi Group. Ammonites collected from below and above the conglomerate will permit an assignment of age to the conglomerate. The presence of chert clasts in the Spatsizi Group is of regional significance when one considers possible sources. The Cache Creek terrane is the source of chert clasts in the Bowser Lake Group (Currie, 1984), and thus the chert clasts have been interpreted to be the first stratigraphic link between Stikinia, on which the Bowser Basin developed, and the Cache Creek terrane (Eisbacher, 1981). Chert clasts in the Spatsizi Group confirm the presence of a source of radiolarian chert prior to deposition of the Bowser Lake Group. Whether or not that source was the Cache Creek terrane is unknown, but there are no other large sources of radiolarian chert in the region.

Bowser Lake Group

Four lithological units in the Bowser Lake Group are identified in Figure 2. At the base, black marine siltstone contains lenses and relatively continuous beds of conglomerate, and rare chert sandstone. These strata are overlain by a unit of black siltstone interbedded with chert sandstone members about 10 m thick. Sandstone constitutes 30 to 80 per cent of the unit. The siltstone-sandstone unit is locally overlain by a unit comprising alternating siltstone and sandstone members 2 to 10 m thick, with rare conglomerate and coal. Uppermost is a rusty weathering, massive, chert-pebble conglomerate unit, locally with minor interbeds of siltstone and sandstone.

Not all units above the basal marine siltstone are present in every area. The units vary greatly in thickness and character between areas of outcrop, but the nature of the changes is obscure, and the continuity of units across structures is difficult to establish. The units are diachronous. For example, the rusty conglomerate west of the confluence of Spatsizi River and Buckinghorse Creek is about the same age (late Oxfordian, H.W. Tipper, pers. comm., 1987) as the sandstone-siltstone-conglomerate-coal sequence between the Little Klappan and Spatsizi rivers. The coal-bearing unit probably reflects a depositional environment similar to that of the strata with anthracite coal seams at Mt. Klappan (Fig. 1), but the two coal-bearing sequences may be a different age. Strata of the Bowser Lake Group in Figure 2 are mid-to late Jurassic, but include rocks as young as Albian farther south (Biernes syncline in Fig. 1; Moffat, 1985). The Bowser Lake Group represents a complex of lithofacies that may be repetitive both vertically and laterally. Correlation of apparently similar strata between widely separated areas may be misleading.

STRUCTURE

Structural style of the Bowser Lake and Sustut groups is dominated by northeasterly-verging tight to open folds, and by thrust faults which sole into the volcanic basement of the Bowser Basin (Evenchick, 1987). The lateral continuity of stratigraphic sequences, folds, and thrust faults is disrupted by dip-slip faults of large displacement.

In the area north of Eaglenest Creek large scale southwest-verging folds are prominent, in contrast to the northeasterly vergence of structures to the east and southeast. Whether these structures predate the northeast-verging structures, or are simply another expression of the same phase of northeast-southwest contraction is unknown.

New data have helped resolve a structural dilema near the confluence of Buckinghorse Creek and Spatsizi River. The highest structure in Figures 2 and 3 is a thrust fault that separates Bowser Lake Group in the hanging wall from Tango Creek Formation in the footwall. It can, with extrapolation across dip-slip faults, be traced from east of the head of Ross River to south of the confluence of Spatsizi River and Buckinghorse Creek (Fig. 2). It cannot be traced to the west across the Griffith Fault. Thus the highest structural level exposed is only 6 km south of the lowest structural level, marked by pre-Jurassic rocks. The proximity demands that stratigraphic and structural elements be missing. Rocks to the east of the confluence do not seem to be seriously displaced relative to those to the west, but are distinctly different from those to the north and south. Recognition of a dip-slip fault along Buckinghorse Creek (herein named the Buckinghorse Fault) has in part solved this enigmatic situation. The combination of down-to-the-southeast displacement on

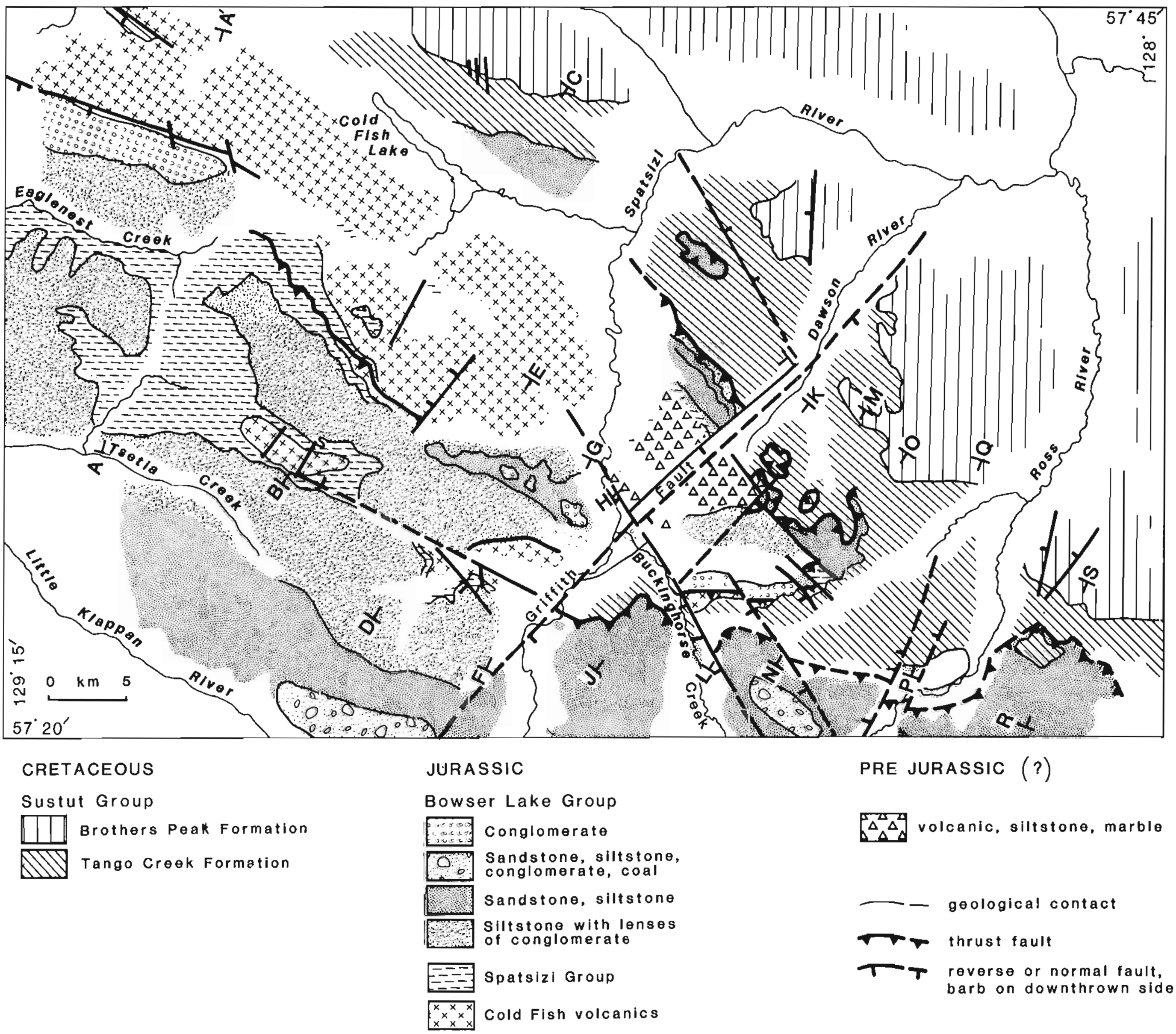


Figure 2. Geological map of the study area.

Griffith Fault with down-to-the-southwest displacement on Buckinghorse Fault results in net downward displacement of the south block relative to the north block that is equal to the sum of the vertical displacement on both the Griffith and Buckinghorse faults. If the magnitudes of displacment on Buckinghorse and Griffith faults are about equivalent, the areas east and west of the confluence would not be largely offset relative to one another; their exposed structural elements would be higher than those to the north and lower than those to the south. These relationships are independent of timing of fault displacements. Both faults offset the Tango Creek Formation, indicating that displacements were no older than Albian.

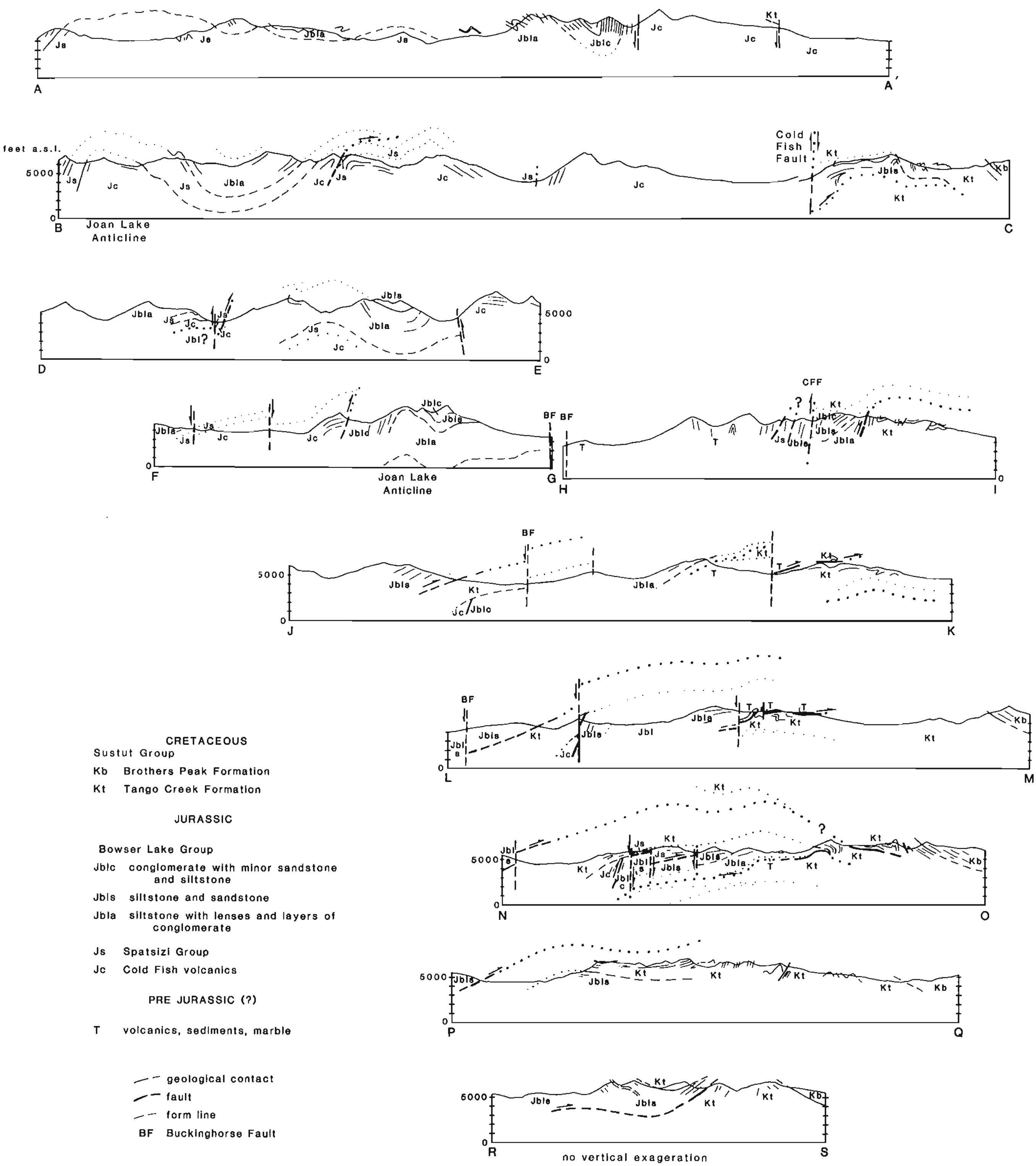


Figure 3. Schematic cross-sections of the study area. The location of the sections is shown in Figure 2.

The next lowest marker in the sections (Fig. 3) is the unconformity between the Tango Creek Formation and older rocks (sections JK to PQ). Immediately east of Buckinghorse Creek the Tango Creek Formation is in unconformable contact with volcanics, and overlaps a fault that separates volcanics from the Bowser Lake Group. The absence of volcanics along the Buckinghorse River is inferred to be a result of down-to-the-southwest displacement of the unconformity by the Buckinghorse Fault (sections JK, LM). The unconformity can be traced to the east and northeast around an open, southeast-plunging anticline to where a thrust fault cuts up section through the Bowser-Tango unconformity into the Tango Creek Formation (section NO). This thrust fault is interpreted to be the next lowest structural element. It places Bowser Lake Group and volcanic rocks in the hanging wall over Tango Creek Formation in the footwall (section LM).

The vertical sequence of thrust fault-unconformity-thrust fault is difficult to trace northwest across a large northeast-trending fault (between sections LM and JK). The steeply-dipping fault separates a block in which Triassic(?) rocks are unconformably overlain by Bowser Lake Group, from the block which has the thrust fault that places volcanic rocks (Triassic (?)) above Tango Creek Formation.The amount of shortening illustrated by the overlap of thrust faults in Figure 3 is only a fraction of the total shortening across the region. Tight folds and local intense cleavage have also accommodated shortening.

SUMMARY

Four lithological units, based on the proportion of siltstone, sandstone, and conglomerate, were recognized in central Spatsizi map area. The distinction between these units is not always clear, particularly in areas of complicated structure. The usefulness of the breakdown regionally is questionable because facies changes cannot be recognized without tight fossil control. For example, in one area the upper conglomerate is known to be Oxfordian, but in the area of the Biernes syncline (Fig. 1), the upper conglomerate is Albian (Moffat, 1985). Athough lithologically the conglomerates have some similarities, it is doubtful that they were ever physically continuous.

An understanding of the interaction of dip-slip faults is important in explaining the distribution of map units and in the correlation of units in the Bowser Lake Group. Only by carefully piecing together the geology across faults does a better picture of the geometry and lateral continuity of the contractional structures emerge (Gabrielse and Tipper, 1984). As previously reported by Evenchick (1987) markers cannot be easily traced across the Griffith Fault. The fault continues to the southwest towards the west side of the anthracite coal-bearing strata at Mt. Klappan (Fig. 1), but it is obscure there because of the lack distinctive lithological units.

The location of coal-bearing strata in the Bowser Lake Group is controlled by: the primary site of deposition within a sequence that grades generally from marine at the base to nonmarine at the top; northwest-trending tight folds and thrust faults which may repeat coal seams; and offset by large-scale northeast- and northwest-trending, steeply dipping, dip-slip faults.

ACKNOWLEDGMENTS

The co-operation and hospitality of staff at Gulf Canada, and the professional service of Northern Mountain Helicopter pilots is appreciated. Jill Pardoe assisted in the field, and Christine Davis drafted the final diagrams.

REFERENCES

Currie, L.

1984: The provenance of chert clasts in the Ashman conglomerates of the northeastern Bowser Basin; B.Sc. thesis, Queen's University at Kingston, Ontario 59 p.

Eisbacher, G.H.

1974: Sedimentary and tectonic evolution of the Sustut and Sifton basins, north-central British Columbia; Geological Survey of Canada, Paper 73-31, 57 p.

1981: Late Mesozoic-Paleogene Bowser Basin molasse and Cordilleran tectonics, western Canada; *in* Sedimentation and Tectonics in Alluvial Basins; ed. Miall, A.D. Geological Association of Canada, Special Paper 23, p. 125-151.

Evenchick, C.A.

1986: Structural style of the northeast margin of the Bowser Basin, Spatsizi map area, north-central British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 733-739.

1987: Stratigraphy and structure of the northeast margin of the Bowser Basin, Spatsizi map area, north-central British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 719-726.

Gabrielse, H. and Tipper, H.W.

1984: Bedrock geology of Spatsizi map area (104H); Geological Survey of Canada, Open File 1005.

Moffat, I.W.

1985: The nature and timing of deformational events and organic and inorganic metamorphism in the northern Groundhog coalfield: implications for the tectonic history of the Bowser Basin; Ph.D. thesis, University of British Columbia, 205 p.

Smith, P.L., Thomson, R.C., and Tipper, H.W.

1984: Lower and Middle Jurassic sediments and volcanics of the Spatsizi map area, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 117-120.

Thomson, R.C., Smith, P.L., and Tipper, H.W.

1986: Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia; Canadian Journal of Earth Sciences, v. 23, p. 1963-1973.

The Hugh Allan (Purcell) fault (a low-angle west-dipping thrust) at Hugh Allan Creek, British Columbia

E.W. Mountjoy[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Mountjoy, E.W., The Hugh Allan (Purcell) fault (a low-angle west-dipping thrust) at Hugh Allan Creek, British Columbia; in *Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 97-104, 1988.*

Abstract

Recent mapping and tracing of strata indicate that the Purcell thrust dips southwest at a low angle and truncates a syncline of McNaughton Formation quartz sandstones and upper Miette pelites in its footwall. Late stage movement on this thrust shifted the staurolite-in isograd about 4 km to the northeast. The thrust is also gently folded, indicating a period of minor compression following the offset of the metamorphic isograds. The Hugh Allan thrust carries Blackman gneisses and their cover of pelites with discontinuous grits, which are tentatively assigned to the lower part of the Kaza Group over middle Miette Group grits. A small thrust slice of carbonates between the Hugh Allan and Blackman gneisses is probably equivalent to the Middle Marble of the Horsethief Creek Group.

Résumé

De récents levés des strates indiquent que le chevauchement d'Allan (antérieurement nommé chevauchement de Purcell) est faiblement incliné vers le sud-ouest et tronque à son niveau inférieur un synclinal contenant des grès siliceux de la formation de McNaughton et des pélites de la partie supérieure de la formation de Miette. Un mouvement qui a touché ce chevauchement durant une phase tardive a déplacé l'isograde de la staurolite d'environ 5 km au nord-est. Ce chevauchement est aussi légèrement plissé, ce qui indique une période de faible compression après le déplacement des isogrades métamorphiques. Le chevauchement de Hugh Allan a entraîné les gneiss de Blackman et leur couverture pélitique accompagnée de grès grossiers discontinus, que l'on a provisoirement placés dans la partie inférieure du groupe de Kaza, au-dessus des grès grossiers du groupe de Miette. Un mince lambeau de charriage composé de carbonates, situé entre les gneiss de Hugh Allan et de Blackman, est probablement l'équivalent du Marbre moyen (Middle Marble) du groupe de Horsethief Creek.

[1] Department of Geological Sciences, McGill University,
3450 University Street, Montreal, Quebec H3A 2A7

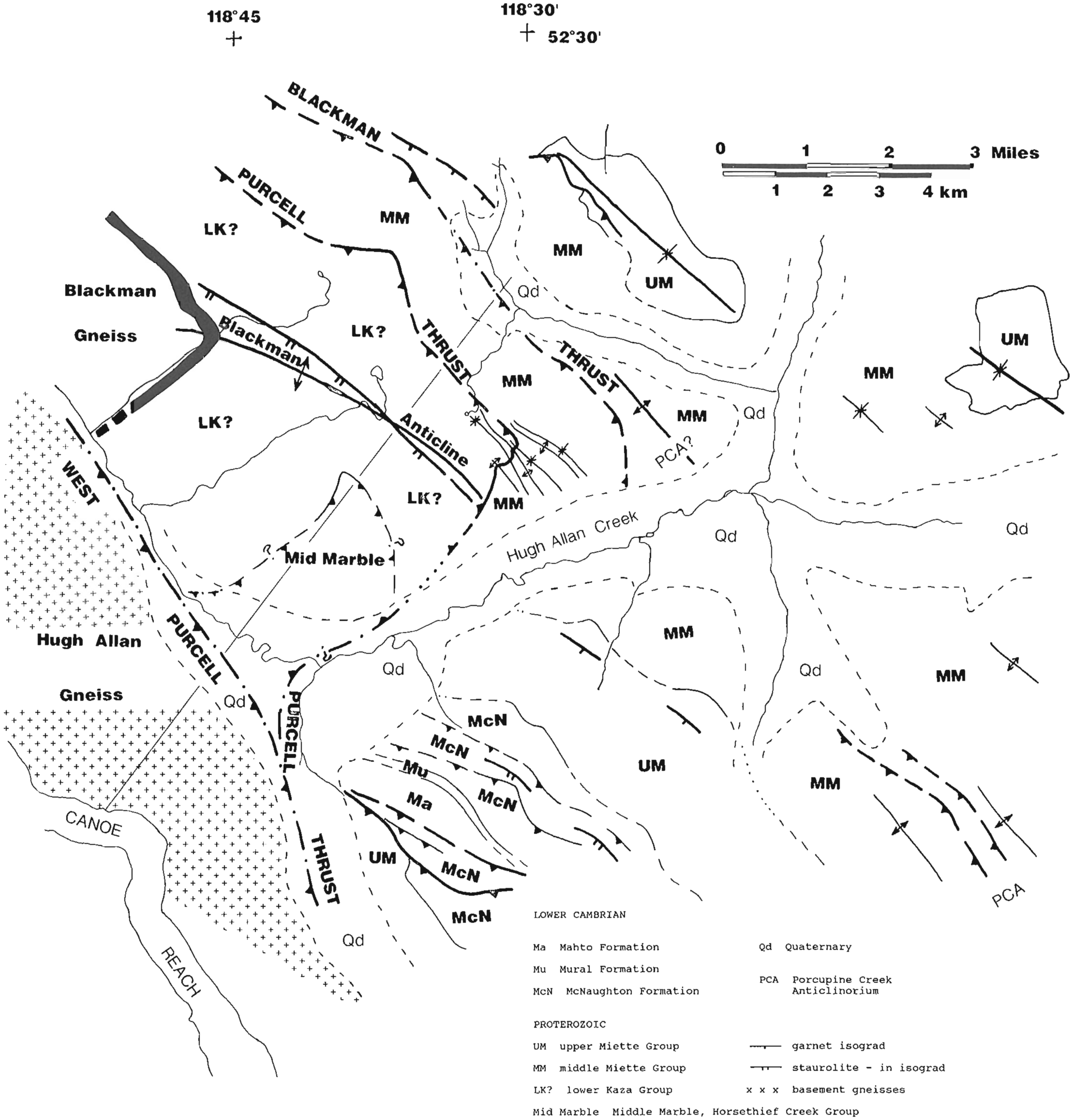


Figure 1. Geological map of Hugh Allan Creek area (parts of 83D/7, 8) adjacent to Blackman and Hugh Allan gniesses showing major structures and distribution of metamorphic isograds.

INTRODUCTION

Mapping and tracing of strata on the northeast margin of the Blackman gneiss body north of Hugh Allan Creek during 1987 near longitude 118°31′ and latitude 52°25′ in both the hanging wall and footwall of the Purcell fault (part of the Trench thrust system, Fig. 1), delineate a thrust fault that dips between 10 and 30 degrees southwest and that has at least two periods of movement.

Previously the area was mapped on a reconnaissance scale by Campbell (1968), and Price and Mountjoy (1970) and in greater detail by Oke and Simony (1981), Leonard (1985) and Mountjoy et al. (1985). Recently to the northwest M. Charland has carried out detailed mapping along the Blackman thrust and the northwest extension of the Purcell thrust fault zone between Ptarmigan and Bulldog creeks (Charland and Hynes, 1987) and discovered two mylonitic thrust zones within the Purcell thrust sheet. New observations are reported here mainly based on detailed tracing of units and structures on the mountain slope immediately north of Hugh Allan Creek viewed from the south (Fig. 2, 3) using air photographs in conjunction with binoculars ("Swiss Hammer"). The exposures are excellent (Fig. 2) and leave little room for interpretation or speculation, especially in conjunction with the mapping of Leonard (1985). The key aspects are summarized here because of their importance and significance in understanding the nature of the Purcell and Blackman thrusts (Trench thrust zone). During the summer of 1984 Leonard and I did not have the opportunity to observe this mountain side to position the Purcell fault more accurately and we incorrectly showed it as dipping steeply southwest.

TRENCH THRUST SYSTEM

Older and generally higher metamorphic grade Kaza Group and Horsethief Creek Group rocks occur west of the Rocky Mountain Trench from McBride to Golden. In most areas these rocks have been thrust eastward onto younger and less metamorphosed rocks except near the Yellowhead culmination. Farther south the Purcell thrust places Precambrian Purcell and Horsethief groups over Paleozoic rocks along the Rocky Mountain Trench. Northwest of Golden additional thrust faults enter the Rocky Mountain Trench on the west side. All of these thrust faults are herein referred to as the Trench thrust system.

The Purcell fault or thrust was extended northwest by Price and Mountjoy (1970), and later mapped by Simony et al. (1980), Oke and Simony (1981), McDonough and Simony (1984), and Mountjoy et al. (1985), and Mountjoy and Forest (1986) (Fig. 1). To the northwest (see regional map in Klein and Mountjoy, 1988) the equivalent thrust was named Bear Foot Fault by McDonough (1984) and McDonough and Simony (1984), and a more westerly fault was named the Purcell that thrust Bulldog gneisses over Yellowjacket gneisses (McDonough, 1984; McDonough and Simony, 1984). Southeastwards the Purcell and West Purcell thrusts merge (Fig. 1). A third thrust fault appears to underlie the Middle Marble forming a small thrust slice between these two thrust faults (Fig. 1). These faults are all part of the Trench thrust system.

PURCELL THRUST

The Purcell thrust places the east limb of the Blackman Anticline (Fig. 1), which consists of complexly folded and faulted pelites containing discontinuous thin grits with minor carbonates and calcsilicates (which were tentatively assigned by Mountjoy et al. (1985) to the Horsethief Creek Group but are now assigned to the lower Kaza Group; see below) over a west dipping upright panel containing folded but continuous thick middle Miette grits. Thus the Purcell thrust juxtaposes older complexly deformed probably lower Kaza strata and basement gneisses over middle Miette strata that outline more continuous upright and open structures of the Blackman thrust sheet. These differences are clearly evident in outcrop (Leonard, 1985) and at a distance (Fig. 2) and are easily mapped from the ridges immediately south of Hugh Allan Creek and on air photographs (Fig. 3). There is a strong contrast between the thick, strongly deformed lower Kaza Group pelites with occasional discontinuous thin grit bands and the abundant, thick composite grit units of the middle Miette Group.

Stratigraphy of Purcell thrust sheet

The proper stratigraphic assignment of the strata within the Purcell thrust sheet is difficult because they are complexly deformed and are strongly metamorphosed. As well correlations across the Rocky Mountain Trench are extremely difficult due to lateral facies changes, structural complications and telescoping. These strata have also been tectonically detached from the underlying basement gneisses and transported some distance from where they were originally deposited relative to this basement. Previously, because these strata were distinctly different from Miette Group strata to the east, Mountjoy et al. (1985) questionably assigned them to the Horsethief Creek Group, following Oke and Simony (1981).

Leonard (1985) mapped four units above a thick quartzite that overlies the Blackman gneisses. This sequence is more than 2000 m thick (all are structural thicknesses) and from bottom to top consists of: 1) recessive pelites up to 900 m thick with minor calcsilicates and quartzites; 2) a 1500+ m thick grit unit with up to 1 m thick grit beds interbedded with pelitic schists and fine and coarse grained psammites, and near the base a 90 m thin bedded, dark grey carbonate and calcsilicate (which might be an equivalent of the Division Carbonate of Pell (1984) and Dechesne (1986)); 3) pelitic schists 800 m thick with 20 per cent grits in 1 to 3 m composite units with calcsilicates containing bluish-green hornblende; and at the top, 4) thin bedded pelitic schists more than 275 m thick with rare psammites and calcsilicate.

With more information now available about the lithologies and sequences in the Horsethief Creek and Kaza groups (e.g. Pell and Simony, 1987; Dechesne, 1986), the above pelitic schist succession with thin grit beds, calcsilicates and carbonates is clearly very similar to the 2000 m thick lower part of the Kaza Group (basal (630 m) and middle (1370 m) subdivisions separated by the Division Carbonate, Pell and Simony, 1987). The basal subdivision of the Kaza Group consists of psammites, pelites and semipelites, and widespread

Figure 2A. Photograph of north side of Hugh Allan Creek viewed from the south showing, from west to east (left to right): lower Kaza Group of Purcell thrust sheet and underlying folded and faulted middle Miette grits of the Blackman thrust sheet.

and locally abundant quartz-rich calcsilicate beds. Grit beds are also common in some areas. A thin, discontinuous white marble and brown weathering sandy calcsilicate unit 0 to 20 m thick forms the top of the basal subdivision (Pell and Simony, 1987). As noted above it is tempting to correlate the 90 m thick brown carbonate and calcsilicate in the lower part of the grit unit on the east limb of the Blackman Anticline with the carbonate-bearing horizon (Division Carbonate) at the top of the Kaza Group basal subdivision. This would mean that the overlying grits and pelitic schists in the Purcell thrust sheet may be part of the middle subdivision of the Kaza Group which are also lithologically similar. The structural setting above the presumably far travelled Blackman gneisses also supports a correlation with the Kaza Group to the southwest rather than the Miette Group to the northeast. The presence beneath the Hugh Allan gneiss of a possible thrust slice (Fig. 5) containing a thick marble (Middle Marble?) further strengthens this correlation.

Middle Marble (Horsethief Creek Group) thrust slice

A thick marble, calcsilicate and associated lithologies forms a distinctive light grey and brown weathering unit on the unnamed mountain that appears to form the southwest limb of the Blackman Anticline (Fig. 1, 5) just north of Hugh Allan Creek (52°25′; 118°32′). Leonard (1985) estimated this carbonate succession to be about 200 to 300 m thick. Similar thick carbonates do not occur on the east limb of this anticline, nor do they occur elsewhere in the cover rocks of the Blackman and Hugh Allan gneisses. Thus this represents an anomalous occurrence of an isolated southwest dipping panel of carbonate rocks and may represent a separate thrust slice. Carbonates of this thickness are unknown in the Miette Group except for carbonate platforms near the top of the upper Miette southwest of Jasper (Teitz and Mountjoy, 1985). Its occurrence just above basement gneisses suggests that it is from low in the stratigraphic sequence. The only carbonates that occur at this level and of about the same thickness occur in the Middle Marble of the Horsethief Creek Group southwest of the Rocky Mountain Trench immediately below the Kaza Group (Pell and Simony, 1987, Fig. 5). Hence these carbonates are assigned to the Middle Marble and appear to represent a small, low-angle thrust slice above the Purcell thrust. This thrust slice was brought up along and overridden by the fault that transported the Hugh Allan gneisses northeastward over the Blackman gneisses and their sedimentary cover (Figs. 1 and 4), herein named West Purcell thrust. Alternatively these carbonates might represent upper Miette strata downdropped several kilometres along a shallow southwest dipping normal fault. There is no evidence along strike of a normal fault of such large displacement and most of the proven normal faults have steep dips. Only along the Rocky Mountain Trench are there normal faults with large displacements. In addition no thick carbonates occur in the upper Miette Group that outcrops south of Hugh Allan Creek (Klein and Mountjoy, 1988.)

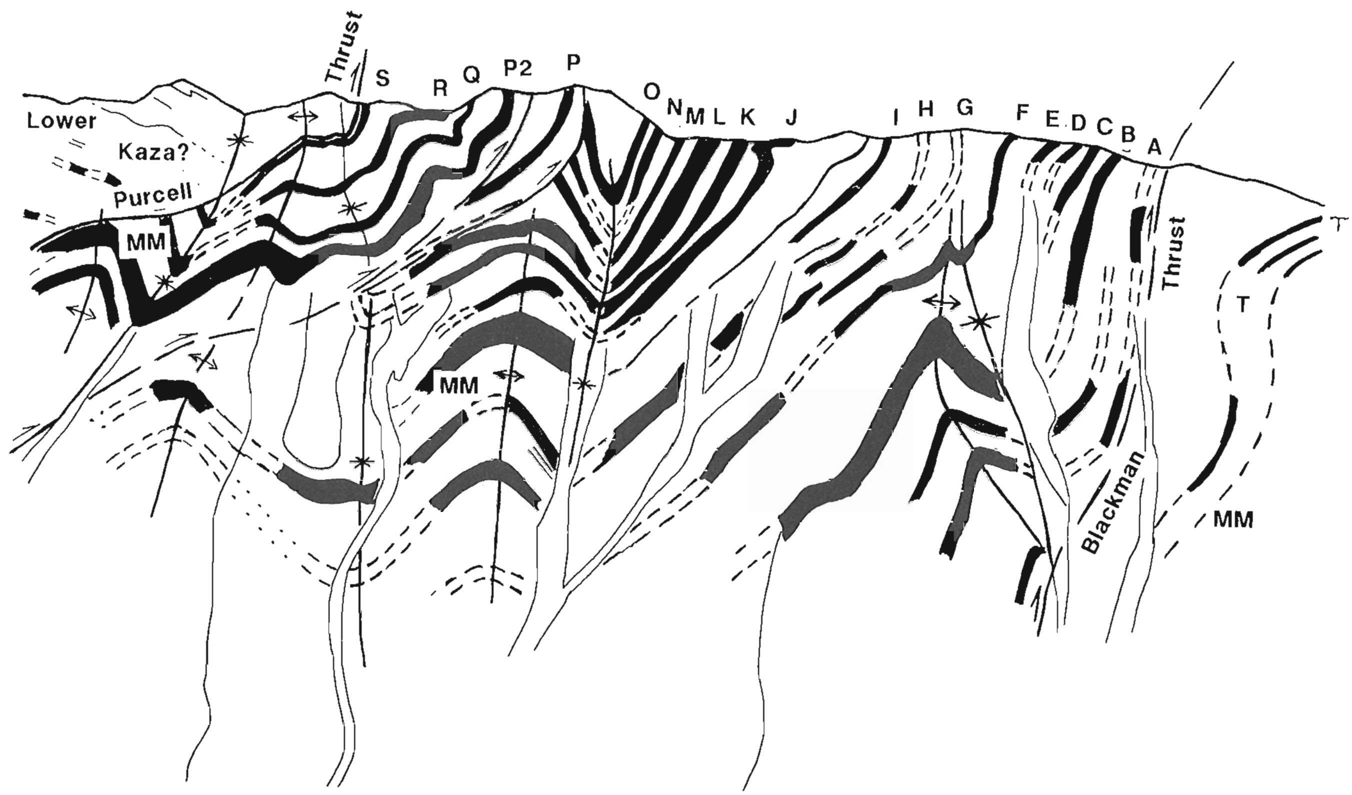


Figure 2B. Tracing from photograph in 2A of grit units utilizing field sketches and air photographs (Fig. 3). Middle Miette grit units are labelled A to S. A minor thrust splay repeats P as P2. P2 to S probably represent a thrust repeat of some part of the sequence J to O. A probably represents a horizon in the upper part of the middle Miette, stratigraphically above O and S. The Purcell thrust is slightly folded by underlying upright folds but much less than the middle Miette strata, indicating that probably folding of this thrust occurred during additional late stage compression and tightening of these folds. The Blackman Anticline occurs outside to the left and the Porcupine Creek Anticlinorium occurs to the right outside this figure (see Fig. 1, 3).

PURCELL AND BLACKMAN THRUST STRUCTURES

The main structural features observed (Fig. 2, 3) are:

1. The Purcell thrust cuts upsection towards the northeast in both the hanging wall and footwall, truncating the east limb of the hanging wall Blackman Anticline and several middle Miette footwall folds.

2. Folding in the middle Miette is abundant and upright with some minor westward overturning, whereas folds in the lower Kaza are few, recumbent, and in part and west verging.

3. The Purcell thrust is southwest dipping and shows minor late stage folding by folds in the underlying middle Miette, which are therefore post-second stage thrust movement (see discussion).

4. A southwest dipping thrust duplicates middle Miette strata.

5. The Blackman thrust dips steeply southwest (about 60 degrees).

The Purcell thrust truncates the southeast plunging Blackman Anticline to the southeast as it is juxtaposed with a west dipping homoclinal panel of middle and upper Miette Group strata that outcrops on the south side of Hugh Allan Creek (Fig. 1, 4; Klein and Mountjoy, 1988).

REGIONAL RELATIONSHIPS

To the north the Purcell thrust is underlain by an upright 40 to 60 degree southwest dipping panel of middle Miette Group which forms the Blackman thrust sheet (Leonard, 1985; Mountjoy et al., 1985). A prominent anticline (Fig. 1, 3) occurs on the north side of Hugh Allan Creek along strike from the Porcupine Creek Anticlinorium (PCA) to the southeast (Klein and Mountjoy, 1988). This suggests that the PCA might continue northwest across Hugh Allan Creek into the Blackman thrust sheet. Alternatively the Blackman thrust lines up with a minor, steep, southwest dipping thrust in the core of the PCA (Klein and Mountjoy, 1988). However the exact relationships between these structures cannot be established because of forest cover in the critical area along Hugh Allan Creek.

Important information about these structural relationships is provided by the metamorphic isograds which appear to be offset by the Purcell thrust and possibly the Blackman thrust (Fig. 1). The staurolite-in isograd is offset about 4 km northeastward by the Purcell thrust, as also is the garnet-in isograd. The Blackman thrust sheet is entirely garnet grade whereas the Porcupine Creek Anticlinorium along strike to the southeast is lower biotite or green schist grade (Klein and Mountjoy, 1988), this causes difficulties in connecting the Blackman thrust with thrust faults in the core of the PCA or in the interpretation that the Blackman thrust sheet represents a continuation of the PCA. The Blackman thrust sheet is a higher grade metamorphic structural slice that may be derived from farther to the southwest. Hence the Blackman thrust may flatten and trend westward joining with the Purcell thrust along Hugh Allan Creek (Fig. 1, 4). The PCA may represent the footwall of this structure. Alternatively

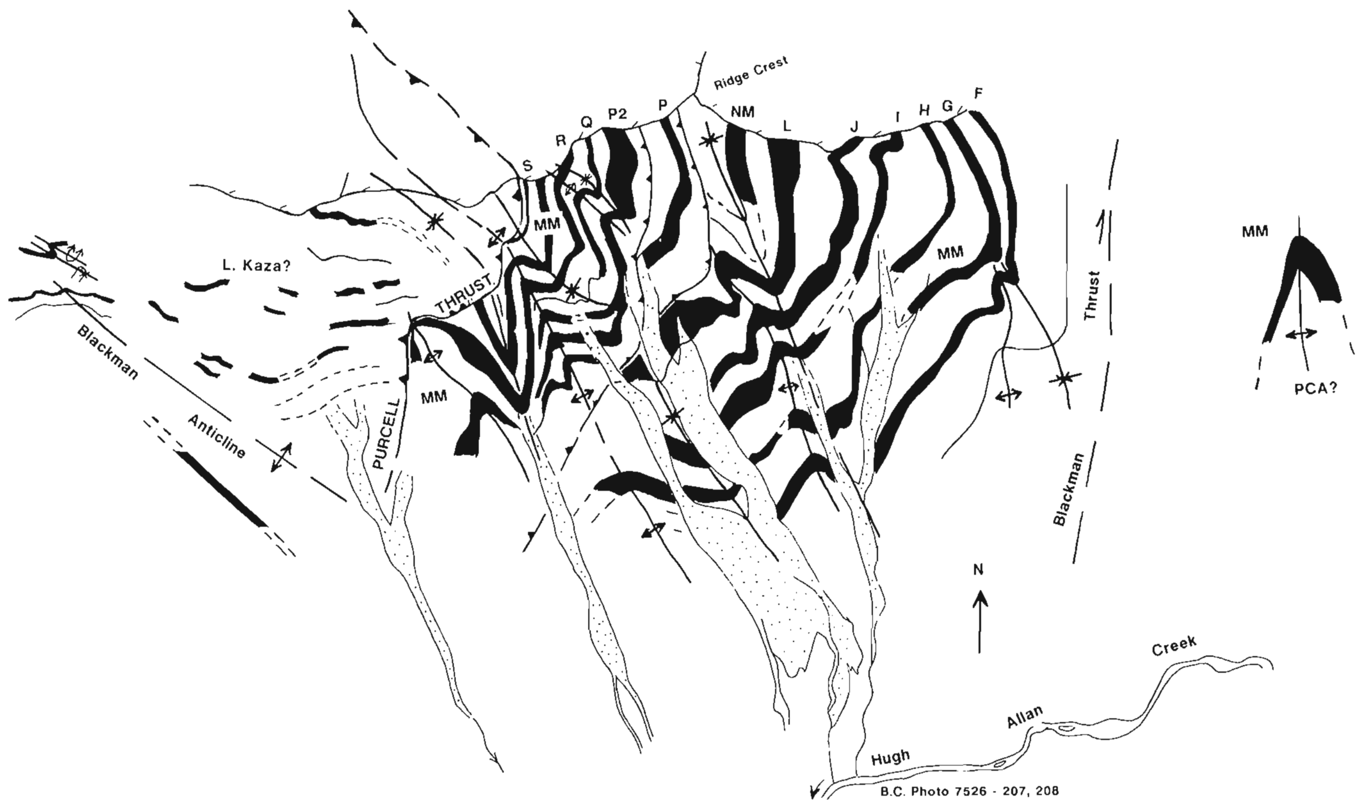


Figure 3. Tracing from air photographs (mainly B.C. Photo 7526 — 207) of the same area illustrated in Figure 2 with middle Miette Group grit units lettered the same. Note the strong differences in thickness, number and distribution of grit beds between the lower Kaza Group and middle Miette Group. The folded nature of the Purcell thrust is exaggerated in this vertical view. The possible northern extension of the PCA occurs on the extreme east (right side).

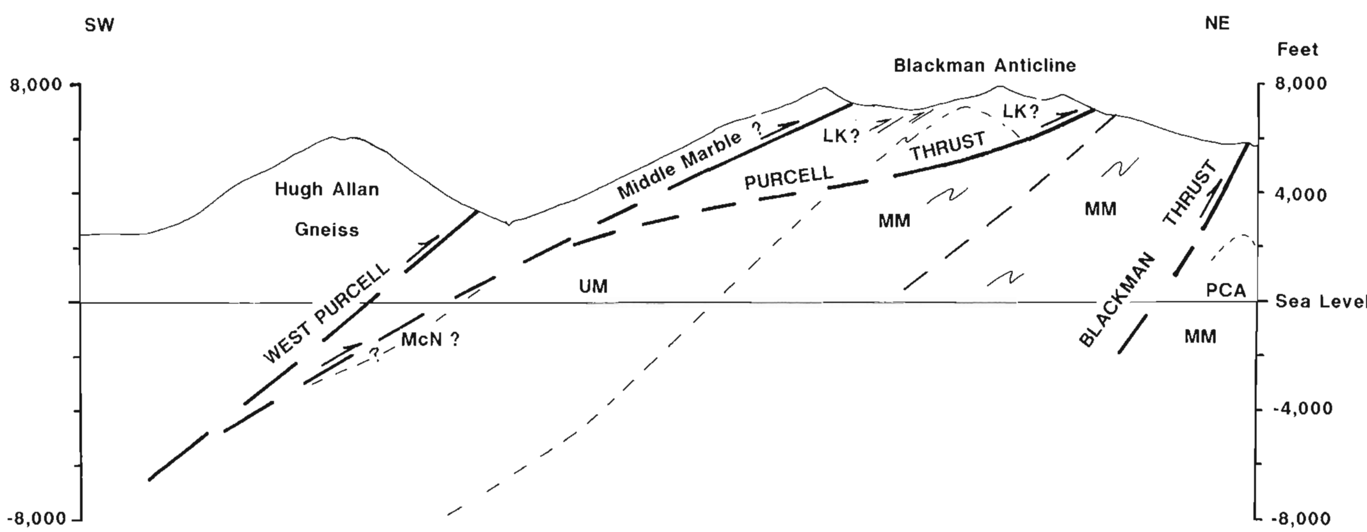


Figure 4. Southwest-northeast structure cross-section immediately northwest of Hugh Allan Creek, illustrating structure projected from the southeast and the relationships between the Blackman and Purcell thrusts.

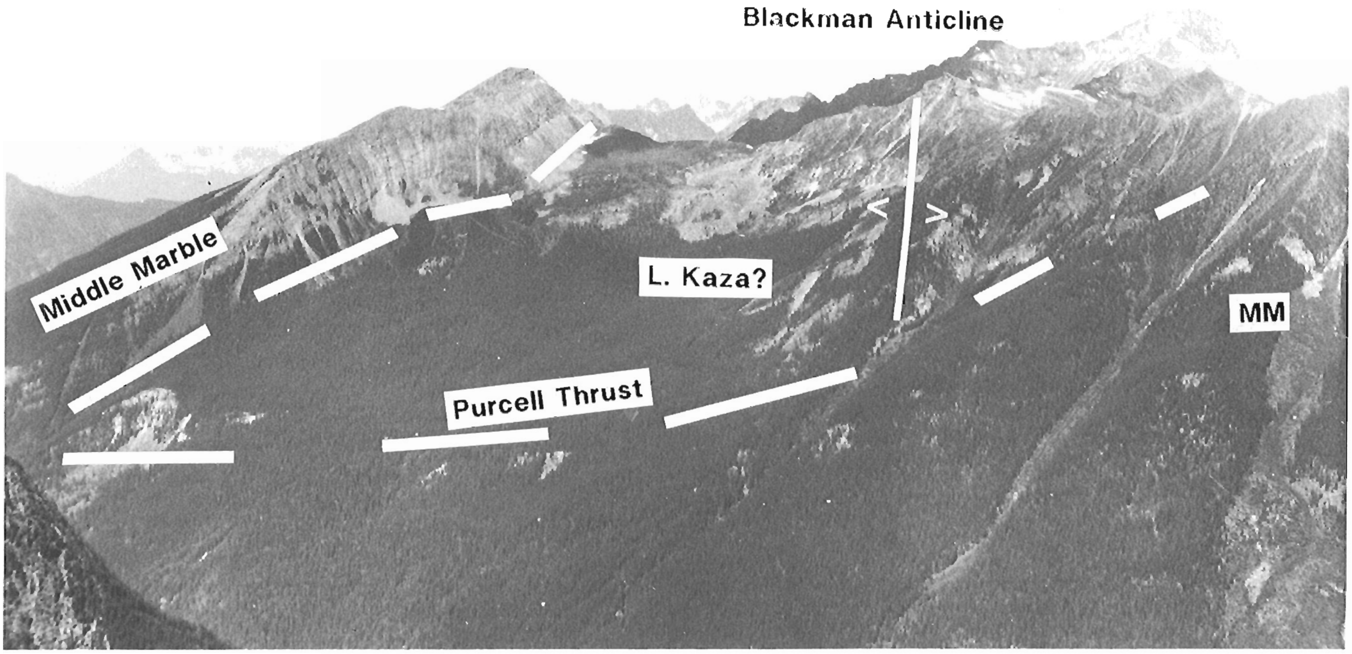


Figure 5. Photograph of Middle Marble(?) thrust slice on the north side of Hugh Allan Creek viewed from the southeast. In the footwall the thrust truncates Kaza strata in the west limb of the Blackman Anticline.

the trends of the garnet isograd might also be due to emplacement of the Purcell thrust sheet being emplaced while it was hot or by some other thermal feature. This second interpretation is favoured because 1) there is no direct evidence that the Blackman thrust swings westward and joins the Purcell thrust, 2) the Blackman thrust dips steeply southwest, and 3) the middle Miette Group strata appear to continue across Hugh Allan Creek. These possibilities should be investigated and the trend and dip of the garnet isograd needs to be mapped in detail.

The offset of the metamorphic isograds also provides important information about the relative timing of various structures. Following emplacement of the far travelled Purcell thrust sheet including the Blackman gneisses during the regional metamorphic episode and the formation of the Blackman Anticline, a second movement occurred on the Purcell thrust offsetting and displacing the staurolite isograd 4 km northeastward. The minor folding of the Purcell thrust (Fig. 2, 3) presumably occurred sometime after this second phase of thrusting and was caused by additional compression of the underlying middle Miette folds. Its timing is uncertain and could range from Late Cretaceous to Tertiary in age. Such late stage thrust movements have been documented on faults associated with the Bulldog gneisses to the northwest (McDonough, 1984; McDonough and Simony, 1984) and to the southeast near Golden (Monger et al., 1985).

SUMMARY AND CONCLUSIONS

1. The structure and stratigraphy of the Purcell thrust hanging wall and footwall differ markedly. The hanging wall strata consist of pelites with discontinuous thin grits which are probably equivalent to the lower Kaza Group. Footwall strata with their thick continuous grit units clearly belong to the middle Miette Group.

2. The Blackman anticline is truncated by the Purcell thrust and does not continue south of Hugh Allan Creek.

3. The Purcell thrust forms a lateral ramp around the northern end of the Porcupine Creek Anticlinorium.

4. Although middle Miette strata occur in the footwall of the Purcell thrust on both sides of Hugh Allan Creek, they are higher grade to the north. Therefore the Blackman thrust may not continue south of Hugh Allan Creek, but may be a thrust that merges with the Purcell thrust to the southeast. However, if the trend of the garnet isograd can be explained by the Purcell thrust sheet being emplaced when it was hot or some other thermal feature, then the Blackman thrust slice might represent a faulted upright southwest limb of the PCA.

5. If the above structural relationships are correct, the Purcell thrust cuts upsection in the footwall to the southwest and therefore truncates a pre-existing structure on the southwest limb of the PCA (Fig. 4). These thrusts may have also truncated the PCA. Due to extensive erosion the corresponding hanging wall structures are not present.

6. The late stage movement of the Purcell thrust sheet is a minimum of 4 km as indicated by the apparent offset of the staurolite isograd.

7. A small thrust slice of carbonates that occurs between the Hugh Allan and Blackman gneisses probably is an equivalent of the Middle Marble of the Horsethief Creek Group.

ACKNOWLEDGMENTS

Financial support for field and office support came from EMR Research Agreement and NSERC Grant A2128. This paper would not have been possible without the mapping of G. Klein south of Hugh Allan Creek. I am grateful to her and R. Leonard for providing information and for helpful discussions. I thank M. Charland, R.G. Dechesne, G. Klein and R.A. Price for discussions and reviews of the manuscript. I very much appreciate the field support and logistics provided by Yellowhead Helicopters of Valemount.

REFERENCES

Campbell, R.B.
1968: Canoe River (83D), British Columbia; Geological Survey of Canada, Map 15-1967, scale 1:250 000.

Charland, M. and Hynes, A.
1987: A mylonite zone east of Rocky Mountain Trench, Selwyn Range, British Columbia; *in* Geological Association of Canada, Program with Abstracts, v. 13, p. 30.

Dechesne, R.
1986: The geology of the southern Cariboo Mountains near Blue River, British Columbia; M.Sc. thesis, University of Calgary, Alberta, 261 p.

Klein, G.A. and Mountjoy, E.W.
1988: Northern Porcupine Creek Anticlinorium and footwall of the Purcell Thrust, Northern Park Ranges, B.C.; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Leonard, R.
1985: Variable structural style, stratigraphy, total strain and metamorphism adjacent to the Purcell thrust near Blackman Creek, British Columbia; M.Sc. thesis, McGill University, Montreal.

McDonough, M.R.
1984: Structural evolution and metamorphism of basement gneisses and Hadrynian cover, Bulldog Creek area, British Columbia; M.Sc. thesis, University of Calgary, Alberta, 163 p.

McDonough, M.R. and Simony, P.S.
1984: Basement gneisses and Hadrynian metasediments near Bulldog Creek, Selwyn Range, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 99-102.

Monger, J.W.H., Clowes, R.M., Price, R.A., Simony, P.S., Riddihough, R.P., and Woodsworth, G.J.
1985: B-2 Juan de Fuca Plate to Alberta Plains; Geological Society of America; Centennial Continent/Ocean Transect E7.

Mountjoy, E.W. and Forest, R.
1986: Revised structural interpretation, Selwyn Range between Ptarmigan and Hugh Allan creeks, British Columbia — an antiformal stack of thrusts; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 177-183.

Mountjoy, E.W., Forest, R., and Leonard, R.
1985: Structure and stratigraphy of the Miette Group, Selwyn Range, between Ptarmigan and Hugh Allan creeks, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 485-490.

Oke, C. and Simony, P.S.
1981: Basement gneisses of the Western Rocky Mountains, Hugh Allan Creek area, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 181-184.

Pell, J.
1984: Stratigraphy, structure and metamorphism of Hadrynian strata in the southeastern Cariboo Mountains, British Columbia; Ph.D. thesis, University of Calgary, Alberta.

Pell, J. and Simony, P.S.
1987: New correlations of Hadrynian strata, south-central British Columbia; Canadian Journal of Earth Sciences, v. 24, p. 302-313.

Price, R.A. and Mountjoy, E.W.
1970: Geological structure of the Canadian Rocky Mountains between Bow and Athabasca rivers, a progress report; Geological Association of Canada, Special Paper 6, p. 7-26.

Simony, P.S., Ghent, E.D., Craw, D., Mitchell, W., and Robbins, D.B.
1980: Structural and metamorphic evolution of the northeast flank of the Shuswap Complex, southern Canoe River area, British Columbia; Geological Society of America, Memoir 153, p. 445-462.

Teitz, M.W. and Mountjoy, E.W.
1985: The Yellowhead and Astoria carbonate platforms in the Late Proterozoic Upper Miette Group, Jasper, Alberta; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 341-348.

Geoarchitecture, evolution, and seismic risk assessment of the southern Fraser River delta, B.C.

John L. Luternauer[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Luternauer, J.L., Geoarchitecture, evolution, and seismic risk assessment of the southern Fraser River delta, B.C.; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 105-109, 1988.

Abstract

The main field components of a study of the geological and geotechnical character of the southern part of the Fraser River delta were completed in 1987. Forty-five kilometres of shallow seismic reflection profiles were collected over the last three years, and seven holes have been drilled to depths of 55 to 367 m. Geotechnical and geophysical parameters were measured in selected holes. Cores were subsampled for radiocarbon and thermoluminescence age determinations and for analyses of grain size, clay mineralogy, fossils, tephra and pumice, and total non-carbonate organic carbon. Analyses for all but the tephra and pumice samples are in progress.

Résumé

On a complété en 1987 les principaux éléments d'une étude sur le terrain du caractère géologique et géotechnique de la partie sud du delta du Fraser. On a réalisé 45 km de profils de sismique-réflexion à faible profondeur au cours des trois dernières années, et réalisé sept sondages atteignant 55 à 367 m de profondeur. On a mesuré dans des sondages sélectionnés les paramètres géotechniques et géophysiques. On a fait un échantillonnage des carottes, afin d'établir des datations par le radiocarbone et par thermoluminescence. Aussi des analyses granulométriques ont été effectuées afin de déterminer la minéralogie des argiles, d'identifier les fossiles, de déterminer le contenu en tephra et pierre ponce, ainsi que la teneur totale en carbone organique non inclus dans des carbonates. Toutes les analyses, excepté celles des échantillons de tephra et de pierre ponce, sont en cours de réalisation.

[1] Project leader, other participants are listed in text.

INTRODUCTION

The Fraser River delta (Fig. 1), located in one of the most seismically active zones in Canada (Milne et al., 1978), is becoming increasingly urbanized and industrialized. Unfortunately, development is proceeding without an appreciation of the seismic risk that may be associated with the thick alluvial and deltaic deposits in this area. Furthermore, a rigorous assessment of this risk has not yet been possible because detailed stratigraphic, structural, and geotechnical data have, until now, been lacking.

In recognition of this problem, the Geological Survey of Canada recently began to acquire subsurface information on the southern part of the delta. A trial shallow seismic profiling survey conducted in 1985 established that this technique could define the delta's structure to a depth of about 170 m (Luternauer et al., 1986). This survey was extended during the 1986 field season to a total of 16 line km (Fig. 2; Pullan and Hunter, 1987; Pullan et al., 1987). Seven holes were drilled in the fall of 1986 and spring of 1987 to provide geotechnical data, ground control for the seismic profiles, and stratigraphic information pertinent to the Quaternary evolution of the delta (Fig. 2).

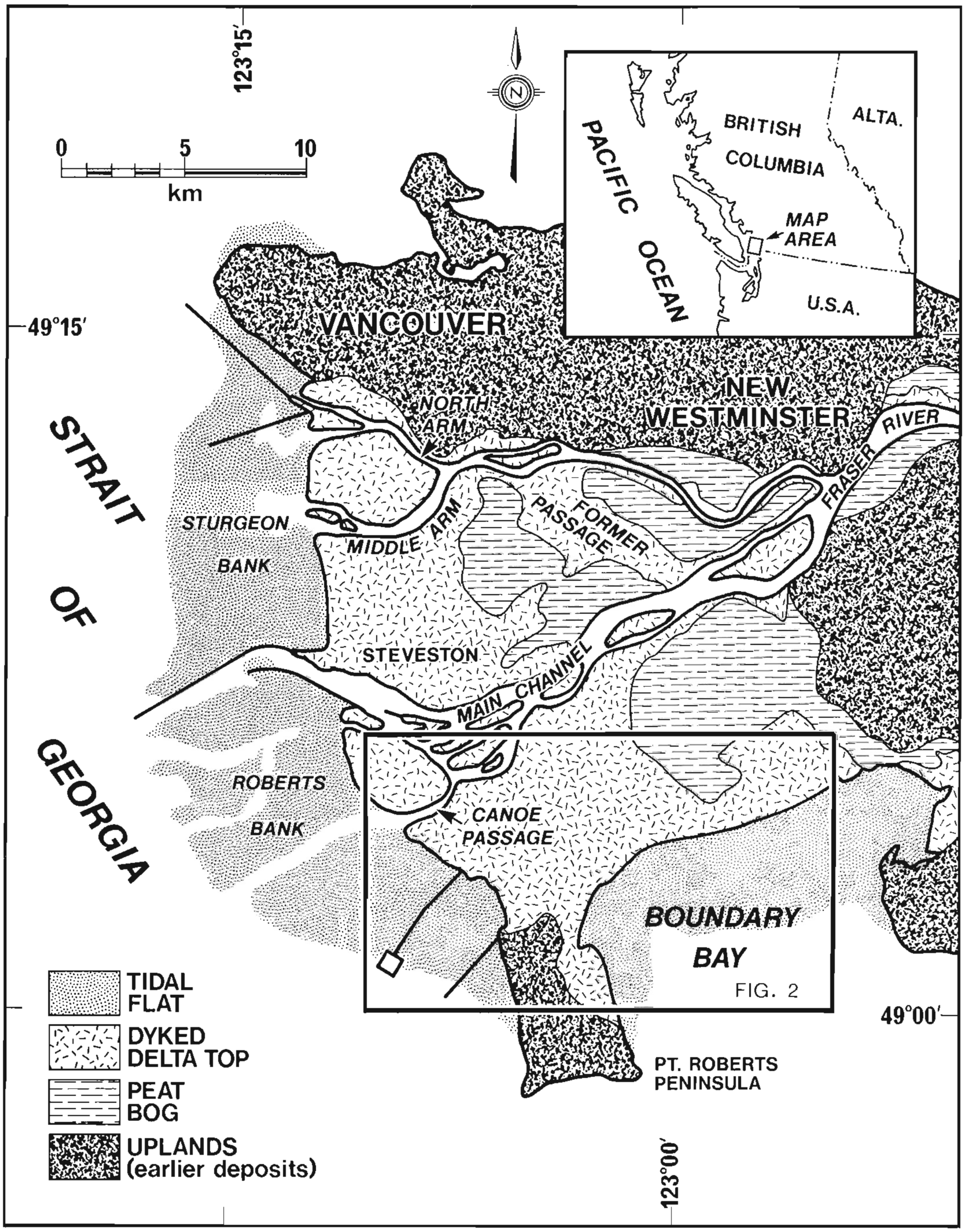


Figure 1. Location and setting of the study area.

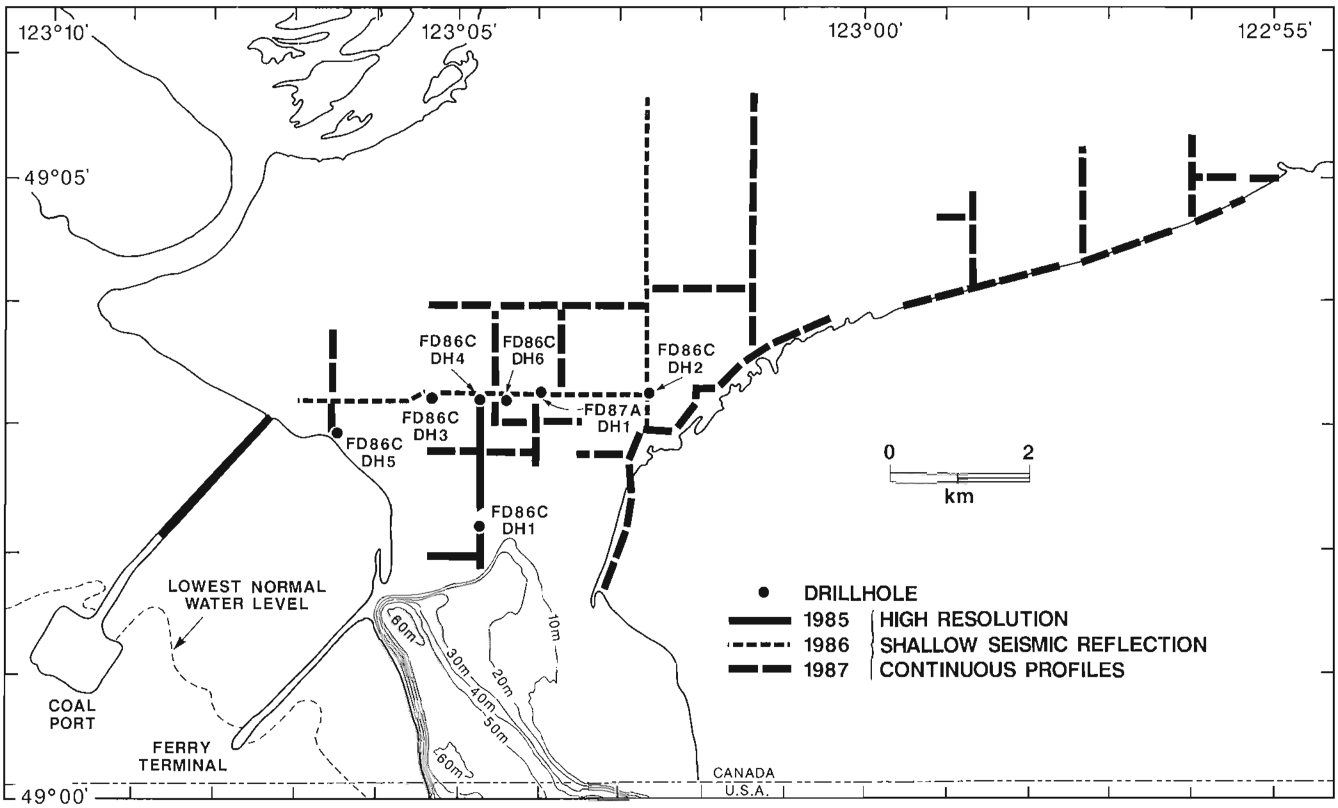


Figure 2. Location of seismic survey lines and boreholes.

RECENT ACTIVITIES (SUMMER-FALL 1987)

During the summer of 1987, an additional 29 line kilometres of shallow seismic reflection profiles were surveyed (Fig. 2). Coverage is now sufficient to reveal the upper subsurface structure of much of the delta south of the Main Channel of the Fraser River.

Data that can be used to assess seismic risk are being derived from borehole samples (split tube and continuous core) and downhole measurements made during 1986 and 1987 (Table 1). These data include: (1) sediment grain size; (2) clay mineralogy; (3) Standard Penetration Test N values (derived from blow-counts recorded during coring); (4) cone penetrometer tip resistance, sleeve friction, and dynamic pore pressure measurements (Robertson and Campanella, 1983; ConeTec Investigations Ltd., unpublished report, 1987); (5) shear and compressional wave velocities, resistivity, self potential, natural gamma radiation, gamma gamma density, magnetic susceptibility, and temperature (Campanella and Robertson, 1984; Serra, 1986; Conetec Investigations Ltd., unpublished report, 1987). Secondary geotechnical parameters that can be calculated from the acquired data and used to evaluate the potential response of sediment to earthquake loading include the dynamic shear modulus (Campanella and Robertson, 1984) and the cyclic stress ratio (Seed et al., 1983).

Selected samples from the deepest borehole were analyzed for total non-carbonate organic carbon by Can Test Ltd. (Vancouver, B.C.) to explain colour variations and help define depositional environments. Wood and shell recovered from borehole cores and cuttings are being radiocarbon dated at the University of Toronto Isotrace Laboratory and Geological Survey of Canada Radiocarbon Laboratory. Additional geochronological control will be provided by thermoluminescence dating (Berger and Luternauer, 1987). Tephra and pumice were extracted from sediments in the deepest borehole to determine provenance. Analyses for pollen, foraminifera, and ostracodes are being conducted in order to elucidate paleoenvironments that prevailed during deposition.

A meeting of project participants was held in December 1987 to present and discuss analytical results, geotechnical data, and seismic profile lines, and to plan future work. The participants are: J.L. Luternauer (Project leader), J.J. Clague (Terrain Sciences Division, Vancouver), J.A. Hunter and S.E. Pullan (Terrain Sciences Division, Ottawa), M.C. Roberts and H.M. Jol (Department of Geography, Simon Fraser University, Burnaby, B.C. V5A 1S6), B.E.B. Cameron (Cordilleran and Pacific Geoscience Division, Sidney), L.E. Jackson Jr. (Terrain Sciences Division, Vancouver), C.J. Mwenifumbo and P.G. Killeen (Mineral Resources Division, Ottawa), R.W. Mathewes (Department of Biological Sciences, Simon Fraser University, Burnaby, B.C. V5A 1S6), G.W. Berger (Department of Geology, Western Washington University, Bellingham, WA, 98225, U.S.A.), B. Blaise (Cordilleran and Pacific Geoscience Division, Sidney), W.D. Liam Finn (Soil Dynamics Group, Department of Civil Engineering, University of British Columbia, Vancouver, B.C. V6T 1W5), D.J. Woeller (ConeTec Investigations Ltd., 2447 Beta Avenue, Burnaby, B.C. V5C 5N1), and W. Bentkowski (Cordilleran and Pacific Geoscience Division, Sidney).

Drill Hole Number and Total Depth (m)	Geotechnical / Geophysical / Geological Parameters											Chemical	Mineralogical	Age				Paleo-Environmental
					Wave Velocities Measured by Seismic Cone Penetrometer and/or Engineering Seismograph		Cont. Geophysical Logging											
	Grain Size	SPT n value	Electric Cone Penetrometer tip resistance / sleeve friction / dynamic pore pressure	Temperature	Shear	Compressional	Resistivity	Self Potential	Natural Gamma Radiation	Density	Magnetic Susceptibility	Total Non-Carbonate Organic Carbon	Clays	Radiocarbon	Thermo-luminescence	Tephra and Pumice	Pollen	Foraminifera, Ostracoda and Misc. Megafossils
FD86C DH1 (85)	7.3, 9.8, 12.2, 19.8, 66.8, 85.0	9.8, 12.2, 19.8, 66.8				1.0 to 72.0 (1 m interval)	4.0 to 68.5	4.0 to 68.5	0.0 to 68.5					7.0				
FD86C DH2 (113)	18.3, 30.5, 45.7, 61.0, 91.4	18.3, 30.5, 45.7, 61.0, 91.4		0.0 to 110.0 (5 m interval)		1.0 to 110.0 (1 m interval)	5.2 to 112.0	5.2 to 112.0	0.0 to 112.0					30.5, 45.7				
FD86C DH3 (55)	15.2, 39.6, 55.0	15.2, 39.6, 55.0		0.0 to 50.0 (continuous)		1.0 to 50.0 (1 m interval)			0.0 to 50.0	0.0 to 50.0	0.0 to 50.0			6.4, 13.4, 43.9				
FD86C DH4 (122)	12.2, 36.6, 61.0, 103.6	12.2, 36.6, 61.0, 103.6		0.0 to 117.0 (continuous) 0.0 to 117.0 (5 m interval)		1.0 to 117.0 (1 m interval)	5.3 to 115.0	5.3 to 115.0	0.0 to 117.0	0.0 to 117.0	0.0 to 117.0			104.8				
FD86C DH5 (88.5)	15.2, 30.5, 45.7, 60.0, 66.8, 78.9	15.2, 30.5, 45.7, 60.0, 66.8, 78.9		0.0 to 88.0 (continuous) 0.0 to 88.0 (5 m interval)		1.0 to 88.0 (1 m interval)	2.9 to 60.0	2.9 to 60.0	0.0 to 88.0		0.0 to 88.0			14.9, 30.5, 33.2, 65.2, 73.8				
FD86C DH6 (61)	17.7, 30.0, 48.0, 61.0	17.7, 30.0, 48.0, 61.0	0.25 to 35.45 (5 cm interval)	0.25 to 35.45 (5 cm interval)	1.0 to 35.0 (1 m interval)	1.0 to 60.0 (1 m interval) 0.2 to 19.2 (1 m interval)	3.0 to 59.0	3.0 to 59.0	0.0 to 59.0					8.5, 18.3, 37.8, 56.4				
FP87A DH1 (367)	3.0, 6.4, 12.2, 15.2, 18.3, 21.3, 24.4, 27.4, 30.5, 33.5, 36.6, 39.6, 42.7, 45.7, 51.8, 57.9, 64.0, 70.1, 76.2, 82.3, 88.4, 94.5, 102.1, 106.7, 112.8, 118.9, 125.0, 131.1, 137.2, 137.8, 138.4, 139.9, 141.4, 143.0, 143.2, 144.5, 146.0, 147.8, 149,0, 150.6, 152.1, 153.6, 155.0, 156.7, 158.2, 159.7, 161.8, 163.4, 164.9, 166.1, 168.2, 171.3, 173.7, 175.3, 177.1, 178.6, 181.0, 182.6, 184.1, 185.6, 191.7, 198.1, 205.4, 213.0, 219.2, 228.3, 243.8, 251.2, 266.4, 278.6, 290.5, 340.5, 347.2, 353.3, 354.5, 360.0, 363.6, 365.8	Every 3.05m to 45.72m Every 6.1m to 137.2m	0.25 to 44.75 (5 cm interval)	0.25 to 44.75 (5 cm interval) 0.0 to 73.0 (continuous) 0.0 to 100.0 (5 m interval)	1.0 to 45.0 (1 m interval)				0.0 to 73.0	0.0 to 73.0		140.0, 153.8, 168.4, 182.7, 198.3, 216.0, 226.8, 227.2, 245.2, 258.9, 274.3, 290.6, 301.6, 340.6, 350.2, 365.8	15.2, 51.8, 64.0, 82.3, 99.4, 112.8, 131.1, 137.2, 137.8, 143.0, 149.0, 156.7, 163.4, 171.3, 182.6, 184.1, 185.6, 191.7, 198.1, 205.4, 213.0, 219.2, 228.3, 243.8, 251.2, 266.4, 278.6, 290.5, 340.5, 347.2, 353.3, 354.5, 360.0, 363.6	39.6, 66.1, 99.4, 138.4, 143.3, 158.3, 168.4, 171.3, 179.1, 199.9, 223.0, 246.7, 266.5, 269.3	155.4 174.6 196.2 259.5 294.4 366.1	144.6 200.0 205.4 207.1 234.5 260.0 269.3 281.8 284.8 287.9 315.3 348.7	143.3 152.2 193.4 168.4 181.2 205.6 216.0 231.5 243.8 261.9 275.5 283.3 298.6 315.3 344.4 351.7 354.5 363.6	12, 25, 83, 113, 141, 148, 154, 163, 173, 177, 183, 199, 214, 229, 252, 279, 291, 302, 347, 348, 355, 364, 367

Table 1. Analyses and measurements that have been obtained from the seven holes drilled on the Fraser River delta in 1986 and 1987. Numbers refer to depths of samples or measurements (in metres).

REFERENCES

Berger, G.W. and Luternauer, J.L.
1987: Preliminary field work for thermolumunescence dating studies at the Fraser River delta, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 901-904.

Campanella, R.G. and Robertson, P.K.
1984: A seismic cone penetrometer to measure engineering properties of soil; University of British Columbia, Department of Civil Engineering, Soil Mechanics Series No. 83, 6 p.

Luternauer, J.L., Clague, J.J., Hamilton, T.S., Hunter, J.A., Pullan, S.E., and Roberts, M.C.
1986: Structure and stratigraphy of the southwestern Fraser River delta: a trial shallow seismic profiling and coring survey; *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 707-714.

Milne, W.G., Rogers, G.C., Riddihough, R.P., McMechan, G.A., and Hyndman, R.D.
1978: Seismicity of western Canada; Canadian Journal of Earth Sciences, v. 15, p. 1170-1193.

Pullan, S.E. and Hunter, J.A.
1987: Applications of the "Optimum Offset" shallow seismic reflection technique in the Fraser Delta, British Columbia; Proceedings, Annual Meeting of the Society of Exploration Geophysicists, New Orleans, October 11-16, 1987, 2 p.

Pullan, S.E., Hunter, J.A., Gagne, R.M., Burns, R.A., and Good, R.L.
1987: High resolution shallow seismic reflection profiles from the Fraser Delta, Tsawwassen, British Columbia; Geological Survey of Canada, Open File 1507, 5 p.

Robertson, P.K. and Campanella, R.G.
1983: Interpretation of cone penetration tests: Part I and II; Canadian Geotechnical Journal, v. 20, p. 718-745.

Seed, H.B., Idriss, I.M., and Arango, I.
1983: Evaluation of liquefaction potential using field performance data; American Society of Civil Engineers, Journal of Geotechnical Engineering Division, v. 109, p. 458-482.

Serra, O.
1986: Interpretation of logging data; Fundamentals of Well-Log Interpretation, v. 2, Developments in Petroleum Science, Elsevier Scientific Publishing Co., Amsterdam, 684 p.

Preliminary results of gravity surveys along the Lithoprobe southern Canadian Cordilleran transect

M.D. Thomas[1], D.W. Halliday[1], and B. Felix[2]

Thomas, M.D., Halliday, D.W., and Felix, B., Preliminary results of gravity surveys along the Lithoprobe southern Canadian Cordilleran transect, in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 111-116, 1988.

Abstract

Detailed gravity surveys totalling 142 observations spaced 1 to 3 km apart have been completed along the five Lithoprobe seismic reflection lines in the southeastern Cordillera with the objective of obtaining supplementary structural information. A further 112 observations spaced 1 to 5 km apart were made near seismic lines crossing the Valhalla Gneiss Complex and Nelson Batholith to examine boundary relationships and a number of seismically-defined features. Preliminary Bouguer anomalies along the seismic lines are presented here in profile form for comparison with a crustal section interpreted from the seismic data. Several gravity features that may ultimately provide structural information are discussed, but because terrain corrections, which attain large magnitudes in this area, have yet to be computed, the geological significance of these features must be treated with caution.

Résumé

Des levés gravimétriques détaillés totalisant 142 observations effectuées à des intervalles de 1 à 3 km ont été exécutés le long de cinq lignes de réflexion sismique Lithoprobe dans le sud-est de la Cordillère dans le but d'obtenir des informations structurales supplémentaires. Cent douze autres observations effectuées à intervalles de 1 à 5 km ont été exécutés près des lignes sismiques traversant le complexe gneissique de Valhalla et le batholite de Nelson afin d'examiner les relations limitrophes ainsi qu'un certain nombre d'éléments définis à l'aide de méthodes sismiques. Certaines anomalies de Bouguer préliminaires observées le long des lignes sismiques sont présentées ici sous forme de profils pour fins de comparaison avec une coupe de la croûte interprétée à partir des données sismiques. Plusieurs éléments gravimétriques susceptibles de fournir plus tard des informations structurales font l'objet d'une discussion, mais parce que les corrections de terrain, qui atteignent de grandes amplitudes dans cette zone, restent encore à calculer, la signification géologique de ces éléments doit être traitée avec prudence.

[1] Geophysics Division
[2] Lithosphere and Canadian Shield Division

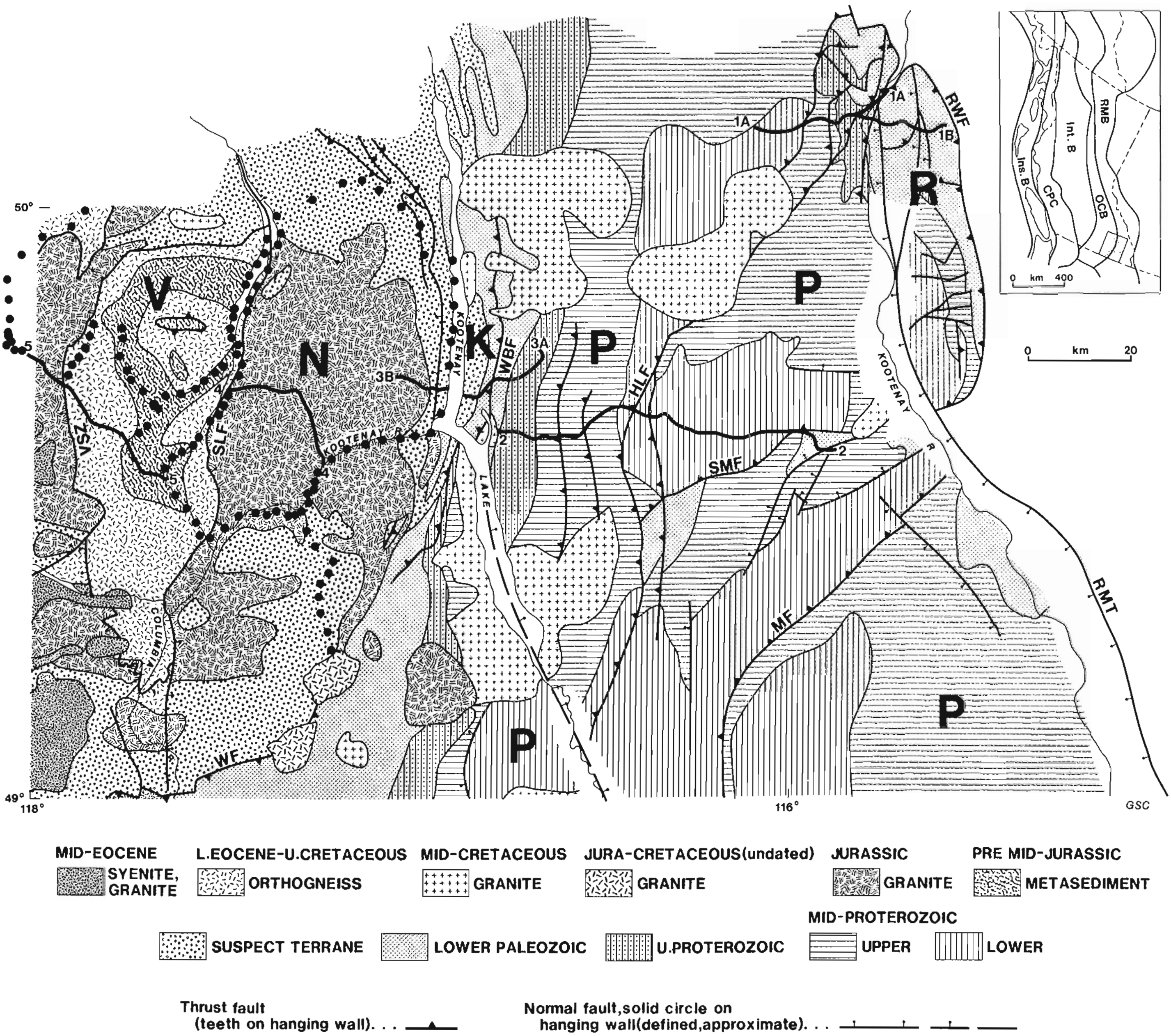


Figure 1. Geological map of southeastern Cordillera after Cook et al. (1987) showing location of Lithoprobe seismic reflection lines 1 to 5. Detailed gravity surveys totalling 142 observations were made along these lines. Locations of 112 additional gravity observations are indicated by dots. Major geological units are identified by: V, Valhalla Gneiss Complex; N, Nelson Batholith; K, Kootenay Arc; P, Purcell Anticlinorium; R, Rocky Mountain Fold and Thrust Belt. Major faults are identified by: VSZ, Valkyr Shear Zone; SLF, Slocan Lake Fault; WBF, West Benard Fault; HLF, Hall Lake Fault; SMF, St.Mary Fault; MF, Moyie Fault; RWF, Redwall Fault; RMT, Rocky Mountain Trench. Inset illustrates location of study-area within the Canadian Cordillera: Ins. B, Insular Belt; CPC, Coast Plutonic Complex; Int. B, Intermontane Belt; OCB, Omineca Crystalline Belt; RMB, Rocky Mountain Fold and Thrust Belt.

INTRODUCTION

Results of a seismic reflection survey carried out as part of the Canadian Lithoprobe Program across the eastern part of the southern Canadian Cordillera have been summarized by Cook et al. (1987). Approximately 270 km of data were collected along five separate profiles (Fig. 1) that together provide almost continuous coverage for about 180 km across the prevailing structural strike. From east to west the profiles cross successively the Phanerozoic Rocky Mountain Thrust and Fold Belt, the Rocky Mountain Trench, the Proterozoic Purcell Anticlinorium, the Proterozoic-Pharerozoic Kootenay Arc, the Jurassic Nelson Batholith and the composite Lower Eocene-Upper Cretaceous and pre-Mid-Jurassic Valhalla Gneiss Complex.

Detailed gravity surveys were carried out along the seismic lines to map density variations in the crust and to examine structures interpreted from the seismic records. Detailed surveys were conducted also along selected traverses in the vicinity of liners 3, 4 and 5 (Fig. 1) to better define the gravity field in the general area of the Valhalla Gneiss Complex and Nelson Batholith. A significant difference in the level of the gravity field over these two units, as defined by regional data (Fig. 2), suggested that improved resolution of the gravity field would benefit studies of boundary relationships and of the overall geometry of the Batholith. At the surface the boundary is marked by the Slocan Lake Fault. Cook et al. (1987) have traced this fault into the lower crust on the basis of a narrow zone of variably strong to weak east-dipping (25°) reflectors (Fig. 3), and it is interpreted to form the boundary between the Valhalla Gneiss Complex and the Nelson Batholith to a depth of about 5 km. Discontinuous flat-lying reflectors above the Slocan Lake Fault reflectors are interpreted to be the floor of the Batholith at a similar depth.

It was anticipated that detailed gravity in this region might also help resolve some of the difficulties experienced by Cook

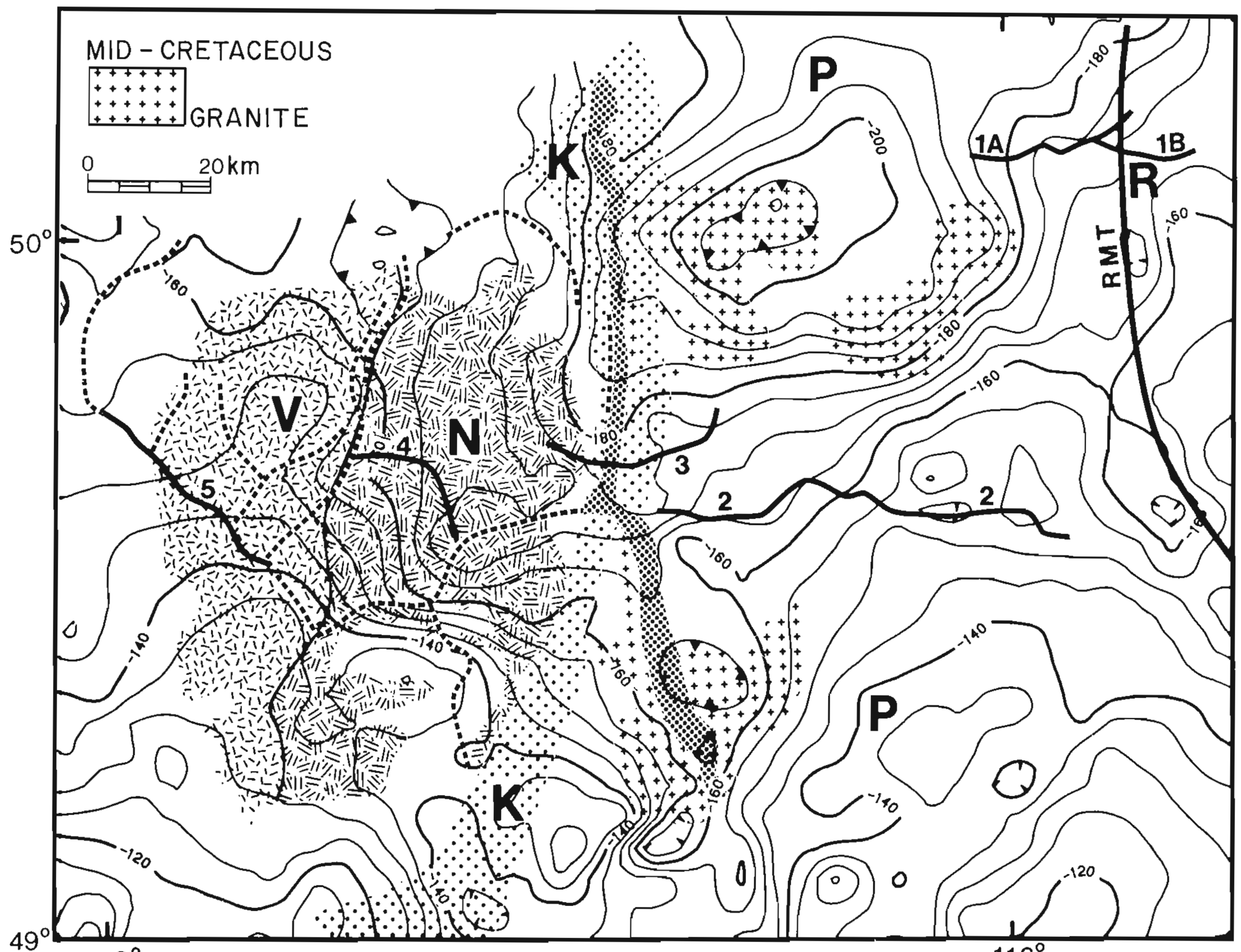


Figure 2. Bouguer gravity contour map based on terrain-corrected regional gravity observations. Map is machine-contoured at 5 mGal contour interval and slight smoothing of the data has resulted. Closures with solid triangles indicate gravity lows. Selected geological units are superposed: V, Valhalla Gneiss Complex; N, Nelson Batholith; K, Kootenay Arc (the complexity of this feature coupled with reconnaissance geological mapping in some areas demands that the boundaries shown here be regarded as approximate); P, Purcell Anticlinorium (unpatterned area between K and RMT); R, Rocky Mountain Fold and Thrust Belt. RMT, Rocky Mountain Trench. Seismic lines 1 to 5 are indicated by solid lines. Supplementary gravity traverses are indicated by dashed lines.

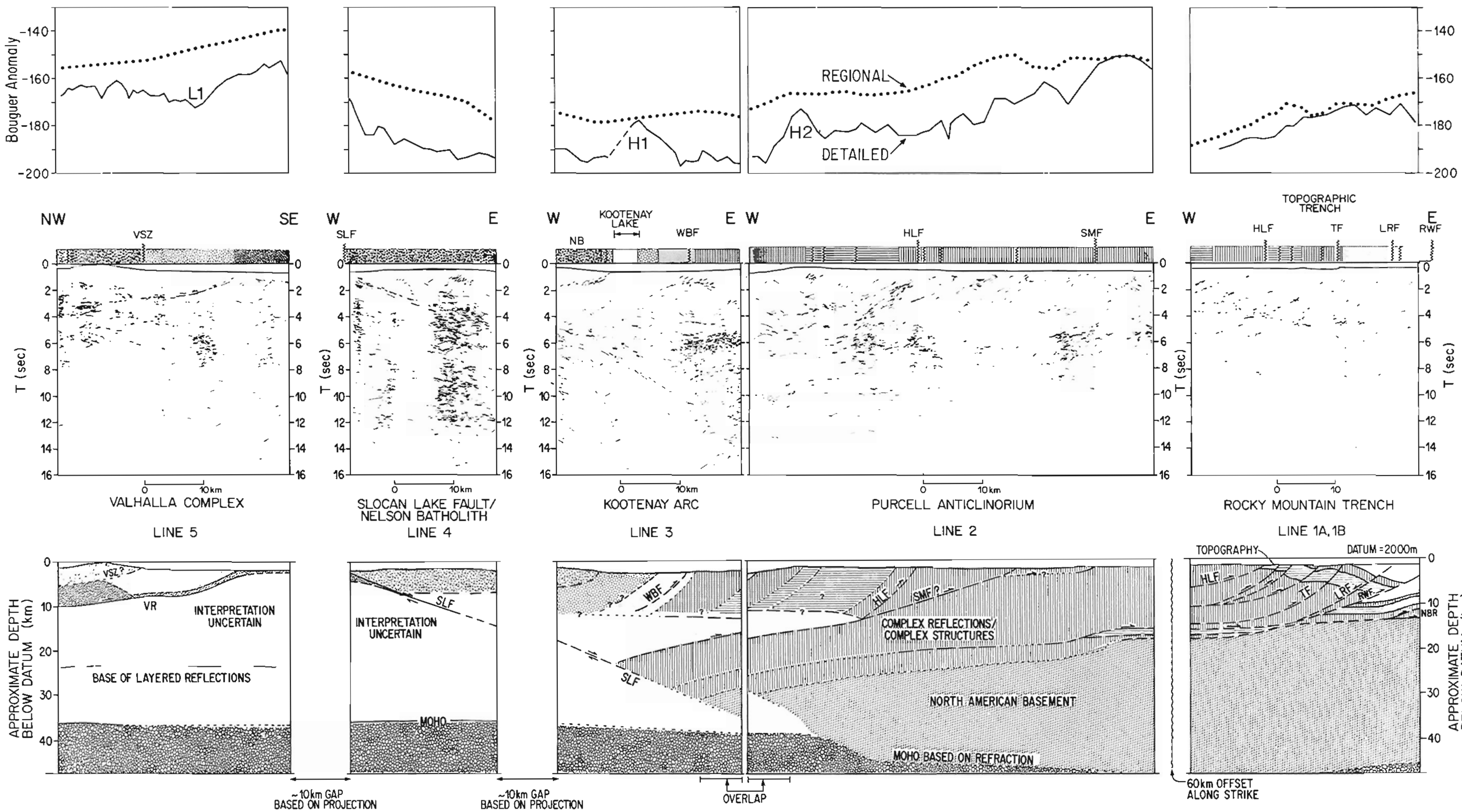


Figure 3.

Top: Profiles of regional (terrain-corrected) and detailed (1987 survey, uncorrected for terrain) Bouguer gravity profiles.

Centre: Line drawing of unmigrated seismic data to a depth of 16 seconds two-way travel time with generalized surface geology at top.

Bottom: Geological interpretation of seismic data. Seismic section and interpretation are reproduced from Cook et al. (1987) with the authors' permission. VSZ, Valkyr Shear Zone; VR, Valhalla Reflection; SLF, Slocan Lake Fault; NB, Nelson Batholith; WBF, West Benard Fault; HLF, Hall Lake Fault; SMF, St.Mary Fault; TF, Torrent Fault; LRF, Lussier River Fault; RWF, Redwall Fault; NBR, Near Basement Reflections.

et al. (1987) in explaining certain features in their seismic records. They were unable to determine the geological nature of the Valhalla Reflection underlying the Valhalla Gneiss Complex (Fig. 3), although they suggested that it might be a compressional shear zone. The significance of a complex zone of reflections between the Valhalla Reflection and about 8 seconds two-way travel time also remained enigmatic.

Farther east, along seismic lines 1, 2 and 3, it was envisaged that gravity would be useful in mapping shallow structures. The definition of reflectors near the surface (down to about 1 second of two-way travel time) is relatively poor, and in some areas shallow reflectors are absent (Fig. 3). This is a consequence of the design specifications of the reconnaissance seismic surveys. Gravity may provide a means of linking faults and stratigraphic boundaries mapped at surface with reflectors below the 1 second surface zone, particularly in the region east of and including the Kootenay Arc. Here, reflectors are predominantly westward-dipping, consistent with a picture of eastward-directed thrusting of Proterozoic and Phanerozoic miogeoclinal deposits above autochthonous basement of the North American craton. Cook et al. (1987) noted that several of these reflectors project to surface near, but not at, fault zones and suggested that they probably coincide with mafic sills and/or stratigraphic horizons. Such sills would doubtless produce small gravity anomalies, as would those stratigraphic boundaries associated with changes in rock density.

GRAVITY SURVEYS

Southeastern British Columbia has been covered by regional gravity surveys with station spacing ranging from about 5 to 20 km. The average spacing is about 10 km. More closely spaced stations, generally about 1 to 2.5 km apart, have been surveyed only along Highways 3 and 95 in the south and along Highway 95 in the east. The rugged terrain of the Cordillera demands that corrections for terrain be computed for all gravity stations in order that variations in the Bouguer gravity field can be confidently ascribed to geological sources. Terrain corrections for this part of the Cordillera range from <1 to 63 mGal and average about 14 mGal with a standard deviation of ± 11 mGal. The Bouguer gravity field based on terrain-corrected regional gravity observations is portrayed in contoured format superposed on a simplified geological map in Figure 2.

Detailed gravity surveys were carried out in June and July 1987 under the direction of one of the authors (DWH) along Lithoprobe lines 1 to 5 with a station spacing ranging from about 1 to 3 km. The closely spaced stations (1 km) were located across the Valkyr Shear Zone on line 5 and the major West Benard and Hall Lake faults, which cross lines 3 and 2, respectively. A total of 142 observations was made along the 5 seismic lines. An additional 112 observations were made along supplementary traverses in the neighbourhood of seismic lines 3, 4 and 5 (Fig. 1) to better define some features of the gravity field. The spacing for these observations ranged from about 1 to 5 km.

Gravity measurements were made with a LaCoste and Romberg Geodetic Gravimeter (No. 790) and were tied to base stations of the National Gravity Net. Elevations along the seismic lines were provided by a series of temporary benchmarks established for the seismic surveys. These were surveyed by trigonometric methods and tied to a base elevation provided by for adjacent stations will probably be fairly similar. Thus, relative changes in gravity as portrayed by the detailed gravity profiles of Figure 3 may not be significantly different from those that will be observed when terrain corrections are applied. It is, therefore, not unreasonable to examine the geological significance of some of the larger gravity anomalies.

On line 5 a gravity low identified as L1, with an amplitude of about -10 mGal relative to the trend of the background field, corresponds closely with orthogneiss of the Valhalla Gneiss Complex, which presumably is less dense than flanking Jurassic granite to the west and metasediment of the Complex to the east. The near-surface section of crust below the orthogneiss is devoid of reflectors to a two-way travel time of about 2 seconds. The gravity method here offers the opportunity of modelling the orthogneiss unit to determine its relationship to the seismically-transparent crust.

The west end of line 4 is displaced approximately 20 km to the northeast of the east end of line 5. This translates into a roughly 10 km east-west gap in seismic coverage (Fig. 3). There is a noticeable difference between the general levels of the gravity field along the two lines, with that along line 4 being about 30 mGal lower. The lower level over the Nelson Batholith doubtless signifies that the underlying granitic rocks are lower in density than metamorphic rocks of the adjacent Valhalla Gneiss Complex. The pattern of regional gravity contours (Fig. 2) supports this. The detailed gravity profile (2 km station spacing) joining lines 5 and 4 (Fig. 1) will provide a detailed picture of the gradient joining these two levels. It is anticipated that gravity modelling of the gradient and the regional field in general will provide information on the subsurface contact of the Nelson Batholith with the Valhalla Gneiss Complex to the west. The question of whether the Slocan Lake Fault forms a major part of this contact, as suggested by seismic interpretation, or whether it is a feature that cuts through the batholith should be answered by such modelling studies.

Along line 3, which runs from the eastern margin of the Nelson Batholith across the Kootenay Arc, the gravity field maintains a level between about -190 and -195 mGal, but a noticeable positive anomaly, H1, about 18 mGal amplitude occurs east of Kootenay Lake. Inspection of topographic maps indicates, however, that this may be an artifact related to terrain. The eastern shore of the lake in this area is relatively flat and would be associated with terrain corrections that would be relatively small compared to those computed for adjacent terrain to the east and the west. Thus, after application of terrain corrections the feature will probably decrease somewhat in amplitude and might even disappear! The example of H1 demonstrates why these preliminary profiles must be viewed with extreme caution. Notwithstanding this caveat, it is observed that the uppermost crust (from surface down to 2 to 3 seconds two-way travel time) is seismically transparent in this region. This crust may represent the so-called "suspect" terrain (Cook et al., 1987) of the Kootenay Arc (Fig. 1). The West Benard Fault is located just east of H1 and may form the eastern limit of dense crust within the

Arc. If H1 persists after terrain corrections and if there is a density contrast between the "suspect" terrain and adjacent rock units, gravity should prove useful in outlining its subsurface geometry.

The eastern boundary of the Nelson Batholith apparently does not correlate with a distinct signature in the detailed gravity profile or in the regional field. Near line 3 it runs parallel to gravity contours that decrease in value eastward and northeastward into a prominent negative anomaly associated with two sizable Mid-Cretaceous granites (Fig. 2). It is concluded that the Nelson Batholith and Mid-Cretaceous granites are contiguous at depth below a thin cover of Kootenay Arc and Proterozoic rocks.

The gravity profile along line 2 portrays a general eastward increase from about −190 mGal to about −150 mGal. This mimics the eastward rise in the underlying North American basement and there may be a causal relationship. In detail there are small perturbations of the order of about ±5 mGal, but nothing that can be meaningfully equated with the near-surface geology, certainly not the major faults where some response was anticipated. There are, however, two features near the west end of line 2 that justify comment. The small gravity high, H2, with an amplitude of about 13 mGal, whose eastern limit coincides with a mapped fault, may be useful in modelling near-surface structure. Examination of topographic maps suggests that this is not an artifact related to terrain, but rather a signal related to geology. The second feature is a noticeable change in level across H2, from −195 mGal west of H2 to about −183 mGal east of H2. There is no ready explanation for this in the interpreted crustal section by Cook et al. (1987), but a correlation may become apparent after density data are compiled.

The gravity profile along line 1 has minor perturbations, < ±5 mGal, to which no geological significance can be attached at this time. Regionally, the gravity field increases eastward and reaches a plateau over Lower Paleozoic deposits east of the Rocky Mountain Trench. The difference in level, of about 35 mGal, between the east end of the gravity profile along line 2 and the west end of the profile along line 1 results from the 60 km offset along strike of these particular lines (Fig. 2).

DISCUSSION

This preliminary examination of gravity anomalies along the Lithoprobe seismic lines in the southern Cordillera shows that several small features (10 to 18 mGal amplitude) may relate to surface geological features mapped along the lines and/or to regions characterized by distinct seismic signatures in the uppermost crust. Definitive assessment and treatment of these anomalies must await the computation of terrain corrections and compilation of rock densities. Future studies will address these problems. Interpretation of the regional gravity field of this general area of the Cordillera, with its many anomalies, promises to provide much new information on the structure and composition of the crust.

ACKNOWLEDGMENTS

We extend thanks to several people in the Geological Survey of Canada for various forms of assistance: to Dr. A.G. Green and Mr. L.J. Kornik for reviewing a preliminary version of this manuscript; to Mr. J.B. Boyd for a variety of logistic information, acquired on a reconnaissance visit to the area; to Mr. W. Miles for preparing contour maps and statistics on terrain corrections; to Dr. A.G. Green and Ms. C. Patenaude for providing original diagrams from the Cook et al. (1987) publication (to which they are contributing authors), reproduced here with slight modification as Figures 1 and 3; to Mr. A. Rafeek for additional drafting requirements.

REFERENCE

Cook, F.A., Simony, P.S., Coflin, K.C., Green, A.G., Milkereit, B., Price, R.A., Parrish, R., Patenaude, C., Gordy, P.L. and Brown, R.L.
1987: Lithoprobe Southern Canadian Cordilleran Transect: Rocky Mountain thrust belt to Valhalla Gneiss Complex; Geophysical Journal of the Royal Astronomical Society, v. 89, p. 91-98.

Comparison of gold, tungsten and zinc in stream silts and heavy mineral concentrates, South Nahanni resource assessment area, District of Mackenzie†

By W.A. Spirito[1], C.W. Jefferson, and D. Paré[2]

Spirito, W.A., Jefferson, C.W., and Paré, D., Comparison of gold, tungsten and zinc in stream silts and heavy mineral concentrates, South Nahanni resource assessment area, District of Mackenzie; in Current Reasearch, Part E, Geological Survey of Canada, Paper 88-1E, p. 117-126, 1988.

Abstract

Stream gravels (< 1 cm) for heavy mineral concentrate (HMC) preparation and silts (< 180 um) were collected at each sample site as part of a non-renewable mineral resource assessment of the South Nahanni River area. Tungsten correlates with gold in HMCs throughout the region and in silts near Cretaceous intrusions of the Ragged Ranges (RR). Sporadic high gold and tungsten anomalies were detected in HMCs, but not in silts, in the Nahanni Karst — Tlogotsho Plateau area (NK-TP). The gold anomalies in NK-TP may be from local tetrahedrite-galena-sphalerite veins (e.g. Prairie Creek). Gold and tungsten do not correlate with zinc except around Prairie Creek. Zinc in silts correlates with zinc in HMCs from RR, but not from NK-TP. HMCs appear to be the optimum medium for northern Cordilleran geochemical drainage surveys, but should still be used with silts.

Résumé

Dans le cadre d'une évaluation des ressources minérales non renouvelables de la zone de la rivière Nahanni sud, on a prélevé simultanément à chacun des sites d'échantillonnage des graviers fluviaux (< 1 cm) pour préparer des concentrés de minéraux lourds (CML) et des silts (< 180μm). Il y a corrélation entre le tungstène et l'or dans les CML dans toute la région et dans les silts près des intrusions crétacées du chaînon Ragged (CR). Des anomalies sporadiques élevées d'or et de tungstène ont été enregistrées dans les CML mais pas dans les silts de la zone Nahanni Karst — Tlogotsho Plateau (NKTP). Les anomalies d'or dans cette région peuvent être attribuables à des filons locaux de tétraédrite-galène-sphalérite (p. ex. Prairie Creek). Il n'y a pas de corrélation entre l'or et le tungstène, d'une part, et le zinc, d'autre part, dont la teneur est de moyenne (de fond) à légèrement élevée dans les sédiments fluviaux. La teneur en zinc dans les silts correspond à celle du zinc dans les CML provenant du CR mais pas de la zone NKTP. Les CML semblent être le milieu optimal pour les levés géochimiques effectués dans les cours d'eau du nord de la Cordillère mais ils devraient être utilisés conjointement avec des silts.

[1] The University of Western Ontario, London, Ontario N6A 5B7
[2] Consor Mines Ltd., 89 Eddy Street, Hull, Quebec J8Z 2E9
† Contribution to Canada — Northwest Territories Mineral Development Agreement 1987-1991. Project carried by the Geological Survey of Canada, Mineral Resources Division.

INTRODUCTION

Cost-effective methods that yield reliable results are fundamental to mineral exploration and resource evaluation. Gold, tungsten and zinc analyses of stream silts and heavy mineral concentrates (HMCs) presented here provide both a calibration of two methods and a progress report on mineral resource assessment of the proposed Ragged Ranges (RR) and Nahanni Karst — Tlogotsho Plateau (NK-TP) extensions to Nahanni National Park Reserve (Fig. 1, 2).

Use of HMCs as a complement to silts has been increasing in the Cordillera due to the heterogeneous distribution of gold in sample media (Harris, 1982). In New Brunswick,

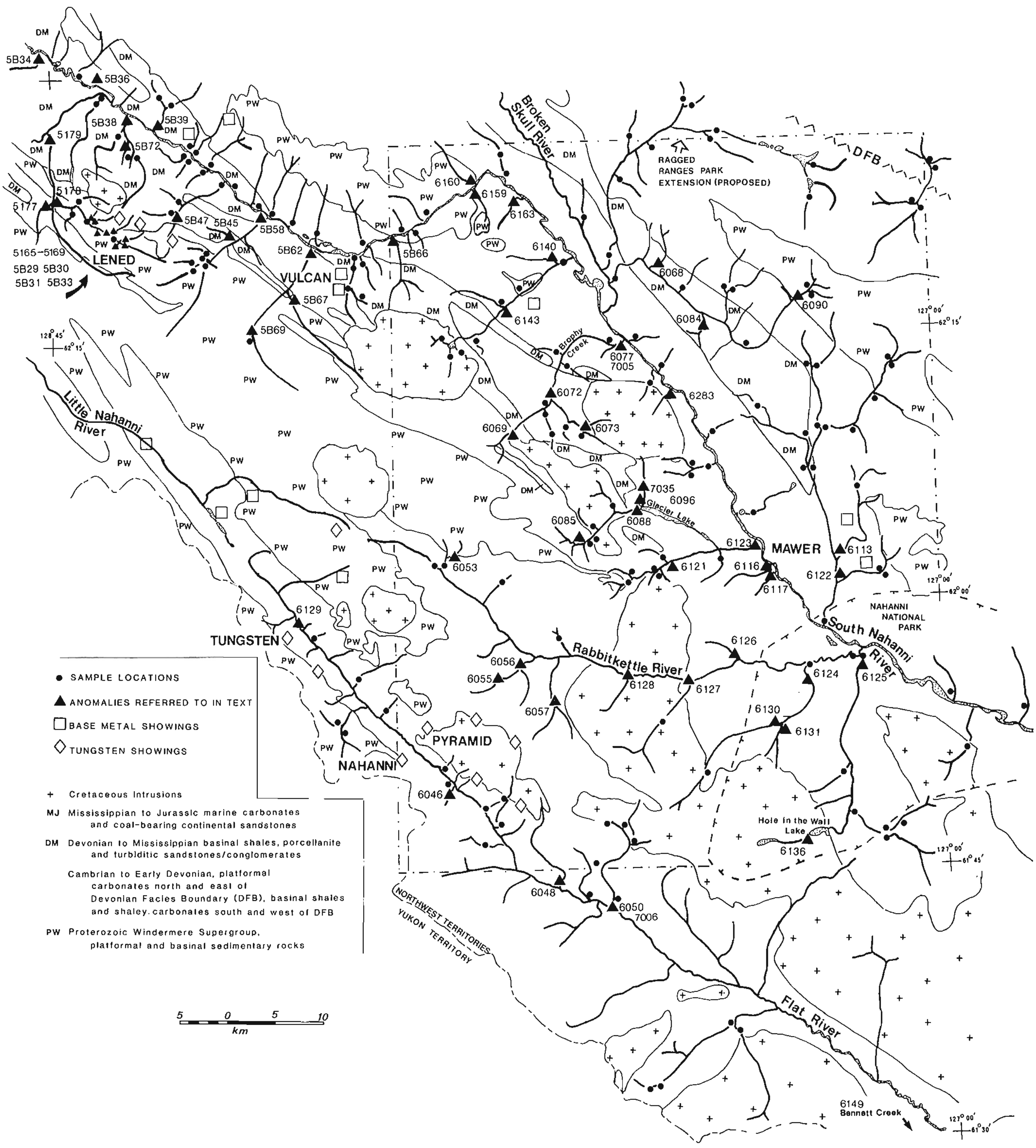


Figure 1. Sample sites and summary geology, Ragged Ranges proposed extension area. Sites listed in Tables 1, 4 and 5, and Figure 4 are shown by labelled triangles; others will be documented in forthcoming publications. Geology from sources cited in Hall et al. (in press).

Friske (1986) noted that stream silts give a measure of hydromorphic and fine-grained mechanical dispersion, whereas HMCs reflect mechanical processes, yet both were successful in detecting known mineral occurrences. This study shows that in the Cordillera the two media give different results for gold, tungsten and zinc.

GENERAL GEOLOGY

Nahanni National Park Reserve, RR and NK-TP (Fig. 1, 2) transect the southern Mackenzie Mountains fold and thrust belt. The bedrock geology, derived from a number of sources cited by Scoates et al. (1986), is summarized as five main packages with reference to symbols in Figures 1 and 2:

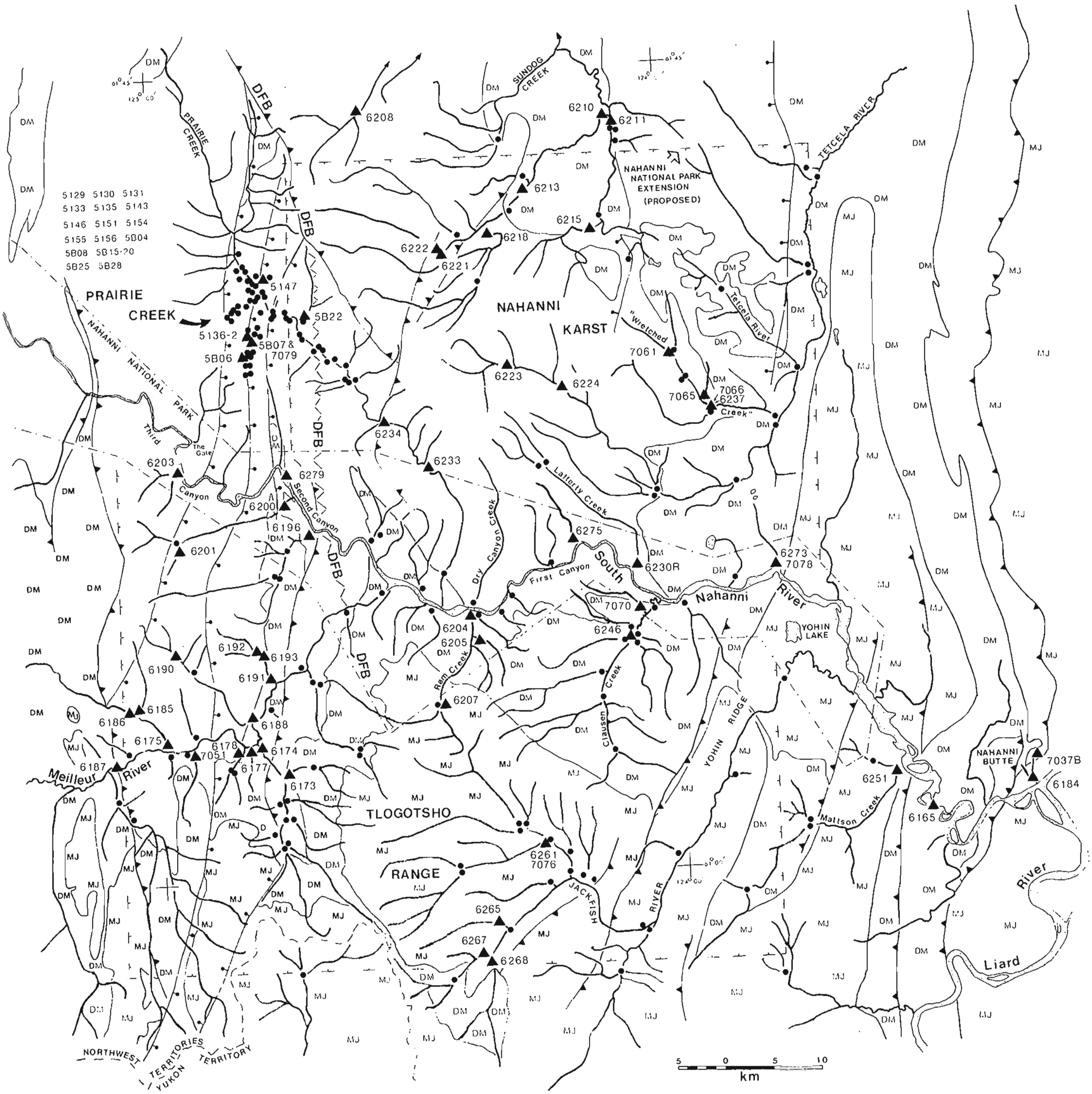


Figure 2. Sample sites and summary geology, Nahanni Karst and Tlogotsho Plateau proposed extension area. Comments and legend in Figure 1.

1. Proterozoic (PW): glaciomarine conglomerate, iron-formation, argillite, shale, quartz-arenite and carbonate of the Windermere Supergroup.

2. Cambrian to Early Devonian (no pattern): platformal carbonate strata on the southwest side, and shales to shaly carbonates on the northeast side of the Devonian facies boundary (DFB). The shaly strata occupy the Prairie Creek Embayment of Selwyn Basin (Morrow, 1984).

3. Devonian to Mississippian (DM): basinal shale, porcellanite and turbiditic sandstone to conglomerate of the Earn Group in RR, and mainly shales to porcellanites of the Besa River and Fort Simpson formations in NK-TP.

4. Mississippian to Jurassic (MJ): Carboniferous shallow marine carbonates and coal-bearing continental sandstones, overlain by Permian to Triassic basinal cherts and mudstones. Late Jurassic to Late Cretaceous fine-to-coarse clastic rocks record a complex interplay of continental to marine deposition and include important coal measures.

Table 1. Gold, tungsten and zinc in samples with one or more anomalous or high background values (Tables 2 and 3). ** = fine gold flakes removed before analysis (see Table 4). -0- = not analysed.

Ragged Ranges Area (Figure 1)

SAMP	EAST	NORTH	Au (ppb)		W (ppm)		Zn (ppm)	
			silt	HMC	silt	HMC	silt	HMC
5165	519100	6913600	2.4	<27	204	1410	840	1100
5166	518600	6913700	2.4	<20	12	549	800	1600
5167	517000	6914900	<1.0	<34	33	9610	150	<490
5168	516800	6914700	<1.0	<40	121	>3 %	280	650
5168S	516800	6914700	2.8	-0-	2750	-0-	260	-0-
5169	517300	6914700	2.7	-0-	3	-0-	680	-0-
5177	513250	6917000	<1.0	-0-	<1	-0-	410	-0-
5178	513400	6917000	<1.0	-0-	18	-0-	270	-0-
5179	512500	6924100	1.2	<38	39	1970	220	1200
5B29	519900	6912950	<1.0	-0-	22	-0-	250	-0-
5B30	519900	6912900	2.0	-0-	5	-0-	410	-0-
5B31	519750	6912850	5.1	-0-	3	-0-	96	-0-
5B33	517800	6914000	2.5	-0-	2	-0-	320	-0-
5B34	512280	6932300	<1.0	3540	2	872	560	650
5B36	517600	6929400	<1.0	330	2	255	550	3200
5B38	528500	6925600	<1.0	<29	3	243	570	1000
5B39	523900	6924600	<1.0	<23	<1	<53	230	3800
5B45	531800	6913200	1.0	<24	1	150	210	2900
5B47	526000	6915600	<1.0	<51	62	14800	160	1400
5B58	534800	6915900	<1.0	2830	2	1010	200	850
5B62	540300	6912000	1.6	140	<1	229	31	710
5B66	548100	6912900	1.7	43	<1	62	230	910
5B67	538300	6905700	<1.0	<42	25	2740	57	1400
5B69	533800	6902600	3.3	160	13	1270	100	<680
5B72	520800	6923000	3.6	<38	<1	238	510	650
6046	551000	6855500	37	32	100	2370	250	470
6048	565000	6846000	<5	<28	10	1310	860	690
6050	570200	6843000	14	<18	52	200	460	480
6053	554000	6879600	6	140	2	<20	46	<560
6055	559000	6867000	<5	869	2	1130	100	<430
6056	561000	6868500	<5	160	8	1630	45	<200
6057	564100	6864500	<5	110	10	496	420	280
6068	575500	6909500	<5	<67	2	29	210	1900
6069	560500	6892300	7	200	3	655	160	<200
6072	564200	6895800	7	<16	2	<8	740	1000
6073	567800	6892500	<5	<25	2	44	200	6600
6077	571000	6901500	6	<35**	2	214	220	<420
6084	580500	6903000	<5	<14	2	<8	720	550
6085	567000	6880800	<5	44	3	1920	62	<200
6088	573500	6884100	<5	23	4	585	80	260
6090	590000	6906100	16	37	2	6	46	<200
6096	573900	6884800	<5	<5	2	<5	600	440
6113	594200	6879200	7	-0-	2	-0-	520	-0-
6116	587000	6878000	<5	<19	2	255	900	1000
6117	587200	6877500	<5	<21	2	32	830	1600
6121	577200	6878500	<5	-0-	2	-0-	800	-0-
6122	594000	6876500	<5	-0-	2	-0-	73	-0-
6123	586000	6880800	<5	-0-	14	-0-	510	-0-
6124	590800	6867000	10	<5	3	<8	470	480
6125	596200	6869000	<5	11	27	17	120	340
6126	583500	6868900	9	<5	2	6	110	<200
6127	578200	6866500	<5	<120	8	2020	62	<200
6128	572000	6867300	<5	<95	17	1550	140	320
6129	538200	6872900	<5	<67	12	971	170	<430
6130	588000	6862200	8	81	5	351	350	680
6131	588100	6862000	<5	<19	4	52	590	860
6136	590800	6850900	<5	<26	15	1800	70	<200
6140	564500	6910200	15	28	2	<5	77	2700
6143	559500	6905200	<5	<19	2	<8	500	870
6149	625200	6795800	8	-0-	19	-0-	100	-0-
6159	556500	6917500	<5	<110	2	<69	51	<1700
6160	556500	6918000	<5	53	2	<20	58	720
6163	560000	6915100	6	60	2	<21	150	<200
6283	577000	6896500	8	<120	5	4520	71	<1100

Nahanni Karst - Tlogotsho Plateau Area (Fig. 2)

SAMP	EAST	NORTH	Au (ppb)		W (ppm)		Zn (ppm)	
			silt	HMC	silt	HMC	silt	HMC
5129	404680	6820880	<1.0	-0-	2	-0-	370	-0-
5130	405020	6822760	<1.0	-0-	<1	-0-	850	-0-
5131	405860	6823010	<1.0	-0-	<1	-0-	490	-0-
5133	403350	6816630	<1.0	-0-	1	-0-	320	-0-
5135	403470	6817510	<1.0	-0-	2	-0-	450	-0-
5143	404750	6824300	<1.0	-0-	<1	-0-	1300	-0-
5146	405150	6826200	<1.0	-0-	<1	-0-	260	-0-
5147	405030	6826030	<1.0	<65	<1	4170	280	>3 %
5151	405770	6824400	1.6	<28	2	<72	290	5300
5154	403450	6826530	<1.0	-0-	<1	-0-	710	-0-
5155	406200	6822640	<1.0	<39	<1	<99	140	3700
5156	407850	6822240	<1.0	<23	<1	<59	94	1600
5B04	403660	6818850	<1.0	-0-	1	-0-	540	-0-
5B06	403610	6818300	<1.0	948	<1	1720	440	<680
5B07	404150	6819800	<1.0	20600	<1	<15	800	>3 %
5B08	398300	6815200	<1.0	-0-	<1	-0-	370	-0-
5B15	405080	6826200	<1.0	-0-	<1	-0-	1100	-0-
5B16	404710	6825590	<1.0	-0-	<1	-0-	720	-0-
5B17	403430	6827790	<1.0	-0-	<1	-0-	280	-0-
5B18	404250	6826080	<1.0	-0-	<1	-0-	290	-0-
5B19	404170	6825670	<1.0	-0-	<1	-0-	240	-0-
5B20	404550	6825360	<1.0	-0-	<1	-0-	290	-0-
5B22	409430	6821900	<1.0	520	<1	<25	48	5400
5B25	410760	6818780	<1.0	<25	<1	<22	58	2400
5B28	413660	6815700	<1.0	<60	<1	24	54	2200
6165	471500	6767500	<5	<26**	<2	16	140	840
6173	404500	6775000	<5	<5	<2	<2	510	360
6174	402200	6778100	<5	<29	<2	35	410	1200
6175	393000	6778000	<5	<11	<2	<4	710	1200
6177	401800	6778000	<5	<5	<2	5	270	620
6178	400700	6777700	5	<5	<2	<2	280	670
6184	482000	6769200	<5	<18	<2	<6	250	1200
6185	389800	6782000	<5	<34	<2	22	250	1300
6186	389500	6781800	<5	<26	<2	<10	280	1000
6187	387000	6777000	<5	<5	2	<2	280	1300
6188	402000	6780800	<5	<15	<2	5	300	2000
6190	394000	6787600	<5	<67	<2	<44	140	<400
6191	404000	6784600	<5	<25	2	<9	210	1200
6192	402600	6787500	<5	<19	<2	8	96	1400
6193	403000	6787500	<5	<70	<2	<25	180	2800
6196	408800	6799800	<5	<13	<2	28	130	530
6200	406000	6802000	<5	<22	<2	13	130	1200
6201	395200	6799500	<5	<33	<2	30	29	<200
6203	395500	6807000	<5	<19	<2	<8	120	3100
6204	425000	6790000	<5	25	<2	25	160	440
6205	425000	6787500	<5	1270	<2	42	91	540
6207	421000	6780700	<5	<18	<2	27	78	1100
6208	416000	6842800	<5	<13	<2	10	65	3300
6210	442000	6841000	<5	<15	<2	37	88	640
6211	442100	6840800	10	<12	<2	14	170	230
6213	433400	6834500	<5	24	<2	<12	75	1200
6215	439500	6829200	<5	<15	<2	31	90	280
6218	428800	6829800	<5	30	<2	18	57	360
6221	424000	6827900	<5	<16	<2	<10	55	3300
6222	423900	6828000	<5	<5	<2	<5	68	3000
6223	430500	6816000	<5	<16	<2	<9	78	1400
6224	435900	6813100	<5	<12	<2	<7	87	1200
6233	422100	6806000	<5	<57	<2	<20	84	5800
6234	417800	6811000	<5	<12	<2	<5	74	2600
6237	451400	6810000	<5	3260**	<2	37	79	<200
6246	441500	6787200	<5	<5**	<2	15	98	310
6251	467800	6761000	<5	62	<2	23	86	260
6261	431600	6766000	8	<35	<2	28	55	350
6265	426800	6758000	<5	<46	<2	35	37	<200
6267	424500	6755500	<5	<19	<2	25	58	<200
6268	424900	6755200	<5	65	<2	7	81	1400
6273	457000	6791500	<5	<5**	<2	13	120	270
6275	436000	6796800	<5	<21	<2	11	140	3600
6279	406500	6806000	<5	<54	<2	<24	64	1200

5. Granitoid rocks (+ pattern): mainly quartz monzonites which range in age from Devonian to Tertiary, most being Early and Mid-Cretaceous, and characterize RR.

During the Pleistocene, RR was covered with Alpine ice, and the eastern NK-TP was invaded by tongues of Laurentide ice, whereas the corridor between the two areas was relatively ice-free (Ford, 1976). The surficial deposits include a variety of glaciolacustrine and glacial-fluvial sediments.

METHODS

General approach and locations of samples

Stream sediments were sampled during the latter part of three summers when water levels were relatively low. During 1985 orientation surveys (5000 series samples of Table 1), 120 streams were sampled to experiment with different methods and to identify potential problems. In 1986 (6000 series samples of Table 1) 244 major drainages were sampled in the study areas. In 1987, anomalous streams and related subsidiary tributaries were resampled.

Orientation surveys in RR were conducted near tungsten deposits associated with granitic rocks (e.g. Lened) and shale-hosted lead-zinc deposits similar to those found at MacMillan Pass and Howards Pass (e.g. Vulcan), and compare well with surveys by Goodfellow (1982). In NK-TP an orientation survey was centred around the Prairie Creek (Cadillac) Ag-Pb-Zn vein structure. Both study areas also contain Mississippi-Valley-type Pb-Zn and vein-hosted precious metal occurrences.

Table 2. Correlations among gold, tungsten and zinc in 1986 silts and HMCs, Ragged Ranges area (anomalous values included except where noted).

Au (S): Au (H) = 0.0116; N = 104; SIG = 0.9072
W (S): W (H) = 0.4140; N = 104; SIG = 0.0
Zn (S): Zn (H) = 0.2359; N = 104; SIG = 0.0159

Au (S): W (S) = 0.7341; N = 123; SIG = 0.0
Au (S): Zn (S) = 0.0231; N = 123; SIG = 0.7998

Au (H): W (H) = 0.2776; N = 109; SIG = 0.0035
Au (H): Zn (H) = -.0024; N = 109; SIG = 0.9802

	Au(S)	Au(H)	W(S)	W(H)	Zn(S)	Zn(H)
SA SIZE	122	104	120	100	122	108
AVERAGE	4.34	18.47	3.4	72.76	179.23	348.04
MEDIAN	3.3	10.85	2	8.7	110	133.3
MODE	3.3	3.3	2	5.3	160	133.3
GEO. MEAN	3.99	10.70	2.65	13.21	117.42	246.26
VAR	5.34	453.93	13.27	35290	34169.2	148714
SD	2.31	21.31	3.64	187.86	184.85	385.63
MIN	3.3	3.3	2	1.3	25	133.3
MAX	16	98	23	1200	860	2700
B/G	8.6	53	10	390	490	1020

N= sample size;
SIG= significance level based on students T distribution; if small (<0.05) they indicate significantly non-zero correlations
GEO. MEAN = Geometric mean calculated excluding anomalous values; assuming 2/3 of detection limit for values below detection.
VAR= variance;
SD= Standard deviation
MAX= Maximum value included for calculation of statistical parameters; anomalous values excluded.
B/G= Background = Geometric mean + 2 SD Au in ppb; W and Zn in ppm.

Table 3. Correlations among gold, tungsten and zinc in stream silts and HMCs, Nahanni Karst and Tlogotsho Plateau area (anomalous values excluded).

Au (S): Au (H) = -.0201; N = 102; SIG = .8414
W (S): W (H) = -.1754; N = 102; SIG = .0778
Zn (S): Zn (H) = .1215; N = 102; SIG = .2239

Au (S): W (S) = -.0304; N = 119; SIG = .7427
Au (S): Zn (S) = .0415; N = 119; SIG = .6539

Au (H): W (H) = .3690; N = 110; SIG = .0001
Au (H): Zn (H) = -.0612; N = 110; SIG = .5253

	Au(S)	Au(H)	W(S)	W(H)	Zn(S)	Zn(H)
SA SIZE	119	108	119	110	119	104
AVERAGE	3.41	11.98	1.33	11.64	115.93	568.1
MEDIAN	3.3	8.85	1.3	8.35	90	420
MODE	3.3	3.3	1.3	1.3	130	133.3
GEO. MEAN	3.37	8.62	1.32	8.08	92.41	421.72
VAR	0.58	128.70	0.02	88.01	9044.64	237757
SD	0.76	11.34	0.013	9.38	95.10	487.6
MIN	3.3	3.3	1.3	1.3	12	133.3
MAX	10	65	2	42	710	2800
B/G	5	31	1.35	27	282	1400

Symbols and comments as in Table 2.

Only Au, W and Zn are discussed here for selected anomalous results (Table 1) as a progress report. Au and W were chosen because some drainages are distinctly anomalous in these elements and because HMCs are typically used to search for them. Zn is presented as a representative of the base metals suite which is typically sought using silts. Point counts of nine 1987 follow-up HMCs are used to corroborate and help interpret some of the 1986 anomalous sites (Fig. 4).

The sample sites were chosen to attain uniform coverage of drainage and bedrock types. Only primary and secondary streams could be sampled on a systematic basis. Tertiary and smaller drainages were sampled mainly for orientation surveys and follow-up. At each site stream silt and gravel were collected. At some sites bank alluvium or till was collected as well as rocks from nearby outcrops. The temperature and pH were measured and water colour, sediment colour, rate of flow, gradient, bank composition and rock types were noted.

Heavy mineral concentrates from gravel

Composite gravel samples were obtained by collecting from different spots at each sample site. The gravels were sieved in the stream to less than 1 cm, then agitated and culled with a standard gold pan to remove the clays and organic matter, reduce the amount of granule-size material, and concentrate the heavy minerals. Where the stream had naturally concentrated the heavy minerals, these lags were also sampled. Samples taken in 1985 were approximately 2-3 kg and in most cases yielded only 0.5-4 g of HMC. In 1986 and 1987 the sample size was 8 kg (larger in carbonates), with most samples yielding 10 to 30 g of HMC. Sieving on-site to <841u might have produced more HMCs from smaller samples, nevertheless the 1985 sampling method was retained for consistency and generated excellent replication of results on gold and other elements.

In the laboratory, the -841u to +63u fraction was separated. The 1985 samples were processed at the Geological Survey of Canada, using methylene iodide (MI; s.g. >3.3) to produce HMCs. This method is adequate for a limited number of test samples, but because of the health hazards inherent in the use of heavy liquids, and the large size and number of samples to be processed in 1986 and 1987, the following method (see Stewart, 1986) was implemented. After being sieved to -2mm (10 mesh), the samples were passed three times on a Deister concentrating table. The magnetic fraction was removed from the HMC and the concentrate was split and analysed by neutron activation (NAA) without further processing. To verify precision, the largest HMCs were coned and quartered without being pulverized, and were inserted as blind duplicates in the ratio of 1:10. Accuracy was checked using laboratory standards, as no standards of the appropriate composition were available in quantity. All HMC processing for 1986 and 1987 samples was done by Consor Mines Ltd.; NAA analyses were done by Bondar Clegg and Company Ltd.

Table 4. Replication of fine gold in HMCs from 1986, and follow-up 1987 sample sites. Individual gold flakes were weighed by J.C. Bisson on a Perkin-Elmer ultramicrobalance, with AD-6 autobalance, giving precisions of +/-.0005 mg on <2mg samples, and +/- 001 mg on samples up to 20 mg. Exact weights of the 1987 HMCs are not yet available, however assuming a maximum weight of 50 g provides conservative estimates of net gold in HMCs. * = flake misplaced; weight and calc. Au estimated.

Samp	Locality	Gross Wt(g)	Wt HMC (g)	# Au Flks	Weight Flks(mg)	NAA (ppb)	Calc.Au in HMC (ppb)
6077	"Brophy Ck.",	5250	15.05	1	0.2062	<35	13,700
7005	Ragged Ranges	8550	26.10	2	0.0403	-0-	>1,540
6237	"Wretched Ck."	9700	33.16	33	2.447	3260	77,000
7066	Nahanni Karst	10575	34.45	17	1.4270	-0-	>41,400
7065	Trib. to 6237	10400	20.10	2	0.0955	-0-	>4,750
6246	Clausen Ck.	10900	48.22	2	0.0744	<5	1,540
7070	two tribs.	9675	18.90	1	0.0284	-0-	>1,500
6165	Nahanni River bulk	23125	155.9	2	0.0226	<14	~145
6273*	North end of	12050	22.14	1	0.3	<5	13,000
7078	Yohin Ridge	11900	18.95	1	0.5876	-0-	>31,000

Table 5. Gold abundance in three tetrahedrite-quartz-carbonate veins. Analyses by J. Vaive at GSC, using AA with graphite furnace; detection limit 1.0 ppb; on two splitz of each pulverized sample.

5136-2	from trench on ridge above stream site 5B07	41.5, 79.5 ppb Au
6230R	from float in Lafferty Creek	<1. , <1. ppb Au
7037B	from outcrop of vein cutting Nahanni Butte	1.2, 1.7 ppb Au

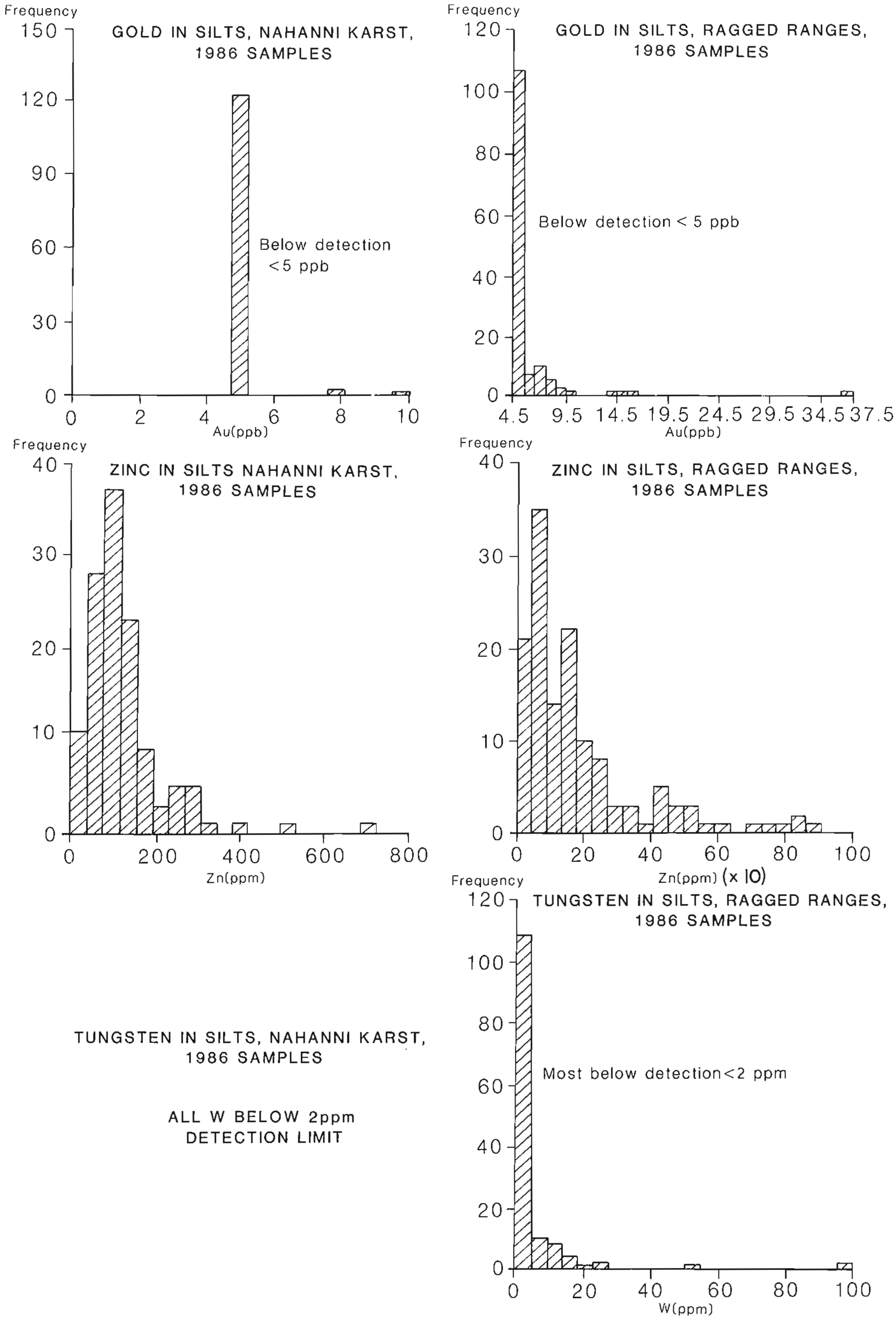


Figure 3. Histograms of gold, tungsten and zinc in 1986 silts.

All gold grains observed during the tabling process were collected individually and counted. They were weighed at GSC, and the weights were integrated with the abundances reported by neutron activation analysis on the remaining concentrate (Table 4). MI was used to clean nine selected HMCs for point counting to assess the origin of the gold particles (Fig. 4).

Stream silts

About 4 kg of silt were generally taken in order to experiment with very fine HMCs. The silts were dried, sieved to completion, and a selected 16 dram portion (about 30-40 g) was pulverized before being sent for geochemical analysis: Th, U, Rb, Sn by XRF pellet; As, Sb, Se, Bi, Te, Cd, Ag, Pb by AA(total dissolution); TiO2, Fe2O3(t), MnO, Ba, Be, Co, Cr, Cu, La, Ni, Sr, V, Yb, Zn by ICP(total dissolution) at GSC; Au + 33 by neutron activation at Bondar Clegg and Company Ltd. All of the 1985 silts were analysed at GSC, with gold being done by AA with graphite furnace.

Blind duplicates and standards in the ratio of one per 7 to 10 samples were inserted at random intervals. Reproducibility of chemical analyses on bulk-sampled field duplicates is excellent for both silts and heavies. An estimate of reproducibility was also obtained by resampling anomalous 1986 sites in 1987.

RESULTS AND DISCUSSION

Sites yielding anomalous values of gold, tungsten and/or zinc are listed in Table 1, summarized in Tables 2 and 3, and illustrated in Figures 1 to 4. Chemical analyses have not been completed on the 1987 samples, but the numbers and weights of gold grains recovered from the concentrating table are remarkably consistent from year to year (Table 4).

The variable detection limits of gold and tungsten in the neutron activation analyses were disappointingly far above the idealized 5 ppb limit, attaining "≤140 ppb" in some samples. This was caused by the high abundances of rare-earth and other radioactive elements which interfere with the spectrum of gold, as well as tungsten, zinc and a variety of other elements. Such radioactive elements might reflect a high proportion of zircon, monazite and sphene in HMCs recycled from sedimentary rocks.

Ragged Ranges (RR) area

Gold and tungsten correlate with each other in both HMCs and silts (Table 2). HMCs provide the strongest anomalies (up to 3540 ppb gold and >3% tungsten), all spatially associated with Cretaceous granitic intrusions. The contribution of these intrusions to the HMC is indicated by point counts (Fig. 4). Samples 7005, 7006, 7051 and 7079 consitute

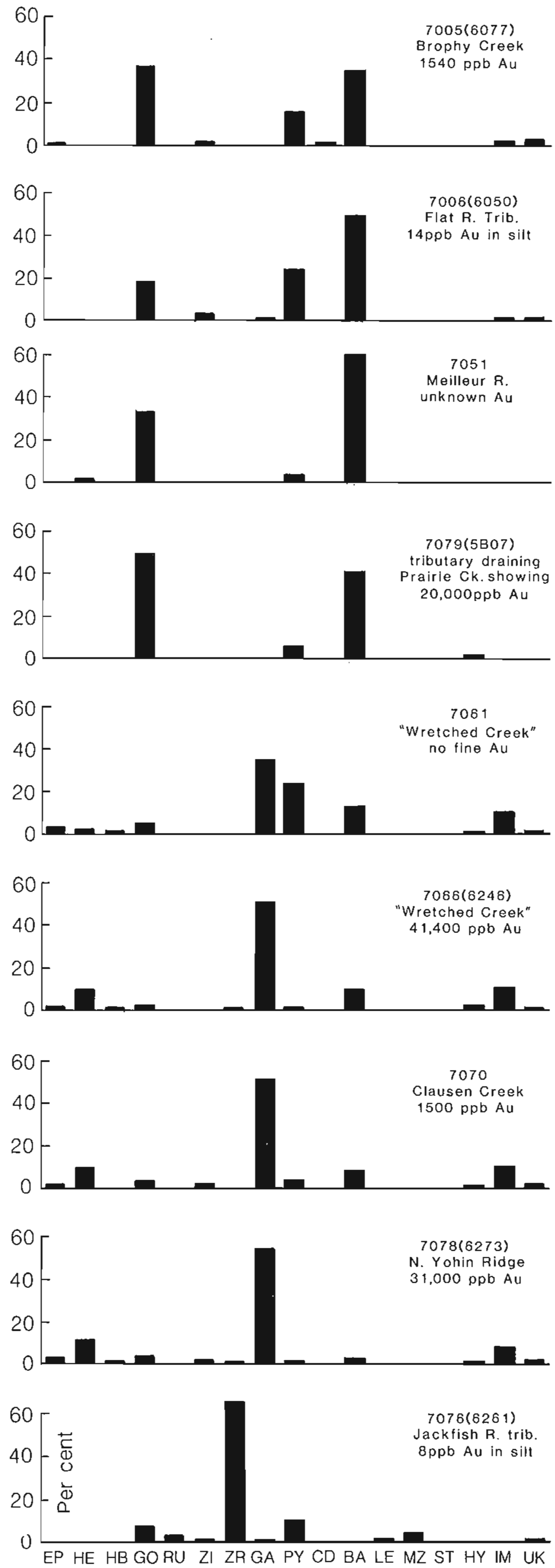


Figure 4. Histograms from counts of 300 points in selected 1987 HMCs, most of which are auriferous (Table 4). Numbers in brackets are previous samples at these sites. Mineral abbreviations are as follows: EP-epidote, HE-hematite, HB-hornblende, GO-goethite, RU-rutile, ZI-zircon angular and euhedral, ZR-zircon rounded, GA-garnet, PY-pyrite, CD-chloritoid, BA-undifferentiated barite and scheelite, LE-leucoxene, MZ-monazite, ST-staurolite, HY-hypersthene, IM-ilmenite, UK-unknown.

a natural group from shale environments, with very similar abundances of goethite, pyrite and barite/scheelite. The small amounts of epidote, euhedral zircon, garnet, chloritoid and ilmenite in 7005 and 7006 are related to the intrusions in RR.

The minor gold in silts (maximum 37 ppb in sample 6046) is poorly correlated with gold and tungsten in HMCs (Table 2). The source for sample 6046 might be the Nahanni tungsten skarn southwest of Flat River. Other gold- and tungsten-bearing streams are distributed radially around the Pyramid Batholith and the Lened tungsten skarn (Fig. 1). Sample 5B34, with 3540 ppb Au and elevated tungsten is located away from the area of influence of the Lened skarns, and lends support for the generalized concept of buried skarns (Aronoff et al., 1986) in that region. The statistical link between gold and tungsten in RR (Table 2), suggests a genetic link and the potential for placer (and lode?) gold deposits such as those in the Bennett Creek area (20 km SE of Fig. 1). The gold may entirely be an accessory element in both small tungsten showings and the world-class Tungsten deposit.

The strong correlation between zinc in silts and HMCs in RR suggests at first glance that the cheaper silt sampling method is adequate for zinc exloration. However, the poor correlation in NK-TP (Table 3), suggests that the correspondence between the two media in RR is circumstantial. This suspicion is supported by the negative correlation between low Zn in silts and high Zn in HMCs for samples 5B39, 40, 45, 67; 6068, 6073 and 6140. Analyses of mineralogy in HMCs and geologic setting may explain these relationships.

Known carbonate-hosted zinc occurrences are indicated by elevated zinc in silts (e.g. 6113, 6122), however in these environments it is difficult to obtain sufficient HMCs for NAA analysis, hence the null (-0-) values reported for these and similar samples in Table 1.

Nahanni Karst — Tlogotsho Plateau (NK-TP) area (Fig. 2)

Gold and tungsten correlate in HMCs; in silts, all tungsten and nearly all gold are below detection limit (Fig. 3). Gold appears to be more important than tungsten in NK-TP (the reverse of their relative importance in RR), and tungsten may well be a useful pathfinder element (e.g. Hall et al., in press). The Prairie Creek vein system is unusual in that tungsten and gold are strongly enriched but heterogeneous (compare samples 5147, 5B06, 5B07, 5B22 in Table 1). Analyses of 1987 follow-up samples may clarify these relationships.

Fine gold flakes were recovered in greater quantity and at more sites in NK-TP than in RR (Table 4). The HMC for Sample 6205 on Ram Creek contains 1270 ppb gold and is considered to be in the same group as those containing fine gold. The origin of this gold is discussed in a following section.

Trace amounts of gold were detected in stream silts at only two localities, 6211 a tributary of Sundog Creek, and 6261 a tributary of Jackfish River. These areas were resampled in 1987; interpretation of these localities awaits analytical results.

The poor correlation between zinc in stream silts and zinc in HMCs (Table 3) is another surprising aspect of NK-TP. Preliminary microscopic examination of HMCs suggests that the zinc is carried with heavily oxidized sulphides (secondary minerals?) of unknown compositions. Such grains may not be present in typical stream silts.

Zinc anomalies are of two types. The first is represented strongly in HMCs and subtly in stream silts, all from sites below trenches in the high grade Prairie Creek Ag-Pb-Zn deposit (samples between 5129 and 5156, and between 5B04 and 5B28 inclusive, in Table 1).

The second type of zinc anomaly is just at or above background levels in HMCs and suggests buried deposits or small surface exposures of the Prairie Creek or Nahanni Butte type. Samples 6203 (near The Gate) and 6208 (top of Fig. 1) are on line with, and may be related to, extensions of the Prairie Creek vein system. Samples 6233 and 6234 are located on Prairie Creek well downstream of exposed showings and are probably contaminated with material from workings upstream. Sample 6184 is located below MVT-type zinc showings and tetrahedrite bearing quartz veins that crosscut Nahanni Butte. Site 6275 (3600 Zn in HMC), which enters First Canyon of South Nahanni River, and sample 6230R (Table 5), float of tetrahedrite-galena-quartz-carbonate vein from Lafferty Creek, together indicate more occurrences like those of Nahanni Butte. Zinc in samples 6221 to 6224 may be related to hidden deposits, or reflect industrial contamination, due to use of roads with galvanized culverts along these stream valleys. Most of these prospective areas have been explored by industry.

The Meilleur River area is of considerable interest because: 1) It is transected by numerous high-angle faults that are similar to those which occur in the Prairie Creek area; 2) zinc abundances approach and exceed the calculated background for NK-TP (samples 6174, 6175, 6185 to 6188, and 6191 to 6193); 3) it is the site of some of the most metalliferous springs discovered to date in the South Nahanni River area (Hamilton et al., 1988); and 4) the Prairie Creek shale embayment (Morrow, 1984), with concommitant facies changes eastward to platformal carbonates, extends south into the Meilleur River area. These attributes suggest potential for buried and/or currently forming base metal deposits.

Origin of fine gold flakes in HMCs

The source of the fine gold in RR must be local, because this area has undergone alpine glaciation and no exotic material has been added by continental glaciers. The commonly held interpretation that the gold is derived by reworking of granite-related vein and skarn deposits appears to be justified by the limited data presented here.

The fine gold flakes may have been derived from two sources. First, gold may have been transported by continental ice from the east, then concentrated as placers in topographically favourable sites. Fluvial reworking of till is indicated by numerous exotic boulders and an abundance of garnet in stream deposits (Fig. 4). Cretaceous intrusions of RR are unlikely sources of garnet.

Second, the gold may be of local derivation, from tetrahedrite-bearing sulphide veins such as those that cross-cut base-metal occurrences at Prairie Creek and Nahanni Butte. This is supported by the high gold abundances and a lack of garnet or other till indicators in samples from the Prairie Creek area (Sample 8079, Fig. 4). Analyses of grab samples from three tetrahedrite-galena-sphalerite-quartz-carbonate veins (Table 5) indicate that heterogeneous gold is present locally. Continued systematic analysis of mineral occurrences is in progress.

CONCLUSIONS

1. A number of significant gold anomalies were detected in HMCs of stream sediments, all in the Nahanni Karst — Tlogotsho Plateau area (NK-TP). Standard stream silt samples did not produce correlative results. The gold is thought to be derived locally from tetrahedrite-bearing veins, although there may have been a contribution from continental glaciation.

2. Tungsten and gold are strongly correlated in the Ragged Ranges area (RR), in both HMCs and silts, and are mainly related to Cretaceous intrusions. Some anomalies are not explained by known deposits. In NK-TP they are correlated only in HMCs, particularly those taken near hydrothermal lead-zinc-silver deposits such as the Prairie Creek (Cadillac).

3. Zinc is not correlated with gold and tungsten in any sample media, although an erratic spatial association is apparent in NK-TP among very high values of zinc, gold and tungsten. Zinc in silts appears to correlate well with zinc in HMCs in RR, but not in NK-TP. Zinc anomalies in HMCs from Meilleur River area indicate potential for buried or modern base metal deposit types.

4. Comparisons of analyses of silts and HMCs in this resource assessment suggest that systematic HMC sampling is an essential component of regional geochemical reconnaissance in the northern Cordillera.

ACKNOWLEDGMENTS

This project is jointly funded by EMR, DIAND and DOE as part of the mineral and energy resource assessment (MERA) of proposed additions to Nahanni National Park Reserve. Heavy mineral preparation was partially funded by Canada — Northwest Territories Mineral Development Agreement 1987-1991 under Federal Project 1.2.3, South Nahanni Tungsten and Rare Metals Corridor. The stream-sediment geochemistry constitutes part of an M.Sc. thesis at the University of Western Ontario by the first author. Polar Continental Shelf Project provided logistic support. Generous hospitality and free exchange of information have been provided by Canada Tungsten Mining Corporation, Procan Resources, and Parks Canada officers in the field. Advice and ideas from B. Ballantyne, R.T. Bell and Y.T. Maurice is gratefully acknowledged. Discussions, information and assistance given by L. Aspler, S. Bartlett, D. Brent, K. Dawson, S. Hamilton, T. Pilgrim and numerous others have helped to shape this project. Critical reading was by L. Aspler, W. Coker and Y.T. Maurice.

REFERENCES

Aranoff, S., Goodfellow, W.D, Bonham-Carter, G.F., and Ellwood, D.J.
1986: Integration of surficial geochemistry and landsat imagery to discover skarn tungsten deposits using image analysis techniques; *in* Proceedings of IGARSS' 86 Symposium, Zurich. Ref. ESA SP-254, p.513-520.

Ford, D.C.
1976: Evidence of multiple glaciations in South Nahanni Park, Mackenzie Mountains, Northwest Territories; Canadian Journal of Earth Science, v. 13, p. 1433-1445.

Friske, P.W.B.
1986: Reconnaissance stream sediment and water surveys and related geochemical studies in New Brunswick; *in* Eleventh Annual Review of Activities, Project Resumes 1986, New Brunswick Department of Natural Resources and Energy, Information Circular 86-2, p. 112-115.

Goodfellow, W.D.
1982: Regional stream sediment and water geochemistry of the Nahanni map-area (NTS 105I), Yukon and Northwest Territories (National Geochemical map NGR 51-1981); Geological Survey of Canada, Open File 868, 156 p., 1:250 000.

Hall, G.E.M., Jefferson, C.W. and Michel, F.A.
— Determimnation of W and Mo in natural spring waters by ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometry) and ICP-MS (Inductively Coupled Plasma Mass Spectrometry): Application to South Nahanni River Area, N.W.T., Canada; Journal of Geochemical Exploration. (in press)

Hamilton, S.M., Michel, F.A. and Jefferson, C.W.
1988: South Nahanni resource assessment, District of Mackenzie I: groundwater geochemistry; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E,

Harris, J.F.
1982: Sampling and analytical requirements for effective use of geochemistry in exploration for gold; *in* Precious Metals in the Northern Cordillera, Proceedings of a Symposium Sponsored by the Association of Exploration Geochemists and the Cordilleran Section of the Geological Association of Canada, p. 53-67.

Morrow, D.W.
1984: Sedimentation in Root Basin and Prairie Creek Embayment — Siluro-Devonian, Northwest Territories; Bulletin of Canadian Petroleum Geology, v. 32, p. 162-189.

Scoates, R.F.J., Jefferson, C.W. and Findlay, D.C.
1986: Northern Canada mineral resource assessment; *in* Prospects for Mineral Resource Assessment on Public Lands: Proceedings of the Leesburg Workshop, *edited by* S.M. Cargill and S.B. Green. U.S. Geological Survey Circular 980, p. 111-139.

Stewart, R.A.
1986: Routine heavy mineral analysis using a concentrating table; Journal of Sedimentary Petrology, v. 56, p. 555-556.

Groundwater geochemistry, South Nahanni resource assessment area, District of Mackenzie

S.M. Hamilton[1], F.A. Michel[1], and C.W. Jefferson
Mineral Resources Division

Hamilton, S.M., Michel, F.A., and Jefferson, C.W., Groundwater geochemistry, South Nahanni resource assessment area, District of Mackenzie; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 127-136, 1988.

Abstract

A hydrogeological sampling program was conducted during 1986 and 1987 field seasons as part of a resource assessment of the proposed expansion areas of Nahanni National Park Reserve. Sites sampled include hot and cold springs, mineralized seeps and ponds and iron-precipitating springs. The springs can be subdivided into four broad categories based on physical and chemical parameters: tufa-precipitating springs; iron-precipitating springs; springs in granitic terrane and, high discharge cold springs. Preliminary chemistry of the groups appears to vary according to lithological setting, and this is controlled by the fault system within which the waters moved. Zn-dominated stream-sediment anomalies and spring-water anomalies in Zn, Cd, Ni, Co, Cu, and U appear to be correlated in the Meilleur River area. Spring-water geochemistry appears to be a useful complement to regional stream-sediment geochemistry.

Résumé

Un programme d'échantillonnage hydrogéologique a été effectué à l'occasion des campagnes de terrain en 1986 et 1987, dans le cadre d'une évaluation des ressources susceptibles de se trouver dans des prolongements envisagés de la Réserve du parc national de Nahanni. Les endroits échantillonnés renferment des sources thermales chaudes et froides, des suintements et des étangs minéralisés ainsi que des sources à précipitation ferrugineuse. Les sources peuvent se répartir en quatre grandes catégories basées sur certains paramètres physiques et chimiques: les sources à précipitation de tuf, les sources à précipitation ferrugineuse, les sources de terrain granitique et les sources froides à débit élevé. La chimie préliminaire des différents groupes semble varier suivant le cadre lithologique, le tout en fonction du réseau de failles au sein duquel circulent les eaux. Les anomalies de sédiments fluviatiles principalement zincifères et les anomalies en Zn, Cd, Ni, Co, Cu et U mesurées dans les eaux de source semblent être corrélées dans la zone de la rivière Meilleur. La géochimie des eaux de source semble constituer un complément utile à la géochimie régionale des sédiments fluviatiles.

[1] Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6

INTRODUCTION

During the 1986 and 1987 field seasons a detailed hydrogeological investigation constituted part of a nonrenewable resource assessment of proposed expansion areas of Nahanni National Park Reserve, N.W.T.. Natural groundwater discharge points were sampled for geochemical analysis. Temperature, electrical conductivity and pH were measured in the field. The discharge points occur as tufa- or iron-precipitating springs, mineralized seeps and ponds, and hot- and cold-springs. They were initially identified by airphoto interpretation and aerial reconnaissance, and were located visually by the presence of iron or sulphur precipitate, tufa deposits, vegetation changes (especially apparent with hotsprings), discoloration of ponds and streams and even by smell in the case of sulphurous hotsprings. The locations of many of the hotsprings and a few coldsprings have been previously reported in the literature (Brook, 1976; Gabrielse et al, 1973; Brandon, 1965; Atchison, 1964; Crandall and Sadlier-Brown, 1976) and these reports were helpful in relocating them.

The study area is made up of the proposed extensions on the northwestern and eastern ends of the park (Fig. 1, 2) and immediately adjacent areas.

During the 1986 field season a large, previously unreported hotspring was discovered within the limits of the proposed park expansion on the south side of the Meilleur River Valley; it is relatively inaccessible except by helicopter. The size and beauty of the spring warrants a name being given to it and it is informally referred to here as the Meilleur River hotspring.

REGIONAL GEOLOGY

Nahanni National Park Reserve covers an elongate area of approximately 4784 km which transects the southern Mackenzie Mountains fold and thrust belt. Figures 1 and 2 present a summary of the bedrock geology derived from a number of sources cited by Scoates et al. (1986), simplified into four main packages in order of decreasing age:

1. The Windermere Supergroup (fine stipple) consists of glaciomarine conglomerates, iron-formation, argillites, shales and some carbonates of latest Proterozoic age (Eisbacher, 1981).

2. The Cambrian to Early Devonian package (unpatterned) comprises platformal carbonate strata on the north, east and south, and Selwyn Basin shales to shaly carbonates (Road River Group as defined by Fritz, 1985; and Prairie Creek Embayment strata of Morrow, 1984) on the DS side of the DC/DS facies boundary (Fig. 1, 2). The carbonate strata contain numerous small Mississippi-Valley-type lead-zinc occurrences, and the shaly strata are host to zinc-dominated stratiform base metal ± barite deposits (e.g. Howards Pass area and Vulcan Deposit) and silver-lead-zinc veins (e.g. Prairie Creek / Cadillac).

3. Late Devonian to Jurassic (coarse stipple) rocks include basinal shales, porcellanites and turbiditic sandstones to conglomerates of the Earn Group (Gordey et al. 1982) in the Ragged Ranges area. The Earn Group is host to numerous stratabound barite — base metal — silver deposits (Abbott et al., 1986). In the Tlogotsho Plateau — Nahanni Karst area the Devonian to Jurassic package includes: a) shales to porcellanites of the Besa River and Fort Simpson formations; b) Carboniferous shallow marine carbonates and continental sandstones with coal measures and c) basinal cherts and mudstones of Permian and Triassic ages. Late Jurassic to Late Cretaceous fine-to-coarse clastic rocks record a complex interplay of continental to marine deposition and include important coal measures in the region (Stott, 1982).

4. Granitoid rocks (mainly quartz monzonites) intrude a broad belt of the northern Cordillera that includes the west-central third of the area shown in Figure 1. The intrusions range in age from Devonian to Tertiary (Sinclair, 1986), most being Early and Mid-Cretaceous, and are associated with numerous tungsten and base-metal skarns some of which contain precious metals.

DESCRIPTION OF SPRINGS

On the basis of appearance and geochemistry, most of the groundwater discharge sites fall into one of four categories:

1) Tufa-precipitating springs,
2) Iron-precipitating springs,
3) Springs spatially associated with granitic intrusions, and
4) High-discharge coldsprings.

The geochemistry of these groups of springs as known so far is discussed herein, as are the important exceptions which do not fit well into any of the above categories.

Selected springs are listed in Table 1. The table is intended to allow comparison between spring types and does not constitute the complete 1986 database. The 1987 chemical results are not yet available.

Tufa-precipitating springs

$CaCO_3$ precipitating springs were found in all parts of the study area except granitic terrane. The tufa deposits range in size from small crumbly fragments lining channels at mineralized seeps to large terraced platforms such as those at Rabbitkettle Hot Springs (no. 20, Fig. 1) and Old Pot Mineral Springs (no. 27, Fig. 1). These springs are easily visible as bare, light coloured patches of tufa with significant seepage. The spring waters provide minerals for various wildlife and the presence of animals, or their footprints, at these animal licks is a good indication that the water is mineralized. The largest tufa deposits are found around thermal springs but most of the tufa springs were non-thermal. The temperatures of the thermal springs with tufa range between 17 and 38.5°C.

The spring water is chemically distinctive in a number of ways:

1) pH is generally between 6.5 and 7.0 but increases within hours after the water leaves the vent due to loss of CO_2. In almost all cases, when measured in the laboratory the pH had risen by at least 1 pH unit.

2) The electrical conductivity which is an indication of total dissolved solids, is moderately high: between 500 and 1200 S/cm and in some cases higher.

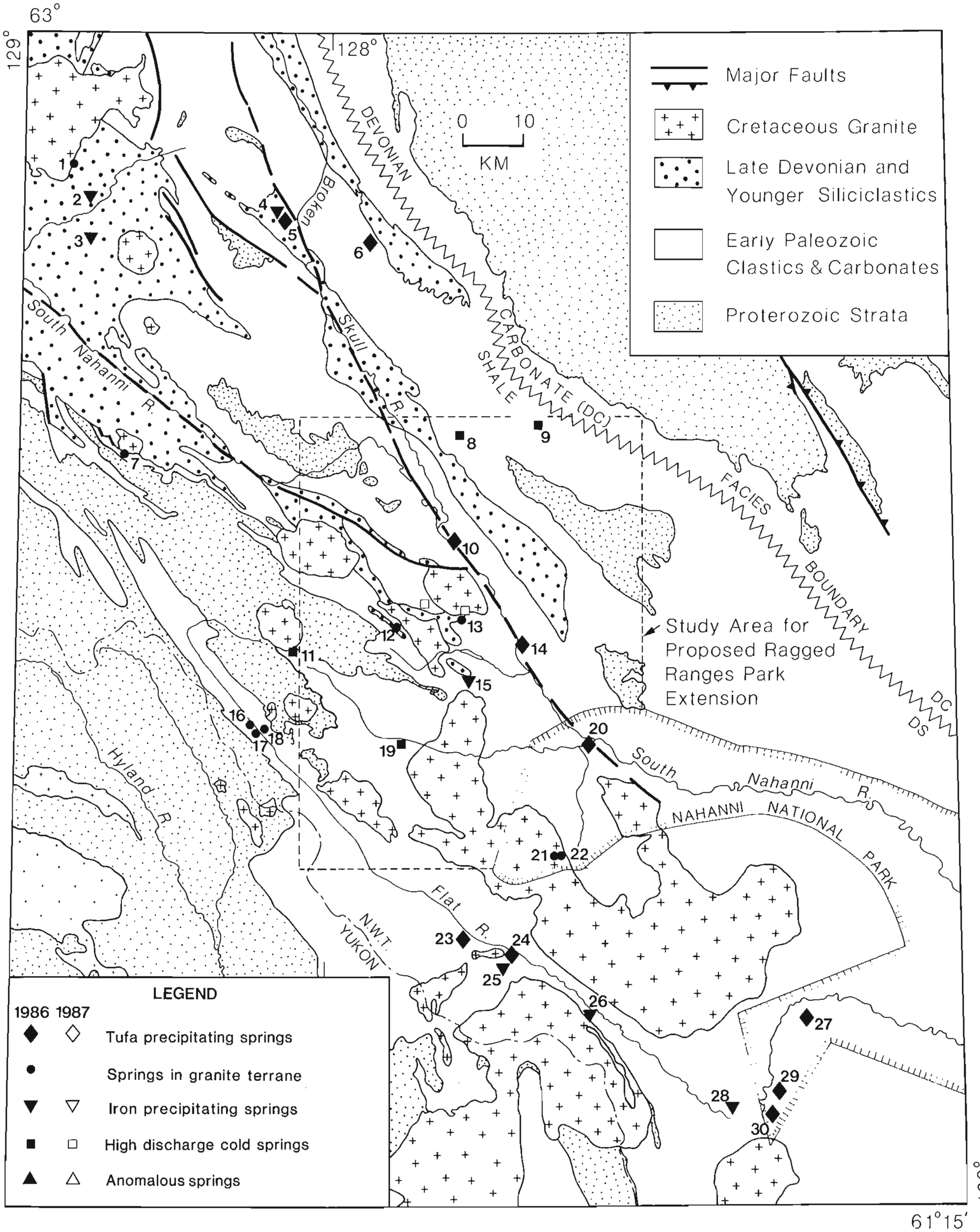


Figure 1. Geology and spring locations in western part of study area (after Hall et al, in press).

3) $CaCO_3$ content (measured as HCO_3-) is invariably high and ranges between 200 and 700 mg L^{-1}. Common cations such as Na, K and Mg are also present in relatively high concentrations.

4) Fe is notably low and other metals such as Mn, Cu, Cr, Ni, Co, Cd, and Zn are below or close to their detection limits (table 1).

5) Gas bubbles can be seen rising in most springs where the vent is pooled. In some cases gas bubbles were seen clinging to submerged objects indicating exsolution of gas in the pooled water.

Iron-precipitating springs

About 30 iron-springs are distributed in all parts of the study area, including granitic, sandstone, carbonate and shale terranes. In most places, they appear to be aligned along faults or major fractures which have allowed the movement of fluids to the surface.

Iron-springs are easily visible from the air due to the bright red precipitate which covers wide areas around the vents. The precipitate is usually a floccular ooze but in some cases it is cemented and locally forms red tufa terraces where enough $CaCO_3$ is present in the water.

Geochemically, iron-spring waters have the following characteristics:

1) Most are quite acidic for natural waters with typical values ranging from 3.0 to 6.4 and with a maximum of 7.2.

2) Conductivity is moderate: lower than that for tufa springs typically and ranges between 350 and 1000 μS.

3) The $CaCO_3$ (HCO_3-) content is the lowest for any of the spring types. For iron-springs with pH below 5.5, $CaCO_3$ was below detection. However, one group of springs along the Flat River Valley contains relatively high concentrations of $CaCO_3$ and has pH between 6.0 and 6.7. These

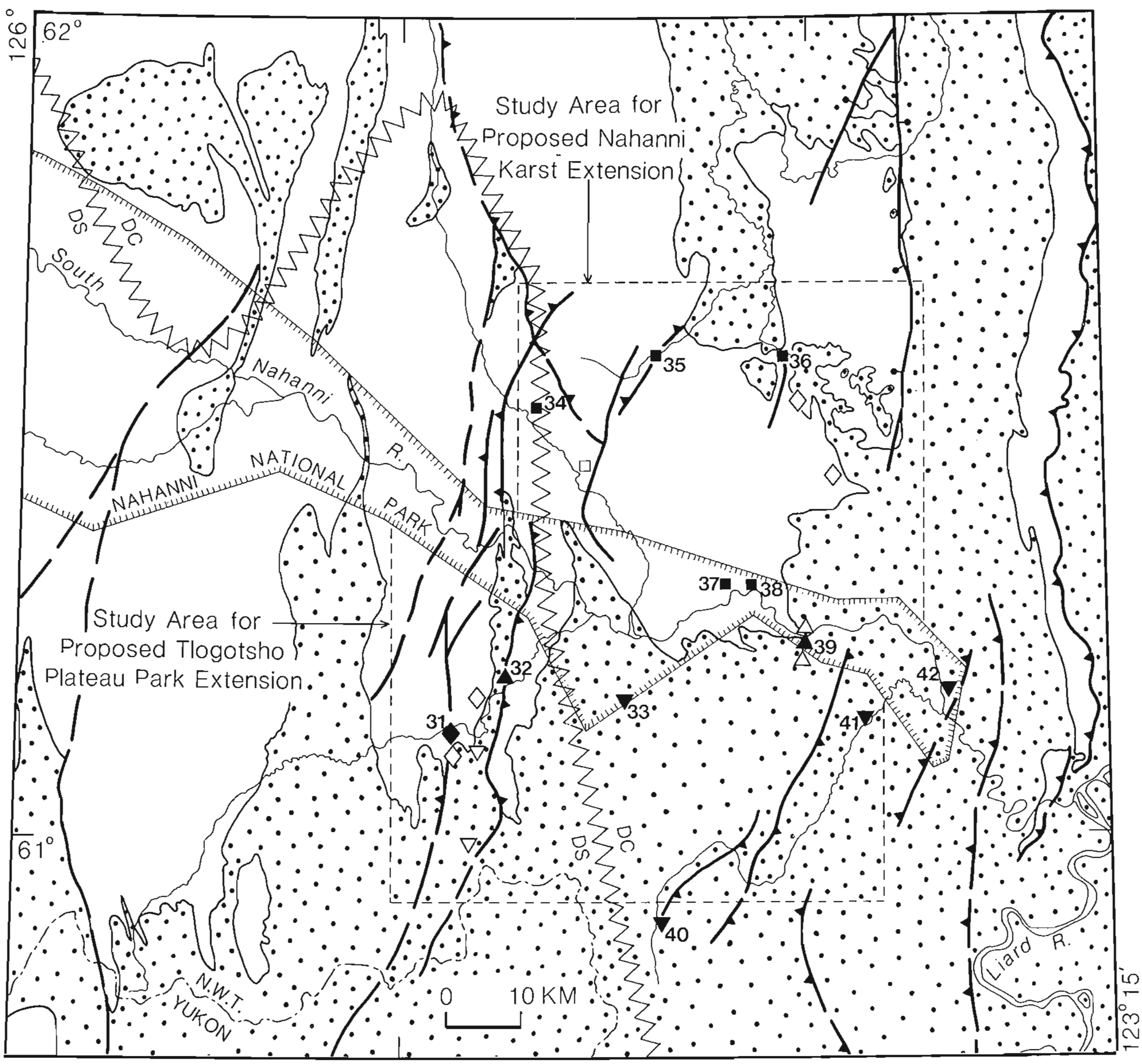


Figure 2. Geology and spring locations in eastern part of study area (after Hall et al, in press). See Figure 1 for legend.

all have red tufa associated with them and a number of other anomalous features. The anomalous nature of these iron-springs is discussed below.

4) The Fe content is extremely high. Values range from 1500 to 122 000 $\mu g\ L^{-1}$ with typical values around 15 000. As would be expected, the concentration of other metals present is also higher than normal. The concentration of Mn is closely associated with that of iron, provided samples were taken close to the vent. The concentrations of metals such as Cu, Cr, Ni, Co, Cd, and Zn are also high but these all

Table 1. Partial listing of field and analytical data for selected 1986 sample areas listed in four main geochemical groups. See Table 2 for analytical methods.

Sample	Description	cond. uS/cm	pH	temp (C)	CaCO3 (ppm)	Fe (ppb)	Cu (ppb)	Mn (ppb)	Ni (ppb)	Co (ppb)	Cd (ppb)	Zn (ppb)	Na (ppm)	Si (ppm)	SO4 (ppm)	Cl (ppm)	Mo (ppb)	W (ppb)
	Tufa precipitating springs																	
5	Broken Skull Hot Spring: main vent (at base of terrace)	1090	6.5	49	277	65	5.	<10.	8.	<2.	3.	<5.	50	19	396	23	0.	<0.1
6	Grizzly Bear Hot Spring (largest vent, south side)	775	6.9	44	165	138	<2.	30.	<2.	6.	<2.	5.	22	19	218	32	0.1	<0.1
10	East side of South Nahanni River Valley (crumbly tufa)	480	7.2	3.8	202	<20	13.	<10.	<2.	6.	<2.	<5.	1	3	69	1	4.	0.2
14	East side of South Nahanni River valley (terraced)	397	7.8	8.0	196	36	3.	<10.	<2.	<2.	<2.	10.	2	7	46	4	3.1	<0.1
20	Rabbitkettle Hot Springs: main vent (pool) on top of mound	580	6.8	21	238	129	3.	13.	<2.	<2.	<2.	8.	4	7	33	1	1.8	<0.1
23	Flat Fruit Mineral Spring (bubbling)	870	6.2	8.9	400	28	5.	158.	<2.	4.	<2.	<5.	29	7	38	4	0.	<0.1
24	Red tufa spring in Flat River Valley	1587	6.1	7.7	662	33	4.	34.	16.	8.	<2.	<5.	85	6	283	22	0.7	<0.1
27	Old Pot Mineral Springs	323	7.6	10.0	159	<20	<2.	<10.	<2.	<2.	<2.	<5.	1	3	13	<1	2.	0.2
29	Wild Mint Hot Spring: upper pool	457	7.3	25.0	223	26	4.	<10.	<2.	<2.	<2.	<5.	1	9	29	<1	1.2	0.1
30	Seepage area on McLeod Creek	440	7.7	12.1	225	<20	<2.	<10.	<2.	5.	3.	<5.	2	8	25	1	0.9	0.1
31	Meilleur Creek hot spring	1038		38.5	237	159	9.	23.	<2.	<2.	<2.	44.	30	19	373	35	4.5	1.2
	Springs in granite terrane																	
1	Nahanni Headwater Hot Spring (O'Grady Batholith)		7.9	63.5	65	26	5.	<10.	<2.	<2.	<2.	8.	53	39	38	10	30.	224.
7	Nahanni North Hot Spring (near Lened W showing)	310	9.0	58	85	36	13.	<10.	11.	<2.	3.	<5.	64	29	69	1	19.	20.8
12	Seepage area at head of unnamed valley (near granite)	183	4.8	1	<1	<20	10.	135.	101.	28.	5.	366.	1	9	68	<1	0.6	<0.1
13	Spring at top of valley, north of Glacier L.	246	4.0	5	<1	147	<2.	169.	<2.	<2.	<2.	3936.	<1	6	123	<1	0.	<0.1
16	Cantung mine, water from 6" DDH	440	8.5	16	118	65	5.	<10.	<2.	<2.	<2.	<5.	85	18	60	25	1.1	169.

vary with only limited association with the concentration of iron. The Mo and W values are very low, almost without exception.

5) Gas bubbles are not common in most of the iron-springs but were seen in the CaCO3-rich springs along the Flat River Valley. Gas samples were collected at these sites and analyzed in 1986 but the results were so anomalous (very high O_2) that resampling was necessary in 1987. The new analytical results are not yet available.

The above chemical characteristics are generalizations, with variations depending on the underlying lithology. The two best examples of these variations are the springs in the Mattson Formation and those in the Flat River Valley.

The Mississippian Mattson Formation is composed of terrestrial sandstone with coal measures. Two iron-springs issuing from the formation were sampled (no. 33, 42) and although separated by 45 km the chemistry of each is remarkably similar (Table 1). Additional springs from the Mattson Formation were sampled in 1987 but the results are not yet available.

Table 1 (cont.)

Sample	Description	cond. S/cm	pH	temp (C)	CaCO3 (ppm)	Fe (ppb)	Cu (ppb)	Mn (ppb)	Ni (ppb)	Co (ppb)	Cd (ppb)	Zn (ppb)	Na (ppm)	Si (ppm)	SO4 (ppm)	Cl (ppm)	Mo (ppb)	W (ppb)
17	West Cantung Hot Spring, main bath-house	252	8.2	41	86	<20	4.	<10.	<2.	<2.	<2.	<5.	48	22	26	6	8.	59.6
18	East Cantung Hot Spring (moderate H2S)	295	9.1	46	91	120	6.	<10.	8.	3.	<2.	<5.	61	38	30	10	19.	121.
21	Hole-in-the-wall Hot Springs, west vent	121	8.5	42	50	57	4.	<10.	<2.	<2.	<2.	<5.	28	32	8	2	10.	14.9
22	Hole-in-the-wall Hot Spring, east vent	124		47.5	52	72	3.	<10.	4.	15.	<2.	8.	29	33	9	2	21.	17.6
	Iron precipitating springs																	
2	Fe spring south of O'Grady Batholith	630	7.0	4.2	92	19082	3.	425.	8.	<2.	<2.	306.	1	9	290	<1	0.4	<0.1
3	Iron precipitating stream (spring source)	318			<1.0	645	4.	534.	168.	46.	<2.	640.	<1		181	<1	0.	0.2
4	Iron precipitating stream (spring source)	280	4.9	4.0	<1.0	5816	25.	225.	273.	29.	39.	1488.	<1	6	140	<1	0.	<0.1
15	Iron and sulphur precipitating spring next to Mt. Ida	1080	4.8	5.5	<1.0	122307	<2.	856.	233.	50.	3.	331.	2	10	562	<1	0.	<0.1
25	Iron spring in Flat River Valley (bubbling + tufa)	1000	6.3	5.5	589	20766	11.	1503.	<2.	<2.	3.	<5.	45	44	55	3	0.	<0.1
26	Iron spring in Flat River Valley (bubbling)	961	5.9	1.6	367	15850	6.	587.	125.	18.	<2.	412.	10	12	126	5	1.7	<0.1
28	Iron spring in Flat River Valley (near Seaplane Lake)	575	6.7	17.7	238	1710	4.	15.	<2.	5.	<2.	<5.	6	5	93	1	1.6	<0.1
33	Iron stream on deadmen syncline (in Mattson Fmt.)	1062	3.9	7	<1.0	21517	18.	1047.	103.	46.	<2.	187.	9	7	611	<1	0.	<0.1
40	Iron spring at Etanda Dome	772		1.5	53	63347	5.	1180.	34.	18.	<2.	15.	1	3	405	<1	0.	0.2
41	Iron spring in Yohin Syncline	285		12	<1.0	9820	9.	217.	11.	5.	<2.	12.	2	15	91	2	0.	<0.1
42	Iron spring on Twisted Mt. (in Mattson Formation)	1342	2.9	11.5	<1.0	51793	6.	1180.	115.	58.	<2.	86.	59	13	722	20	0.	<0.1

The Flat River springs are in shales of the Road River Group and carbonates of the Rabbitkettle Formation. The iron-springs and some of the tufa springs located along the valley show similar chemistry and physical characteristics. Three of the springs are bubbling vigorously and the gas in each is similar in composition. The similarities between these springs may be partly due to a common fault conduit. The 1987 chemical results will provide more insight.

Springs in granitic terrane

These springs are located in or adjacent to granitic intrusions in the western part of the study area and have a geochemical signature related to that of the granites.

Most of the springs in this category are hot, between 32 and 63.5C and show definite differences in both chemistry and outward appearance compared to hotsprings in non-granitic areas. The spatial and geochemical associations

Table 1 (cont.)

Sample	Description	cond. S/cm	pH	temp (C)	CaCO3 (ppm)	Fe (ppb)	Cu (ppb)	Mn (ppb)	Ni (ppb)	Co (ppb)	Cd (ppb)	Zn (ppb)	Na (ppm)	Si (ppm)	SO4 (ppm)	Cl (ppm)	Mo (ppb)	W (ppb)
								High discharge coldsprings										
8	In Black Wolf River Valley south side, at break in slope	385	7.5	11.1	189	<20	<2.	<10.	<2.	<2.	<2.	<5.	2	4	38	1	0.6	<0.1
9a	Near Avalanche Lake discharging from boulder debris	152	8.3	8.8	68	<20	3.	<10.	<2.	<2.	<2.	<5.	<1	1	14	<1	0.7	<0.1
9b	Seepage area along Avalanche Creek 75-100m long along west bank	186	7.6	5.0	80	33	<2.	<10.	<2.	<2.	<2.	<5.	<1	1	24	<1	1.2	0.1
11	Tallus spring in Upper Rabbitkettle River Valley	142		4.0	71	57	4.	<10.	<2.	<2.	<2.	6.	<1	2	6	<1	0.	0.2
19	Cold spring from valley wall next to Rabbitkettle River	98	8.3	5.2	36	361	4.	12.	<2.	3.	3.	<5.	<1	2	6	<1	0.2	<0.1
34	Discharging from between bedding plane.	232	8.0	3.3	108	81	8.	<10.	<2.	<2.	3.	14.	<1	1	20	<1	0.	<0.1
35	Cold spring west of karst area on major fault.	218	7.9	5	107	337	9.	<10.	<2.	<2.	<2.	36.	<1	1	10	2	0.3	0.1
36	Bubbling Spring	314	7.6	4	161	158	6.	10.	8.	<2.	<2.	<5.	<1	2	24	2	2.5	0.2
37	Cold spring from fracture, in north wall of First Canyon	239	8.2	8.2	132	67	9.	<10.	3.	<2.	<2.	40.	<1	1	4	<1	1.7	0.3
38	White Spray Cold Spring	770	7.8	4.3	121	136	4.	<10.	6.	6.	<2.	10.	<1	1	9	1	0.6	0.2
								Anomalous springs										
32a	At base of fault, 5m north of green pond.	2970	6.3	5	94	136	14.	2824.	2318.	170.	34.	4977.	14	6	2404	17	0.	0.2
32b	10m east of (a)	2730	3.8	5	<1	1402	49.	5396.	2311.	405.	30.	5351.	15	9	2284	2	0.8	0.1
34	Prairie Creek Ag, Pb, Zn Mine: 200 level seepage	937	7.5	3.0	223	337	448.	92.	65.	9.	135.	61877.	<1	2	393	1	0.6	<0.1
39	Kraus Hot Springs: pool on river bank	7780	6.6	37.5	184	129	16.	57.	<2.	<2.	3.	13.	1118	14	860	3321	0.	0.3

between the hotsprings and the granitic intrusions are indications that the plutons play a role in the heating of the water (Hall et al., in press).

Around thermal springs, thin calcium sulphate precipitate coats rocks around the vents forming wide white patches which is in marked contrast to the lush vegetation of deciduous trees, ferns and wild mint growing around the hotsprings and facilitates easy aerial identification. The very hot water at the vent supports the growth of green and red algae and white bacteria in long filaments. In most cases the H_2S smell is mild compared with some of the fault-controlled hotsprings in the eastern part of the study area.

The geochemistry of these waters shows the following consistent trends:

1) pH is the highest of any of the spring types sampled, ranging from neutral to greater than 9.0 but typically between 8.2 and 8.5.

2) Conductivity is relatively low: typically between 150 and 450 μS/cm locally reaching 1100 μS/cm.

3) $CaCO_3$ (HCO_3-) content in most cases is low: values are between 20 and 275 mg L^{-1}. The SO_4 content, although not high, is elevated with respect to $CaCO_3$. The $SO_4/CaCO_3$ ratio is between 1:2 and 2:1 whereas in other springs with pH above 6 the ratio seldom exceeds 1:2.

4) Fe content is low: no values exceeded 460 μg L^{-1} and most are below 150. The concentration of Mn is below the detection limit of 10 μg L^{-1}. Similarly Cu, Cr, Ni, Co, Cd and Zn all show low values.

5) The trace metals Mo and W are anomalously high in almost all of the granite hosted hot springs (Hall et al., in press). Si and F are also elevated.

6) Gas was not seen rising in any of these hotsprings. The mild H_2S smell is probably caused by exsolution of very small amounts of gas or bacterial reduction of SO_4.

The two coldsprings included in the granite terrane type (no. 12, 13, Table 1) are geochemically different from the hotsprings but are listed together with them because they were found adjacent to plutons. Both springs have metal values, particularly Mn and Zn which are above average. The Fe values are low.

High-discharge coldsprings

These nonthermal springs have flow rates up to 10 000 L/s and are subdivided into two categories:

1) Springs discharging from coarse overburden such as talus. In places these appear to be derived from streams which flow into scree or rock glaciers and re-emerge downslope. In other places they are a result of percolation through overburden directly from lakes or melting glaciers.

2) Springs discharging from carbonate bedrock. These are a result of karstic dissolution (Brook, 1976). The water may originate from a single source such as a lake or a disappearing stream or the spring may be a discharge point for a conduit system which drains a large area. Usually the source is not known.

Table 2. Analytical methods used in obtaining values for Table 1.

Element	Instrument	Lab	Units	Detection
Mo	ICP-MS	GSC	PPB	0.1
W	ICP-MS	GSC	PPB	0.1
Zn	AA-Direct	GSC	PPB	5
Fe	AA-Direct	GSC	PPB	20
Mn	AA-Direct	GSC	PPB	10
Na	AA-Direct	GSC	PPB	0.2
Cu	AA-Opt 2	Bondar-Clegg	PPB	2
Ni	AA-Opt 2	Bondar-Clegg	PPB	2
Co	AA-Opt 2	Bondar-Clegg	PPB	2
Cd	AA-Opt 2	Bondar-Clegg	PPB	2
Si	ICP	GSC	PPM	1
Cl	Dionex	GSC	PPM	0.05
So_4	Dionex	GSC	PPM	0.2

Both types of spring have similar chemical characteristics:

1) pH varies within a narrow range, between 7.5 and 8.2.
2) Conductivity, in most cases is less than 200 μS/cm.
3) Low $CaCO_3$ content in the waters, none greater than 200 mg L^{-1}.
4) Metals are close to or below the detection limit.

The low total dissolved solids in the waters indicate that subsurface travel times are relatively short. The water discharging from White Spray Cold Spring (no. 38, Fig 2) has an estimated subsurface residence time of between 7 and 30 days (Brook, 1976). The conductivity value for White Spray is the highest of the high discharge coldsprings listed in Table 1, it is assumed that these other coldsprings also have subsurface residence times of 30 days or less.

Karst topography and karstic groundwater flow has been known for some time in the region covered by the eastern part of the study area (Brook, 1976). In the 1986 field season a high discharge coldspring was discovered in the western area (no. 19, Fig. 1) which appears to be discharging from carbonate bedrock. During the 1987 field work, a disappearing stream and sinkholes were also found in the area. These provide evidence for active karst development within the Ragged Ranges.

ANOMALOUS GROUPS OF SPRINGS

In the eastern part of the study area a group of springs have been found which have common physical and chemical characteristics but do not fit into any of the above categories. The largest of these is Kraus Hot Spring which has been previously described in the literature (Brandon, 1965). They are localized in one area but are far enough apart that a linear trend can be established. This trend is assumed to be the strike of a fault from which the springs discharge. The springs are characterised by highly sulphurous water (H2S), cloudy with suspended sulphate precipitate. The algal and bacterial content is high, the latter having a variety of colours including white and bright mauve. The chemical features are as follows:

1) pH has a narrow range from 6.6 to 7.1.

2) Conductivity is extremely high, reflecting the large amount of dissolved solids. Values from springs sampled in 1986 and 1987 range from 1400 to 9100 S/cm.

3) $CaCO_3$ (HCO_3-) content is fairly low, but the SO_4 content is very high: up to 860 mg L^{-1}. The ratio $SO_4/CaCO_3$ at Kraus is 5:1.

4) Fe content is moderate. Most other metals show concentrations which are elevated above background but do not constitute significant anomalies. The exception is uranium which is significantly higher in Kraus than in most other springs tested.

5) The very high conductivity of these springs is due to high salinity. K, Mg and Sr have high concentrations, while Na and Cl have extremely high concentrations measurable in g L^{-1}.

The Meilleur Creek hotspring shows chemical similarities to the Kraus group except the carbonate content is higher and the sulphate content lower. The high salinities and other anomalous features of the Kraus group and Meilleur hotsprings are probably a result of the formations through which the waters pass. Kraus Hot Springs occur on the edge of the Besa River Formation. When this formation outcrops, it often has coatings of white and yellow secondary minerals which precipitate from fluids seeping from between fractures and bedding planes.

The most significant anomalous springs come from the Meilleur River area. These springs are grouped together because they are anomalous in metals and the magnitude of the anomalies is not immediately explained by surface lithologic changes. Springs 32 A and B have extremely high values of metals such as Ni, Co, Cd, Zn and U. The iron values are low in comparison. The conductivity of these two springs is similar as is the chemistry, however the pH is radically different: 3.8 vs. 6.8. These two outlets occur within 5m of each other along the South Headless Thrust fault. A number of other springs were found in this area during the 1987 field season. These are located near large faults and have the same field characteristics: high conductivity, variable pH and produce enormous amounts of SO_4 precipitate upon addition of $BaCl_2$, suggesting high SO_4 and metals content. One spring in particular has a conductivity of 3120 μS/cm and an Fe content so high that even after the addition of HNO_3 a great deal of Fe dropped out of solution. A green precipitate formed upon addition of $BaCl_2$ which later oxidized to red. This suggests that ferrous iron is the predominant species of iron in this spring indicating that conditions are strongly reducing.

DISCUSSION

We have shown that the chemistry of the spring water in the study area is affected by lithology. The lithology to which the waters are exposed is, in turn, controlled by the fault system in which it moved. Chemical variations within the springs must be examined carefully to determine factors which might have contributed to the variation. The term "anomaly" as used here indicates a significant deviation from the chemistry of other springs emerging from similar rock types and having similar fault control.

In the Meilleur River area most of the springs found in 1986 and 1987 are located along faults, both mapped and unmapped. Some of the springs analyzed so far show extremely anomalous metal values. A number of others which have yet to be analyzed have a high probability of showing similar results. The high values cannot be explained by changes in lithology and may be an expression of buried base metal sulphide deposits, or or an actively mineralizing system such as that which formed the Prairie Creek (Cadillac) Ag-Pb-Zn vein.

Spring sampling for exploration is a relatively new technology and has been used in the Howards Pass area (Jonasson et al, in press). The possibility of detecting unexposed mineralization at depth makes this technique worthy of consideration. The location of springs is irregular and cannot be controlled by the sampler, therefore some areas have been well covered while others have received little coverage. Stream sediment sampling has the advantage of covering the entire area of a given catchment basin, but will only detect mineralized rock exposed at the surface. This spring sampling program was done in conjunction with a detailed stream sediment sampling program (Spirito, Jefferson and Paré, 1988) and joint application of the two methods has been stimulating. In the Meilleur River area the correlation between stream sediment anomalies and spring anomalies for the same elements, combined with the possibility that spring water is indicating the presence of metal deposits at depth, adds validity to the use of spring sampling as a complement to regional stream sediment sampling.

ACKNOWLEDGMENTS

This project was jointly funded by EMR, DIAND and DOE as part of the mineral and energy resource assessment (MERA) of proposed expansions to Nahanni National Park Reserve. Polar Continental Shelf Project provided logistical support. Travelling and living expenses for S.M. Hamilton were paid for by a Northern Studies Training Grant from DIAND. Additional funding to F.A. Michel came from NSERC grant A2646. The groundwater geochemistry constitutes part of a MSc thesis at Carleton University by the first author. Generous hospitality in the field was provided by Canada Tungsten Mining Corporation and Parks Canada. W. Spirito and T. Pilgrim assisted and collaborated in the field. I.R. Jonasson and D. Boyle critically read the manuscript.

REFERENCES

Abbott, J.G., Gordey, S.P. and Templeman-Kluit, D.J.
1986: Setting of stratiform sediment-hosted lead-zinc deposits in Yukon and northeastern British Columbia; *in* Mineral Deposits of Northern Cordillera, edited by J.A. Morin, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 1-18.

Atchison, M.E.
1964: A study of springs and spring deposits in the Flat River Map area, District of Mackenzie, N.W.T.. Unpublished BSc thesis, University of British Columbia, Canada, 53 p..

Brandon, L.V.
1965: Groundwater hydrology and water supply in the District of Mackenzie, Yukon Territory, and ajoining parts of British Columbia; Geological Survey of Canada Paper 67-22, 77 p.

Brook, G.A.
1976: Geochemistry of the north karst, South Nahanni River region, Northwest Territories, Canada; Unpublished Ph.D. thesis, McMaster University, Canada, 627 p..

Crandall, J.T. and Sadlier-Brown, T.L.
1976: Data on geothermal areas Cordilleran Yukon, Northwest Territories, and adjacent British Columbia, Canada; Report to Energy Mines and Resources Canada; Earth Physics Branch Open File 78-1, 72 p.

Eisbacher, G.H.
1981: Sedimentary tectonics and glacial record in the Windermere Supergroup, Mackenzie Mountains, Northwestern Canada; Geological Survey of Canada, Paper 80-27, 40 p.

Ford, D.C.
1976: Evidence of multiple glaciations in South Nahanni Park, Mackenzie Mountains, Northwest Territories; Canadian Journal of Earth Sciences, v. 13, p. 1433-1445.

Fritz, W.H.
1985: The basal contact of the Road River Group — a proposal for its location in the type area and in other selected areas in the northern Canadian Cordillera; *in* Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 205-215.

Gabrielse, H., Blusson, S.L. and Roddick, J.A.
1973: Geology of the Flat River, Glacier Lake and Wrigly Lake Map Areas, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Memoir 366. Part 1, 153 p.; Part 2 , 268 p..

Gordey, S.P., Abbott, J.G. and Orchard, M.J.
1982: Devono-Mississippian (Earn Group) and younger strata in east-central Yukon; *in* Current Research Part B, Geological Survey of Canada Paper 82-1B, p.93-100.

Hall, G.E.M., Jefferson, C.W., and Michel, F.A.
— Determination of W and Mo in natural spring waters by ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometry) and ICP-MS (Inductively Coupled Plasma Mass Spectrometry): Application to South Nahanni River Area, N.W.T., Canada; Journal of Geochemical Exploration, 1987 (in press).

Jonasson, I.R.. Goodfellow, W.D., Walker, D.A. and Jackson, L.E.,
1987: Secondary zinc mineralization in post-glacial sediments and talus at Howards Pass, Yukon, Canada — minralogy, geochemistry and genisis, *in* Weathering, Its Products and Deposits; Theophrastus Publishing, Athens Greece. Ed. Augustithis, S.S., 1987, 55 p..

Morrow, D.W.
1984: Sedimentation in Root Basin and Prairie Creek Embayment — Siluro-Devonian, Northwest Territories; Bulletin of Canadian Petroleum Geology, v. 32, p. 162-189.

Scoates, R.F.J., Jefferson, C.W. and Findlay, D.C.
1986: Northern Canada mineral resource assessment; *in* Prospects for Mineral Resource Assessment on Public Lands: Proceedings of the Leesburg Workshop, edited by S.M. Cargill and S.B. Green; U.S. Geological Survey Circular 980, p. 111-139

Sinclair, W.D.
1986: Molybdenum, tungsten and tin deposits and associated granitoid intrusions in the northern Canadian Cordillera and adjacent parts of Alaska; *in* Mineral Deposits of Northern Cordillera, edited by J.A. Morin, Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 216-233.

Spirito, W.A., Jefferson, C.W. and Paré, D.
1988: Comparison of gold, tungsten and zinc in stream silts and heavy mineral concentrates, South Nahanni resource assessment area, District of Mackenzie; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Stott, D.F.
1982: Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the foothills and plains of Alberta, British Columbia, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Bulletin 328, 124 p.

Geology, geochemistry and geochronology of subvolcanic intrusions associated with gold deposits at Freegold Mountain, Dawson Range, Yukon†

Brent I.A. McInnes[1], Wayne D. Goodfellow, J.H. Crocket[2], and R.H. McNutt[2]
Mineral Resources Division

McInnes, B.I.A., Goodfellow, W.D., Crocket, J.H. and McNutt, R.H., Geology, geochemistry and geochronology of subvolcanic intrusions associated with gold deposits at Freegold Mountain, Dawson Range, Yukon; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 137-151, 1988.

Abstract

Freegold Mountain is part of a northwesterly-trending volcanoplutonic arc comprising the eastern portion of the Yukon Crystalline Terrane. Plutonic rocks intrude Paleozoic metasedimentary rocks and include Late Triassic to Early Cretaceous granodiorite which is intruded by the Big Creek Syenite dated at 138 10 Ma. The youngest rocks belong to a suite of K-rich subvolcanics which comprise an early period of basalt-andesite-dacite intrusions and a later rhyolitic intrusion dated at 78 ± 6 Ma. These rocks at Freegold Mountain can be correlated with Mount. Nansen Volcanics.

Associated with the Freegold Mountain rhyolites are epithermal gold-quartz veins, vein-breccias and heterolithic diatreme breccias. Rare-earth element data suggest that rhyolitic magmas were produced by partial melting of upper crustal rocks, whereas andesitic-dacitic magmas may have been derived by crustal contamination of mantle-derived mafic magma.

Résumé

La montagne Freegold fait partie d'un arc volcanoplutonique orienté vers le nord-ouest comprenant la partie est du terrane cristallin du Yukon. Des roches plutoniques font intrusion dans des roches métasédimentaires du Paléozoïque et comprennent de la granodiorite, de la fin du Trias au début du Crétacé, qui est pénétrée par la syénite de Big Creek dont l'âge est évalué à 138±10 Ma. Les roches les plus jeunes appartiennent à une suite de roches sous-volcaniques riches en K qui comprennent une première période d'intrusions de basalte-andésite-dacite et une dernière intrusion rhyolitique dont l'âge est évalué à 78±6 Ma. Ces roches à Freegold Mountain peuvent être mises en corrélation avec les roches volcaniques du mont Nansen.

En association avec les rhyolites de Freegold Mountain on trouve des filons de quartz aurifères épithermiques, des brèches filoniennes et des brèches diatrèmes hétérolitiques. Les données sur les terres rares suggèrent que des magmas rhyolitiques ont été produits par une fonte partielle des roches corticales supérieures, tandis que des magmas andésitiques-dacitiques peuvent avoir été dérivés d'une contamination corticale d'un magma mafique dérivé du manteau.

† Contribution to Canada-Yukon Mineral Development Agreement 1985-1989.
[1] Present address: Dept. of Geology, University of Ottawa, Ottawa, Ontario K1N 6N5
[2] Dept. of Geology, McMaster University, Hamilton, Ontario L8S 4M1

INTRODUCTION

Freegold Mountain is at latitude 62°18′ N and longitude 137°07′ W on NTS mapsheet 115 I/6 (Fig. 1). It occupies the eastern portion of the Dawson Range, a northwesterly trending volcanoplutonic arc that forms an important component of the Yukon Crystalline Terrane in southwest Yukon.

The Freegold Mountain area has undergone relatively little detailed geological work in the past. The Carmacks map-area, including Freegold Mountain and Mount Nansen areas, was investigated in the early 1930's by Bostock (1935) and mapped at a 1 inch to 4 mile scale. During a three-year period, he documented the rock types in the region and assigned relative ages to the major lithologies based on contact relationships.

Bostock's field assistant in 1932 and 1933, J.R. Johnston, returned to the Carmacks area in 1936 to investigate the geology of the gold deposits discovered in the Freegold Mountain area (Johnston, 1937). He mapped entire length and width of the northwest-trending Freegold Mountain at a scale of 1 inch to 1000 feet. Although exposure is poor in the Dawson Range, he prepared a high quality map by tracing surficial float material in areas devoid of outcrop. This method is useful in most of the Dawson Range since Pleistocene glacial advance was arrested to the southeast (Bostock, 1966).

The area saw little further work until D.J. Tempelman-Kluit conducted a reconnaissance scale (1 : 250 000) geological survey of the Carmacks map-area (N.T.S. 115 I) in 1978 (Tempelman-Kluit, 1984). This work was the first attempt to resolve structure and age relationships by radiometric dating within the Carmacks map-area.

During 1985 and 1986 the first author conducted detailed investigations of the geology of gold deposits on the east side of Freegold Mountain, and mapped the surrounding terrain at a scale of 1 : 5000. The following is a detailed report on the geology of Freegold Mountain, including petrographic analysis of representative rock types, geochronology of intrusive rocks, and chemical classification of subvolcanic rocks in the area.

GEOLOGY

Five major rock-types occur (Fig. 2): metasediments, syenite, granodiorite, andesite and rhyolite. These are further divided into subtypes, designated by the presence or absence of phenocrysts, fabric (ie.schist or gneiss) and compositional variations. These descriptive parameters are useful for field classification, and do not have any genetic implications.

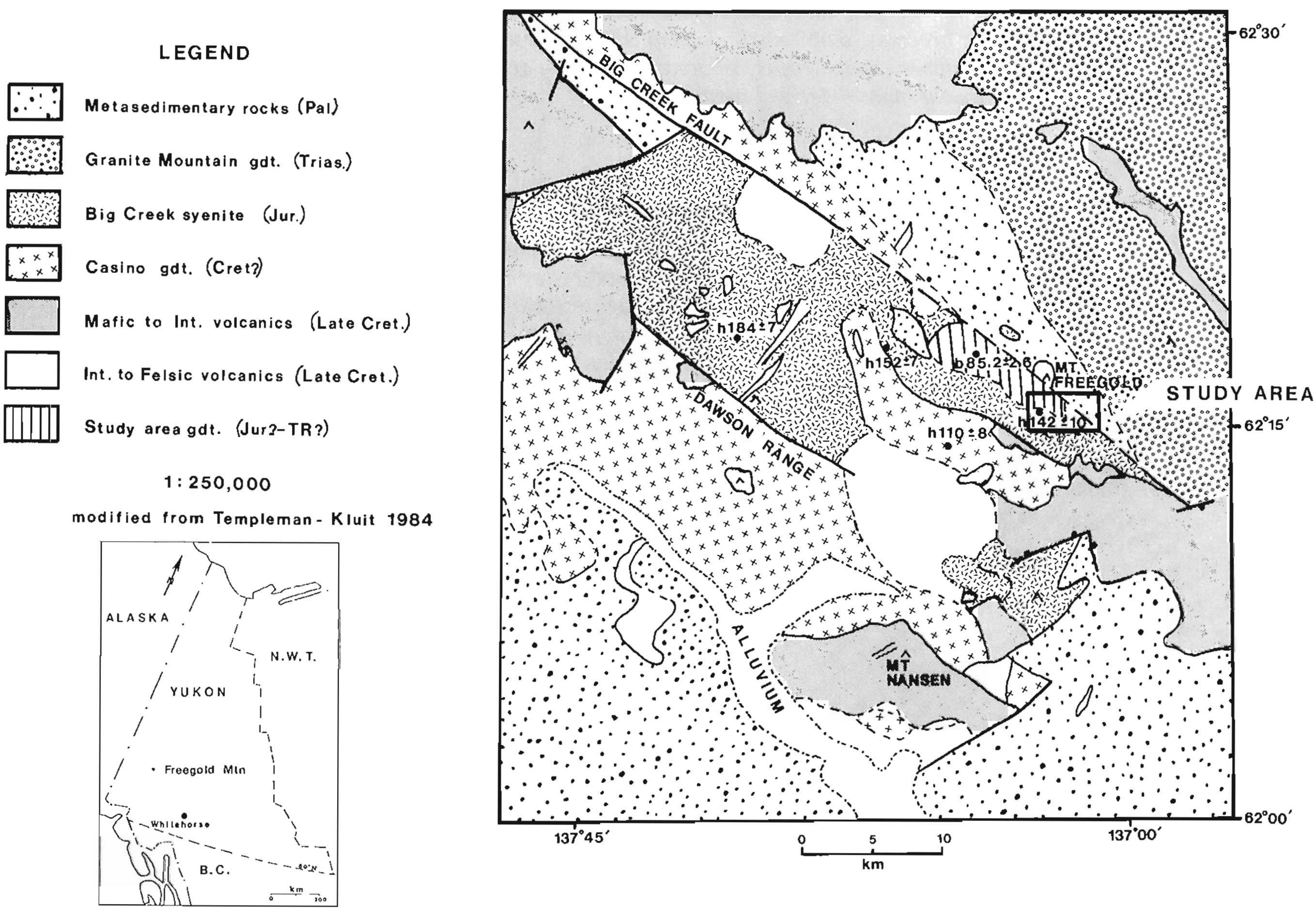


Figure 1. Location map and geological setting of the southeastern Dawson Range, (modified from Tempelman-Kluit, 1984).

Metasedimentary rocks

The northeast portion of the map area is dominated by schists and gneisses of the Yukon Metamorphic Complex. The dominant lithology at Freegold Mountain is quartz-biotite schist, characterized by strongly foliated light and dark layers. The light coloured layers are rich in quartz and plagioclase, the darker layers, in biotite. In some areas thin, discontinuous lenses of coarse-grained quartz-feldspar-hornblende gneiss occur interbanded with quartz-biotite schist. Along contacts with syenite the metasediments are strongly foliated and indurated, and contain porphyroblasts of K-feldspar elongated parallel to the foliation. In general, the orientation of schistosity is concordant with the syenite contact.

These rocks are thought to represent quartzites and greywackes of Paleozoic age (Johnston, 1937; Tempelman-Kluit, 1984) which have been regionally metamorphosed during Jurassic arc-continent collision.

Syenite

The Big Creek Syenite (Tempelman-Kluit, 1984) occurs in the central and southern portions of the map area (Fig. 2). This unit consists of hornblende syenite porphyry and hornblendite. The two lithologies are clearly related, the hornblendite being the cumulate zone of a magma chamber and the hornblende syenite porphyry the residual material which crystallized above the cumulate zone. The contact between the two is subhorizontal and sharp.

The hornblendite is intruded by hornblende syenite porphyry and cut by veins of potassium feldspar. Hornblendite occurs predominantly on the north side of Freegold road east of Forrest Gulch, but has also been observed in trenches south of the head of Schist Creek where it is in contact with gneiss. This latter type of occurrence is also found at Emmons Hill. At a contact between syenite and the metasediments exposed in a trench south of the head of Schist Creek (Fig. 2), the syenite is hornblende-rich with the hornblende grains aligned parallel to the contact. The hornblendite generally contains between 80-100 % hornblende, with plagioclase making up the remainder. Sphene, magnetite and apatite are accessory minerals.

The hornblende syenite porphyry is the dominant lithology making up 95 % of the total syenite exposed. Outcrops of this intrusion are massive and well jointed. This rock is characterized by the trachytoidal texture of tabular orthoclase megacrysts which can be up to 5 cm in length, but are commonly about 3 cm long. The rock has been estimated visually to contain on average, 50 % orthoclase, 20 % plagioclase, 5-10 % quartz and 20-25 % hornblende (Johnston, 1937). According to Streckeisen's (1975) classification scheme for igneous rocks the proper name for this rock is 'quartz syenite'.

Granodiorite

Granodiorite occupies the north-central and northwest portions of the map area (Fig. 2), and continues to the northwest for another 8 km. This intrusion was named the Seymour Creek stock by Johnston (1937). It is the eastern outlier of two larger granodiorite bodies mapped by Tempelman-Kluit (1984) (Fig. 1) as Casino Granodiorite. The rock is medium- to coarse-grained, equigranular to porphyritic with phenocrysts of pink and white feldspar. It contains oligoclase, quartz, orthoclase, hornblende and biotite with accessory sphene, iron oxide and apatite. The feldspars commonly show oscillatory zoning, and albite, pericline and Carlsbad twinning. Twinning is also common in the hornblende.

Dykes

The area is frequently dissected by two types of subvolcanic intrusions: andesitic to dacitic dykes and rhyolite dykes. No volcanic rocks are preserved in the Freegold Mountain area.

Andesite and dacite dykes

Green to grey dykes occur sporadically throughout the study area and are not volumetrically significant. There are too few dykes in the map area to establish a dominant orientation; however, those prevalent near the summit of Freegold Mountain strike northwest (Johnston, 1937). These dykes cut all rock types in the area except rhyolite.Hand samples vary from aphanitic to porphyritic, with phenocrysts of plagioclase, quartz and in places biotite or hornblende. Some dacite dykes contain xenoliths of granodiorite and metasedimentary country rock.

Monzonite porphyry and granophyre dykes (Johnston, 1937) have not been differentiated and are shown on Figure 2 as monzonite porphyry. They are relatively rare and cross-cutting relationships suggest that they were intruded after pluton and before andesite-dacite dyke emplacement. They have a distinctly granitic character in comparison to the andesite and rhyolite dykes and are probably the residual components of a granitic magma introduced after batholith emplacement.

Rhyolite dykes

Rhyolite dykes are conspicuous in the area in that they often form walls of outcrop, especially on the hillsides. Their resistant nature in outcrop is due to silicification, with quartz cementing brecciated dyke fragments and adjacent country rock, or occurring as veins within and concordant to the dyke.

Two centres of rhyolitic intrusion are present in the area. A major dyke swarm occurs within the Antoniuk Breccia gold deposit in the north-central area of Figure 2 above Nabob Gulch. These dykes, which strike dominantly at 45° and dip vertically, are interpreted from diamond drill core observations to be apophyses of a shallow, buried intrusion which generated the explosive event that created the Antoniuk Breccia. A second centre of rhyolitic intrusive activity is inferred north of the Camp Fault between Forrest and Rambler gulches. Although this area is considerably less exposed, a 350-m-long outcrop of brecciated rhyolite occurs along the north side of the Laforma road, east and west of Fairclough Gulch. The Alpha adit, between Forrest and Fairclough Gulch, is 75 m long and Johnston (1937) reported that most of it is in quartz porphyry. To the east, subcroppings of rhyolite are abundant south of the Rambler Vein and near Rambler Gulch. A dyke is exposed in Rambler Gulch above the Laforma road. This area of rhyolite intrusion is bounded by the Camp Fault, south of which no indications of rhyolite have been found.

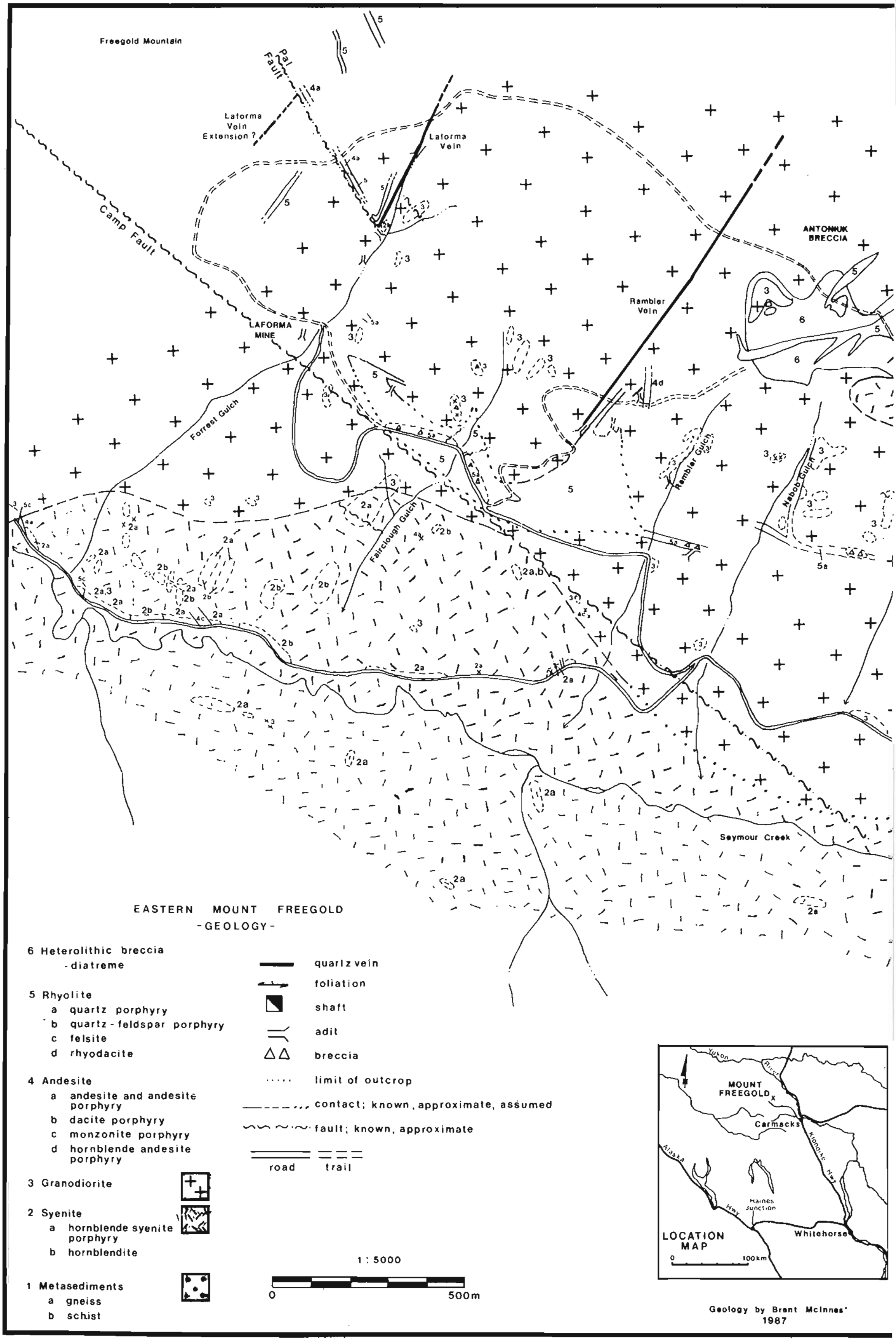
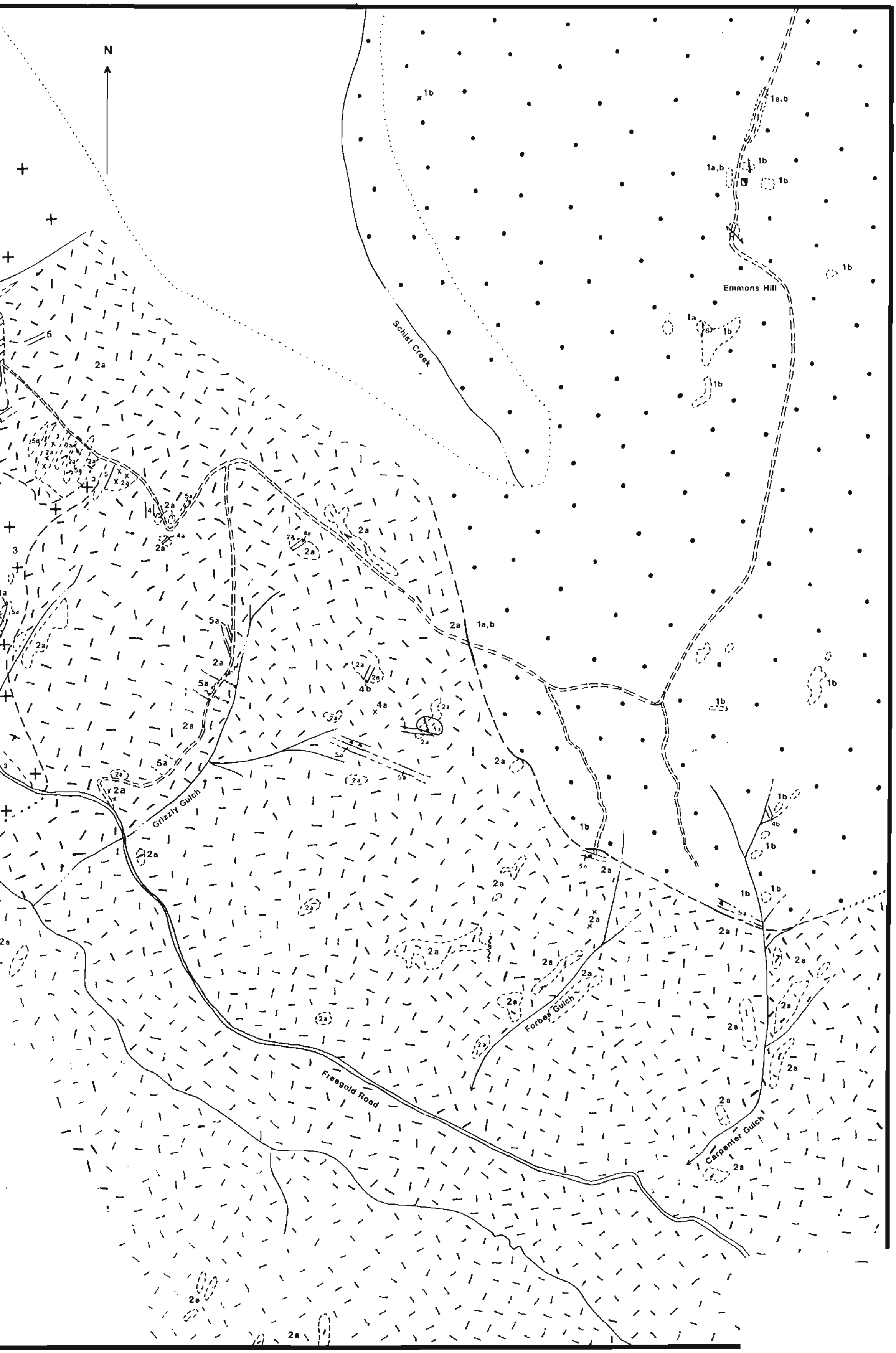


Figure 2. Geology of eastern Freegold Mountain.


N
Emmons Hill
Schist Creek
Grizzly Gulch
Forbes Gulch
Freegold Road
Carpenter Gulch

Isolated rhyolite dykes, in addition to those exposed in two major centres of rhyolite intrusion, occur sporadically throughout the map-area. A long, possibly continuous set of rhyolite dykes oriented in a northwesterly direction outcrop discontinuously from west of Grizzly Gulch to Carpenter Gulch. These exposures, called the Whale Vein by Johnston (1937), are commonly brecciated and silicified. An impressive northeasterly trending "wall" of silicified rhyolite occurs along the east side of Nabob Gulch and joins a northwesterly trending wall which is well exposed in Nabob Gulch. It may be connected to the Whale Vein to the east. This wall is 3 to 10 m in width and up to 10 m high.

Banding is common in small dykes and along the contacts of larger ones. They are generally white to buff coloured and aphanitic to porphyritic with phenocrysts of quartz and, less commonly, feldspar. There are three main varieties as indicated on Figure 2: quartz porphyry, quartz-feldspar porphyry and felsite. The porphyritic varieties contain phenocrysts of quartz and/or alkali feldspar, which are commonly strained and brecciated. Quartz phenocrysts are embayed and have coronas with granophyric intergrowths, possibly resulting undercooling during emplacement of the rhyolitic magma. The matrix occurs either as a microcrystalline groundmass or as micrographic intergrowths of fine-grained quartz and feldspar. Minor sericite, chlorite, tourmaline and pyrite occur as accessory phases, probably of secondary origin. The felsitic variety contains no phenocrysts and is homogeneously cryptocrystalline.

Brecciation of rhyolite dykes is common. Autoclastic brecciation (syn-emplacement) is evident where the outer portions of the dyke are brecciated when in contact with country rock and inner portions are massive or flow banded. Later tectonic brecciation is apparent where rhyolite dykes have been emplaced along fault zones. In these locations, both rhyolite and country rock have been brecciated and silicified.

Gold deposits

Freegold Mountain hosts several different gold deposits but three distinct types of deposits are present within the map-area (Fig. 2): (1) high grade, low tonnage gold-quartz vein deposits, e.g. the Laforma and Rambler veins; (2) low grade, high tonnage gold-bearing diatremes, e.g. the Antoniuk Breccia; and (3) Au-bearing stibnite-barite breccia veins, e.g. the Emmons Hill prospect.

The vein deposits are narrow, discontinuous gold-bearing quartz veins trending north-northeast. Gold occurs as tiny inclusions within arsenopyrite and isolated fine grains, although visible gold is not uncommon. Qualitative analysis of gold particles by SEM equipped with an x-ray dispersion unit indicate a very low silver content ($< 5\%$ Ag). Associated minerals are arsenopyrite, pyrite, galena, sphalerite, tourmaline and tennantite. The Laforma deposit has reserves of 181 488 tonnes @ 11.3 g/t Au (Yukon Exploration Geology, 1983).

The Antoniuk Breccia deposit consists of heterolithic and monolithic diatreme breccias intruded by dacite and rhyolite dykes. Diamond drilling indicates that a large body of fine to medium-grained alaskite is present beneath the auriferous breccia. The deposit is interpreted to have formed by the explosive escape of volatile components evolved by retrograde boiling from the alaskitic magma. Gold occurs as isolated grains. Pyrite and arsenopyrite commonly replace Fe-bearing silicates in breccia fragments. Chalcopyrite, sphalerite, galena and pyrrhotite occur in trace amounts, as minute intergrowths or as inclusions within pyrite.

The Emmons Hill gold-bearing vein-breccia deposit has a mineral assemblage of barite, stibnite, cinnabar, orpiment, Fe- and Mn-carbonates and chalcedonic silica. This deposit shows marked similarities to near-surface precious metal deposits in New Zealand (Ewers and Keays, 1977; Weissberg, 1969) and western United States (Weissberg et al., 1979).

A close spatial relationship is apparent between rhyolite dykes and gold-bearing quartz veins and breccias in the area. A rhyolite dyke exposed at surface and at depth in underground workings is spatially associated with and concordant to the trend of the Laforma gold-quartz vein (Fig. 2). This association can also be seen along the southern portion of the Rambler Vein. As discussed before, rhyolite dykes are also common in the Antoniuk Breccia gold deposit. In addition, samples of stibnite-barite cemented breccia from the Emmons Hill prospect contain clasts of rhyolite, and recent trenching of the property indicates that rhyolite dykes are present in the vicinity (C. Hart, Noranda geologist, pers. comm., 1987).

GEOCHRONOLOGY

Metasedimentary rocks

The metasedimentary rocks are the oldest lithology in the area based on field relationships showing that all igneous rocks cut them. They are considered to be Late Paleozoic (Tempelman-Kluit, 1984).

Syenite and granodiorite plutons

Contacts between syenite and granodiorite clearly show that the syenite has intruded the granodiorite. Figures 3 and 4 show xenoliths of granodiorite within syenite and small "dykes" of coarse-grained syenite intruded along joints in the granodiorite. This observation shows that the Big Creek syenite is younger than the Casino granodiorite. This conclusion is problematic, however, in that K-Ar radiometric ages for the granodiorite and syenite (Tempelman-Kluit, 1984) indicate that the syenite predates the granodiorite (Table 1). Of the two granodiorite samples in Table 1, the latter sample was taken from a rock type which does not resemble the granodiorite in the Freegold Mountain area, but is more characteristic of a fine-grained granite. It may therefore, represent an intrusion different in age from the Freegold granodiorite.

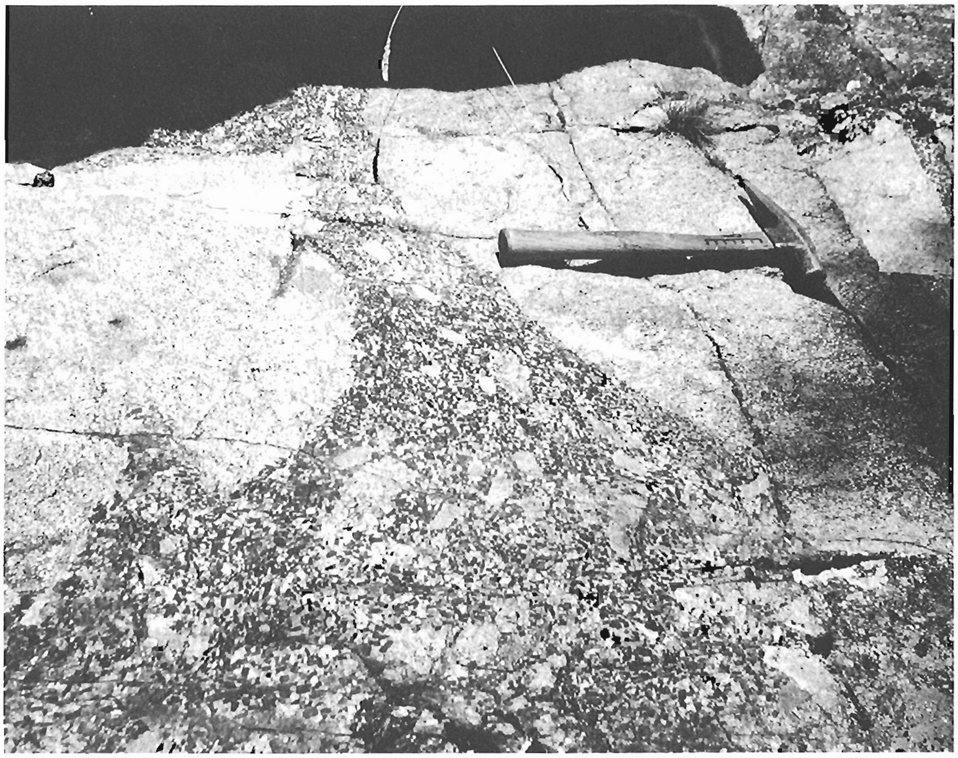


Figure 3. Xenoliths of granodiorite within matrix of Big Creek syenite.

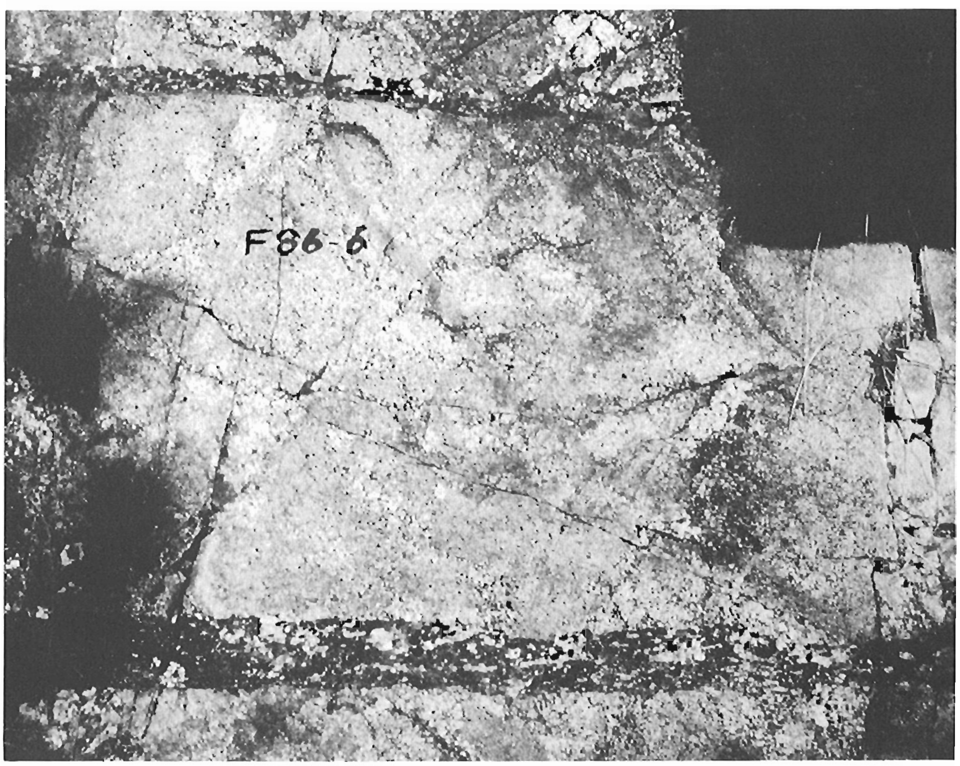


Figure 4. Small (3- to 8-cm-wide) dykes of syenite intruding along joint planes in granodiorite.

Table 1. Radiometric age dates of granodiorite and syenite in the Freegold Mountain area (from Tempelman-Kluit, 1984)

Granodiorite
1. 110 ± 8 Ma (hornblende separate, 7.2 km SW of study area)
2. 85 ± 3 Ma (biotite separate, 4.5 km NW of study area)

Syenite
1. 142 ± 10 Ma (hornblende, within study area)
2. 184 ± 7 Ma (hornblende, 22 km west of study area)
3. 152 ± 7 Ma (hornblende, 11 km west of study area)

Due to the discrepancies between field relationships and radiometric dates it was decided to investigate this problem furthur by dating the syenite using Rb-Sr method. Widespread propylitic alteration of the granodiorite in the study area precluded application of Rb-Sr or K-Ar dating.

Analytical results

Rb and Sr concentrations were determined by a Phillips PW 1450 automated X-Ray Fluorescence spectrometer using the Mo-Compton peak method described by Reynolds (1963) and Turek et al. (1977). The $^{87}Sr/^{86}Sr$ ratio was determined on a VG 354 five-collector solid-source mass spectrometer with magnetic field switching and data processing controlled by a Hewlett-Packard computer. All analyses were conducted at the McMaster University geochronology laboratory.

The results obtained by XRF analysis and mass spectrometry are presented in Table 2. Reproducibility of XRF results was generally less than 3 % relative error at the 2 level for the Rb/Sr ratio. Blanket errors of 3.0 % were assigned to the $^{87}Rb/^{86}Sr$ ratio when calculating the radiometric age of the syenite. The error in the $^{87}Sr/^{86}Sr$ ratio was less than 0.004 % at the 2σ level.

Calculation of the regression line using a modified York (1969) regression model on the 7 data points results in an age of 138 10 (2σ error, MSWD = 0.62) with an R_I = 0.70597 ± 0.00002 using blanket errors of 0.004 % for $^{87}Sr/^{86}Sr$ and 3.0 % for $^{87}Rb/^{86}Sr$. The isochron is plotted on Figure 5.

Discussion of Rb-Sr dating results

The age of 138 ± 10 Ma is in agreement, within error, with two of the three K-Ar ages reported by Tempelman-Kluit (1984) for the Big Creek Syenite and very similar to the K-Ar date of 142 ± 10 Ma for a sample taken in the vicinity of the study area. Thus it appears that the granodiorite from Freegold Mountain is older than granodiorite (dated 110 ± 8 Ma) 7.2 km to the southwest. This leads to two possibilities: either the K-Ar date for the granodiorite has been reset and is, therefore, in error or the granodiorite in the study area (Fig. 2) is not equivalent to the granodiorite dated by Tempelman-Kluit (1984).

No comment can be made as to the accuracy of the K-Ar date or whether the granodiorites from the two areas are mineralogically and compositionally similar. An age for the Freegold Mountain granodiorite greater than 140 Ma, however, would make it comparable in age to a large granodioritic body located just northeast of the study area which has yielded K-Ar ages of: 142 ± 10 Ma (hornblende, Stevens et al., (1982)), 174 ± 6 Ma (biotite), 177 ± 9 Ma (biotite), and 180 ± 9 Ma (biotite). The last three ages are corroborated by a zircon age of 192 Ma (no errors given) (Stevens et al., 1982; Tempelman-Kluit, 1984).

Based on physical characteristics, this Triassic granodiorite cannot be correlated with the study area granodiorite since it has a lighter colour, lesser potassium feldspar, and a well developed penetrative foliation. Based on available radiometric dates, the granodiorite in the Freegold Mountain area known as the Seymour Creek stock is a separate entity in time and space. Samples of granodiorite from the study area have been submitted to the geochronology laboratories at the Geological Survey of Canada where U-Pb dating on zircons and sphene will be undertaken in an attempt to further clarify the situation.

Initial $^{87}Sr/^{86}Sr$ ratios greater than 0.706 reflect the contribution of radiogenic strontium from Precambrian rocks to rising magma bodies according to Rodgers et al., (1974) and Le Couteur and Tempelman-Kluit, (1976). If Mesozoic magma ascended through oceanic crust of Phanerozoic age, the initial $^{87}Sr/^{86}Sr$ ratio of about 0.704 would not be significantly affected by assimilation of wallrock Sr since the crust would not have accumulated much radiogenic strontium. The Big Creek Syenite is interpreted to be on the transition zone between regions floored by older Precambrian continental crust and younger oceanic crust and was probably derived mainly by subduction- related melting of the younger oceanic plate (Le Couteur and Tempelman-Kluit, 1976). The initial Sr isotope ratio of 0.706 of Big Creek Syenite suggests that the magma was contaminated to a minor extent, if at all, by Precambrian continental crust ($^{87}Sr/^{86}Sr$=0.707-0.709; Faure and Powell, 1972) upon ascent. Thus the isotopic data are compatible with the model that the Big Creek Syenite marks the western boundary of continental crust in the Early Cretaceous.

Andesites, dacites and rhyolites

The dykes of these rock-types cut all other rocks in the study area and represent the last intrusive events in the area. The age differences of the above three are probably small although one outcrop between Grizzly and Nabob gulches shows a rhyolite dyke cutting a dacite dyke. It is evident from reconstruction of the Laforma Mine workings that fault structures cutting and displacing andesite dykes are parallel to faults along which rhyolitic magmas have intruded. The age of rhyolitic intrusion is important because many precious metal deposits are temporally and spatially related to shallow-emplaced silicic magmas. The dating of rhyolitic dykes at Freegold Mountain may help therefore constrain the age of gold deposits in the area.

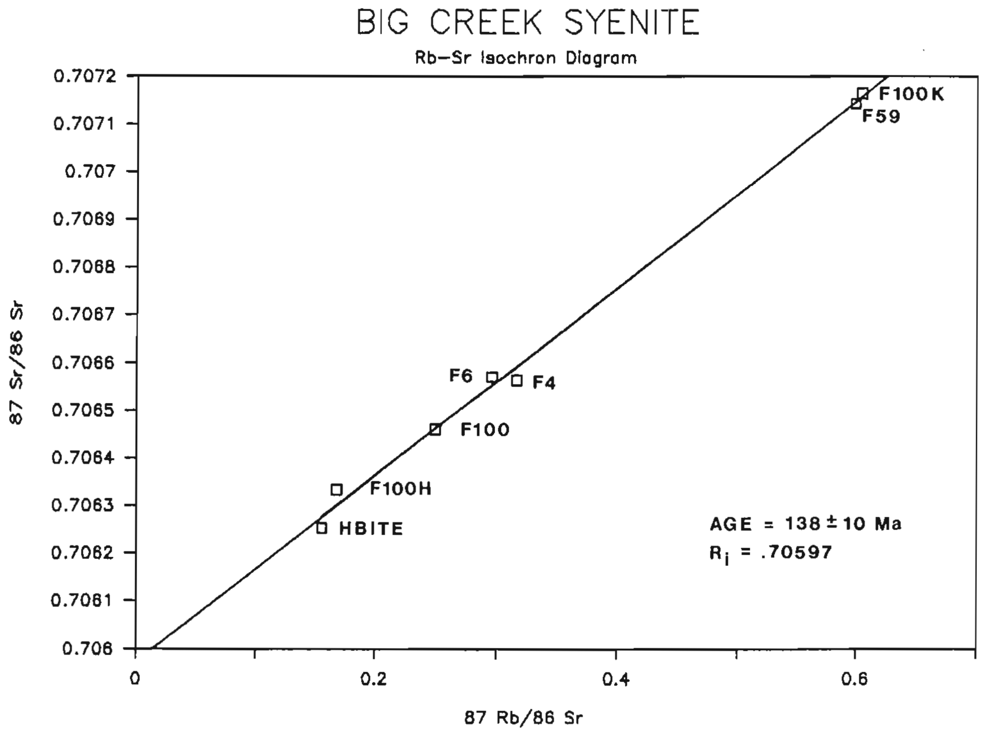


Figure 5. Plot of $^{87}Sr/^{86}Sr$ against $^{87}Rb/^{86}Sr$ for the Big Creek syenite.

Table 2. Rb-Sr isotopic data for the Big Creek Syenite

Sample #	Rb (ppm)	Sr (ppm)	Rb/Sr (2σ rel. error)	87Sr/86Sr (± 0.5 % error)	87Rb/86Sr	Comments
Hornblendite	19.8 21.2 21.1 x = 20.7 ± 0.8	384.5 385.1 300.3 x = 383.3 ± 2.6	0.054005	0.706253 ± 0.003%	0.15545	
F86 — 100H	13	230	0.05824	0.706334 ± 0.002 %	0.16764	hornblende separate
F86 — 100K	87	417	0.20961	0.707164 ± 0.002 %	0.60339	orthoclase separate
F86 — 4	59 61 59 x = 60 ± 1	542 551 548 x = 547 ± 5	0.10884 0.11153 0.10768 x = 0.10932 ± 3.0 %	0.706564 ± 0.002 % 0.706555 ± 0.002 %	0.31574	
F86 — 59 x = 54 ± 1	54 55 54 x = 260 ± 2	262 268 258 x = 0.21044	0.20967 0.21092 0.21072 ± 0.5 %	0.707142 ± 0.003 %	0.59786	
F86 — 100	96 95 96 x = 96 ± 1	1110 1099 1107 x = 1105 ± 6	0.08642 0.08642 0.08647 x = 0.08637 ± 0.2 %	0.706460 ± 0.003 %	0.25008	
F86 — 68	130 135 133 x = 133 ± 3	1277 1307 1299 x = 1294 ± 16	0.10189 0.10342 0.10269 x = 0.10267 ± 1.2 %	0.706570 ± 0.002 %	0.29585	

The age of rhyolite dykes in the area has until now been unknown, although they have generally been correlated by Tempelman-Kluit (1984) with the Mount Nansen Volcanics, which have recently been dated as Late Cretaceous (73.1 ± 2.5, 67.9 ± .3, and 68 ± 2.2 Ma; Grond et al., 1984) from samples taken near the village of Carmacks. A sample of coarser grained rhyolite dyke from the summit of Freegold Mountain, F85-33B, was submitted to Geochron Laboratories, Cambridge, Mass. for whole-rock K-Ar dating in order to determine the approximate age of rhyolitic intrusion and, by association, the age of precious metal deposits. The analytical results done in duplicate are presented in Table 3. This sample yielded an age of 77.5 ± 6.2.

Sample F85-33B, like most other rhyolite samples in the Freegold Mountain area, has undergone hydrothermal alteration. Thus the age may not reflect the actual time of intrusion and cooling but rather the age of hydrothermal alteration. However, the close spatial relationship between rhyolite dykes and quartz veins indicates that the period of time between intrusion and alteration is probably minimal and within analytical error.

The model age of 77.5 ± 6.2 Ma is similar, within error, to the age of Mount Nansen and Carmacks group volcanics (Grond et al., 1985). The correlation of subvolcanic rocks in the Freegold Mountain area with Mount Nansen volcanics as suggested by Tempelman-Kluit (1984) is reasonable. The close temporal and spatial association of precious metal deposits with rhyolitic intrusion in the study area indicates that the age of mineralization is Late Cretaceous. The gold-bearing Casino porphyry copper complex located 100 km northwest of Freegold Mountain has been dated at 70 ± 5 Ma (Godwin, 1975). The association of gold-bearing quartz veins and porphyry copper deposits with felsic intrusion of Late Cretaceous age in the Freegold Mountain, Mount Nansen and Casino areas suggests that a regional volcanogenic-metallogenetic event occurred in the Dawson Range.

The Late Cretaceous age of Freegold Mountain rhyolitic intrusion discounts any temporal correlations with Skukum rhyolites (53 ± 2 Ma; Pride and Clark, 1985), and also precludes correlation with the Nisling Range Alaskite (52-67 Ma: Tempelman-Kluit and Wanless, 1975; Le Couteur and Tempelman-Kluit, 1976).

Table 3. Analytical data for K-Ar age determination for rhyolite sample F85-33B

Argon Analyses:

$^{40*}Ar$, ppm	$^{40*}Ar$/Total ^{40}Ar	Average $^{40*}Ar$, ppm
0.01529	0.562	
0.01518	0.568	0.01523

Potassium Analyses:

% K	Ave. % K	^{40}K, ppm
2.806	2.776	3.311
2.745		

Apparent Age = 77.5 ± 6.2 (2 error)

Constants Used:

$\lambda_\beta = 4.962 \times 10^{10}$/year

$(\lambda_e + \lambda'_e) = 0.581 \times 10^{10}$/year

$^{40}K/K = 1.193 \times 10^4$ g/g

$^{40*}Ar$ = radiogenic ^{40}Ar

Fresh samples of 'andesitic' rocks from the Freegold Mountain area plot within the subalkaline field of Figure 6A and within the calc-alkaline field of Figure 6B. Also plotted on Figure 3B are rocks found elsewhere in the Dawson Range thought to be contemporaneous (e.g. Quartz Porphyry dykes from Mount Nansen and Revenue areas) with the Freegold Mountain samples. These also plot within the calc-alkaline field.

Unlike the andesite samples, most of the rhyolitic rocks in the Freegold Mountain area have been hydrothermally altered. Brecciated portions of the dykes are cemented by silica and cut by quartz veins. The rhyolite samples submitted for geochemical analysis appeared fresh in hand specimen but when examined microscopically, they contained small microveinlets of quartz and secondary sericite. Hydrothermal alteration appears to have been pervasive, even in massive samples, to the extent that Na_2O contents are all less than 0.15 wt. % (Table 4). The chemical compositions of fresh Cordilleran rhyolites compiled by Ewart (1979) show average Na_2O and K_2O contents to range between 3.5 - 4.2 wt. % and 3.3 - 4.8 wt. %, respectively. Although the average K_2O content of Freegold rhyolites (4.0 ± 1.25 wt. %), is similar to the Cordilleran rhyolite average (4.1 ± 0.7 wt. %; Ewart, 1979), the large spread of values for Freegold rhyolites (Fig. 7) suggests that some remobilization of K has occurred.

Alkali mobilization (particularly sodium) in rhyolitic samples precludes their classification as alkaline or subalkaline rocks (Fig. 6A) using alkali-dependant classification methods. Based on the content of secondary minerals, Freegold rhyolite samples have been subdivided into highly altered (HA) and least altered (LA) fields (Fig. 6A). For comparison, fresh samples of Nisling Range alaskite which have similar silica contents and which are physically similar to coarser-grained rhyolite from the Antoniuk Breccia, are also plotted. By virtue of this similarity, it is proposed that

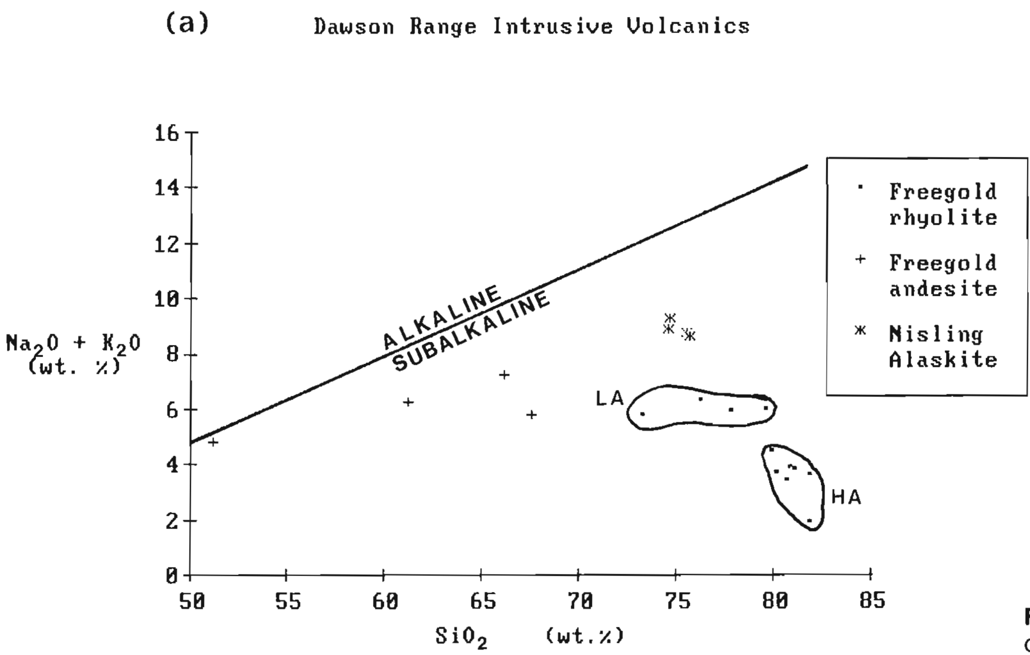
GEOCHEMISTRY

Representative chemical analyses of intrusive rocks in the Freegold Mountain area are listed in Table 4, and the data are plotted in Figures 6 to 8.

Subvolcanic rocks

The two types of subvolcanic rocks present in the map-area (Fig. 2) have been given the field terms andesite and rhyolite, based on Johnston's (1937) nomenclature. Chemical analyses of these rock types have allowed their classification to be refined according to methods proposed by Irvine and Baragar (1971), and Pecerillo and Taylor (1976). The classification system widely accepted for volcanic rocks is based on a binary alkalies-silica diagram and a ternary AFM plot (Figures 6A and B) using raw chemical data (Irvine and Baragar, 1971).

(a)



(b)

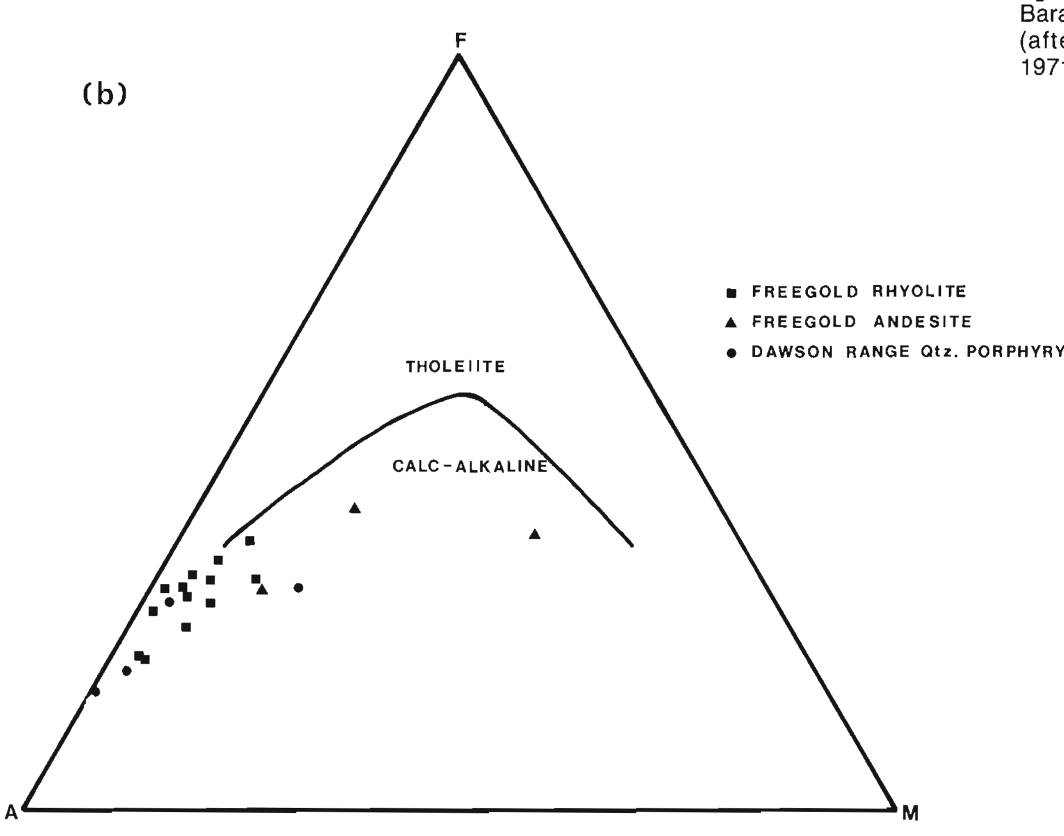


Figure 6. Chemical classification diagrams for dykes of the Dawson Range: (a) binary K_2O-silica plot (after Irvine and Baragar, 1971); (b) AFM plot (after Irvine and Baragar, 1971).

Table 4. Geochemical analyses of intrusive volcanic rocks from Freegold Mountain and Misling Range Alaskites

	Freegold Mountain Rhyolites										Freegold Andesites				Misling Range Alaskite				
								TR16N-0	TR22N	QFP-LAF VN					ALASKITE	ALASKITE	ALASKITE	ALASK DYKES	ALASK DYKES
SAMPLE #	TR24-235W	ANT86-12-333	F85-33A	F85-33B	F86-57	TR18-60E	F86-29	#1151869005	#1151869006	#1151869007	F86-54	F85-1	F86-40	F86-41	#115J867001	#115J867002	#115J867003	#15J867004	#115J867005
SiO2	80.8	80.6	81	79.8	81.8	77.7	79.5	76.2	80.1	81.8	67.5	66.1	51.1	61.2	75.5	74.5	75.6	74.6	76.4
TiO2	0.1	0.1	0.07	0.08	0.08	0.04	0.11	0.07	0.13	0.17	0.39	0.4	0.89	0.65	0.08	0.12	0.09	0.12	0.23
Al2O3	11.6	11.5	12	11.9	11.9	11.6	11.9	12.8	12.6	10	13.5	15.5	14.4	17.1	12.4	13.1	12.6	13.1	4.01
Fe2O3T	0.68	0.95	0.51	0.66	0.39	1.03	1.13	1.15	0.33	1.4	3.22	3.76	8.17	6.36	1.2	1.41	1.28	1.24	1.51
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.08	0.09	0.15	0.09	0.02	0.03	0.02	0.02	0.02
MgO	0.24	0.18	0.08	0.11	0.18	0.3	0.22	0.25	0.14	0.16	1.05	1.53	8.34	2.69	0.02	0.02	0.02	0.02	1.06
CaO	0.09	0.09	0.08	0.08	0.06	0.07	0.14	0.05	0.05	0.05	3.23	2.81	7.97	5.25	0.11	0.28	0.14	0.41	4.27
Na2O	0.11	0.12	0.11	0.12	0.11	0.14	1.95	0.05	0.05	0.05	1.49	4.33	2.31	3.83	4.28	3.87	3.85	4.2	0.05
K2O	3.71	3.23	3.63	4.29	3.46	5.74	4	6.2	3.58	1.82	4.26	2.84	2.46	2.35	4.42	4.97	4.74	4.99	1.53
P2O5	0.02	0.03	0.03	0.02	0.01	0.02	0.04	0.02	0.02	0.06	0.21	0.2	0.38	0.21	0.02	0.02	0.01	0.03	0.35
H2OT	2	1.8	3.1	2.4	2	2	1.3	1.3	1.5	2.4	3.1	1.8	3.3	1	0.6	0.6	0.6	0.6	1
CO2T	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	2.2	0.2	0.7	0.1	0.1	0.1	0.1	0.1	3.6
S	0.04	0.53	0	0.01	0.04	0.03	0.56	0.3	0.01	0.11	0.02	0.01	0.01	0.15	0.01	0.01	0.01	0.01	0.65
Ag	0	0	0	2	0	0	0	BLD (1)	BLD (1)	BLD (1)	1	0	0	3	BLD (1)	BLD (1)	BLD (1)	BLD (1)	BLD (1)
Au	400	930	12	31	940	53	nd	392	1685	136	BLD (5)	BLD (8)	BLD (9)	BLD (8)	BLD (1)	BLD (1)	BLD (1)	BLD (1)	BLD (1)
As	790	330	61	38	250	56	nd	nd	nd	nd	7	6	5	2	nd	nd	nd	nd	nd
Ba	480	620	100	550	770	6800	2100	nd	nd	nd	1100	2100	1000	1200	nd	nd	nd	nd	nd
Be	1.9	1.8	1.2	1.4	2	1.2	1.3	nd	nd	nd	2.5	1.5	2.6	1.7	nd	nd	nd	nd	nd
Co	71	86	39	42	39	28	5	BLD (5)	BLD (5)	BLD (5)	17	26	41	20	BLD (5)	BLD (5)	BLD (5)	BLD (5)	BLD (5)
Cr	4	5	3	4	3	3	5	30	30	30	16	15	380	16	30	30	30	30	100
Cu	8	14	9	8	8	15	12	134	4	7	14	20	57	19	6	8	6	5	48
Hf	2	2	BLD (1)	3	3	2	nd	nd	nd	nd	4	BLD (1)	4	2	nd	nd	nd	nd	nd
Ni	3	3	4	0	0	0	0	8	10	10	4	0	160	13	5	8	5	5	68
Pb	0	20	19	59	72	23	69	40	20	15	23	19	15	200	25	10	15	10	35
Rb	150	130	180	190	180	200	nd	220	160	90	220	130	BLD (60)	90	270	190	260	160	40
Sr	30	5	61	44	5	57	130	60	10	80	290	460	740	770	10	10	10	10	20
Sb	19	11	37	50	6.6	45	nd	nd	nd	nd	4.8	3.1	1.3	0.9	nd	nd	nd	nd	nd
Sc	1.9	1.8	2.8	2.7	2.8	1.8	nd	nd	nd	nd	5.1	6.2	22.5	11.4	nd	nd	nd	nd	nd
Se	BLD (5)	BLD (5)	BLD (5)	BLD (5)	BLD (5)	BLD (5)	nd	nd	nd	nd	7	15	BLD (9)	BLD (9)	nd	nd	nd	nd	nd
Th	18	29	27	29	9.7	5.9	nd	nd	nd	nd	13	11	25	13	nd	nd	nd	nd	nd
U	2.2	8.8	4.9	5.4	1.9	3.2	nd	nd	nd	nd	7.5	5.3	9.3	5.2	nd	nd	nd	nd	nd
V	6	3	2	1	0	1	9	nd	nd	nd	48	54	160	120	nd	nd	nd	nd	nd
W	BLD (4)	BLD (4)	130	81	16	47	nd	nd	nd	nd	9	22	4	BLD (4)	nd	nd	nd	nd	nd
Zn	15	16	23	96	9	31	94	88	10	14	67	53	69	61	100	162	166	76	540
Zr	83	82	71	80	68	61	68	20	70	50	170	180	200	180	270	240	230	190	10
La	20	19	14	18	19	15	nd	nd	nd	nd	37	27	37	29	nd	nd	nd	nd	nd
Ce	42	30	27	29	33	22	nd	nd	nd	nd	46	29	69	35	nd	nd	nd	nd	nd
Sm	1.8	1.9	2.4	2.3	2.6	1.4	nd	nd	nd	nd	2.9	1.7	4	2.1	nd	nd	nd	nd	nd
Eu	0.4	0.2	0.4	0.5	0.4	0.3	nd	nd	nd	nd	1	BLD (1)	1.8	1.5	nd	nd	nd	nd	nd
Gd	1.9	2.1	3	2.9	3.1	1.5	nd	nd	nd	nd	3.6	2.9	5	3.3	nd	nd	nd	nd	nd
Yb	1.1	1.2	2.2	1.7	1.6	0.9	nd	nd	nd	nd	0.9	1	1.6	1.3	nd	nd	nd	nd	nd
Lu	0.12	0.28	0.37	0.3	0.2	0.13	nd	nd	nd	nd	0.13	0.27	0.27	0.28	nd	nd	nd	nd	nd

Major elements are expressed in wt. %
Trace elements are expresed in ppm, gold in ppb
nd = not determined
BLD = concentration below limit of detection (detection limit)

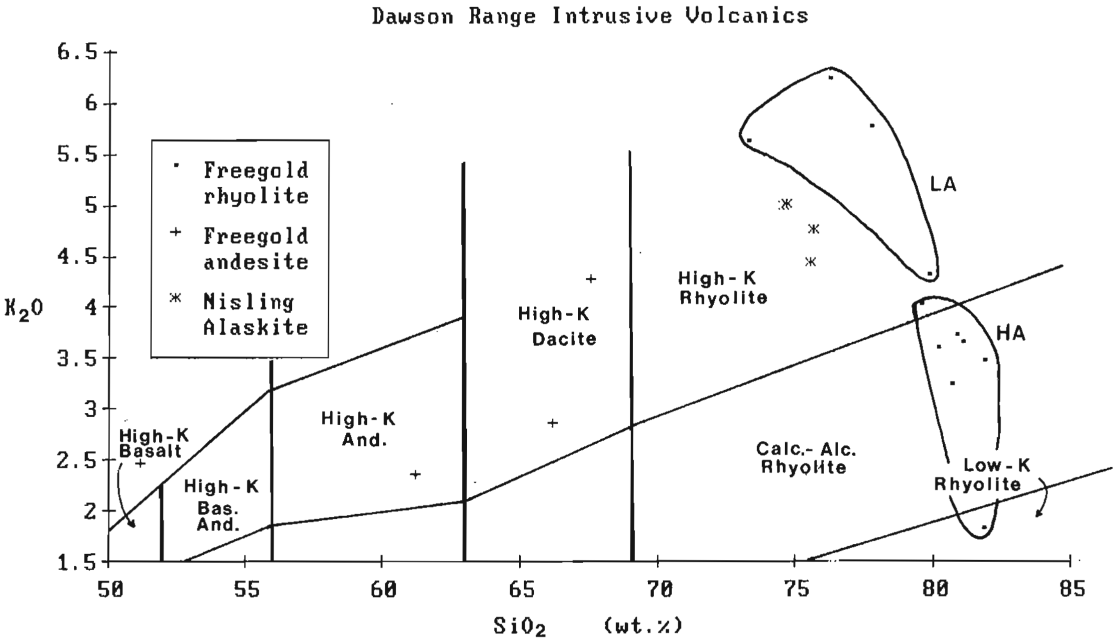


Figure 7. Chemical classification of dykes at Freegold Mountain and Nisling Range (after Pecerillo and Taylor, 1976).

unaltered Freegold rhyolite samples would plot near the Nisling Alaskite samples on Figure 6A, still within the subalkaline field.

A simple but useful chemical classification, particularly for relatively young (ie. not Archean) fine grained volcanic rocks, was proposed by Peccerillo and Taylor (1976) and modified by Ewart (1979). Figure 7 is a binary plot of K_2O (wt. %) vs. SiO_2 (wt. %) with the type-fields as proposed by Pecerillo and Taylor (1976). Samples plotted in Figure 6B are replotted on Figure 7 and fall within the basalt, andesite, dacite and rhyolite fields. Of the four samples shown as andesite on Figure 6B, two plot as high-K dacites, one as high-K andesite and the other as a shoshonite (above the high-K basalt field). This shoshonitic sample was obtained from a dyke intruded into quartz syenite and the high K_2O content of the basalt may reflect partial melting and incorporation of K-feldspar from the syenite. The rhyolitic rocks in the Freegold Mountain area span the low-K, calc-alkaline (highly altered samples), and high-K rhyolite (least altered samples) fields.

RARE EARTH ELEMENT DATA

Basalt-andesites-dacites

The range of chondrite normalized REE patterns for four samples of this rock group is plotted on Figure 8A. The upper limit is defined by the high-K basalt and the lower limit by the high-K dacite. The generally parallel trends in REE patterns, positive Eu anomaly and high-K content of this group suggest that they were derived from a single parental magma source. The similarity in shape of the REE pattern between the 'andesitic' rocks and those of granodiorite (Fig. 8B) from the study area suggests that the andesites were derived from a granodioritic melt which had evolved slightly by minor fractional crystallization. Temporal relationships, however, exclude the Freegold Granodiorite itself as the parent magma.

The basalt is aphanitic, while the andesite and dacite contain phenocrysts of plagioclase, hornblende and quartz. If the basalt is the earliest intrusive phase and formed from an undifferentiated melt, then decreasing REE abundances in andesitic and dacitic samples may be attributed to a fractional crystallization process. The REE partition coefficient for most minerals in basaltic to andesitic melts is less than 1 (Henderson, 1982, Table 5.2a, p. 91), and therefore crystallization of minerals such as pyroxene and plagioclase would tend to enrich the residual liquid in REE, particularly the LREE. The REE pattern for this group of rocks, however, shows the opposite trend in that the more 'evolved' dacitic rocks have lower total REE abundances.

The REE data, therefore, does not suggest that this group of rocks has evolved from a basaltic to a dacitic composition by fractional crystallization of a mafic melt. An alternate explanation involves mixing of mantle-derived magmas and magmas generated by partial melting of lower crustal material depleted in total REE's. This mechanism is supported by the documented tectonic setting of the area where volcanism and plutonism result from subduction of an oceanic plate under the North American continent (Tempelman-Kluit, 1979; Ewing, 1980).

Rhyolites

Chondrite normalized REE patterns for six rhyolitic intrusions are shown in Figure 8C. LREE are enriched compared to HREE, and a negative Eu anomaly is present in all samples. The negative Eu anomaly can be accounted for by the fractionational crystallization of plagioclase or sanidine from the original liquid. Since Eu partition coefficients ($K_{MINERAL-LIQUID}$) for plagioclase and sanidine with respect to silicic melts is 3.8-7.9 and 3.3-6.5 respectively (Nash and Crecraft, 1985), the crystallization of either phase could produce a negative Eu anomaly in a rock formed from the residual magma. The low absolute abundances of LREE's, however, cannot be attributed to fractional crystallization of feldspar, but may be due to the fractionation of LREE-rich accessories such as allanite (K_{LREE} = 750-2800; Mahood and Hildreth, 1983) or monazite (Miller and Mittlefehldt, 1982). These minerals were not detected in the aphanitic rhyolite samples from Freegold Mountain although the fine grain size of these rocks would make their recognition difficult.

Aplite dykes of rhyolitic composition associated with the Nisling Range alaskites to the west are interpreted by Lynch and Pride (1984) to be the residual phases of a fractionally crystallized, coarse- to medium-grained, alaskitic alkali granite. These residual phases are chemically and texturally similar to Freegold Mountain rhyolites. The Nisling Range dykes, which have REE patterns similar to Freegold rhyolites, are LREE depleted, HREE enriched and have a more negative Eu anomaly relative than the coarse grained, allanite-bearing alaskite. Lynch and Pride (1984) argue that fractional crystallization of allanite in the early coarse- and medium-grained phases accounts for the REE trend. Similarily, fractional crystallization of allanite or monazite in the source melt of the Freegold rhyolites could account for the observed REE patterns.

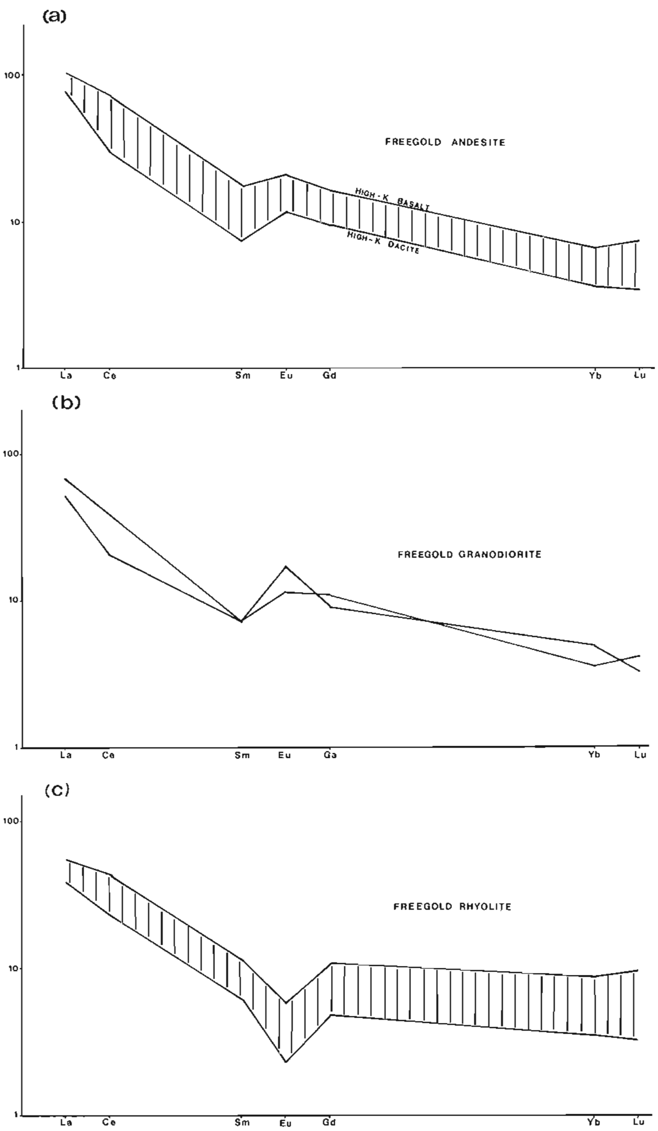


Figure 8. Chondrite normalized REE patterns for Freegold Mountain rocks: (a) Basalt-andesite-dacite group; (b) Study area granodiorite; (c) Rhyolite dykes.

Another possibility is that the Freegold rhyolites were derived by partial melting of upper crust already depleted in residual plagioclase (Albuquerque, 1977), such as arenaceous sandstone or greywacke. Anatexis of such a rock type could produce the REE patterns observed for the rhyolites.

The REE abundances for the Freegold Mountain rhyolites are low compared to high-silica rhyolites from Twin Peaks, Utah (Nash and Crecraft, 1985), Taupo Volcanic Zone, N.Z. (Cole, 1979), Sierra La Primavera, Mexico and the Bishop Tuff, California (Mahood and Hildreth, 1983). They are comparable however, with high level rhyolite intrusion at Mount Skukum, Yukon (Smith, 1982). Smith also attributed the low LREE abundances and negative Eu anomaly of the Skukum rhyolites to fractionation of feldspar and LREE-rich accessory minerals.

Comparisons of the REE patterns for rhyolitic intrusions (Fig. 8C) with those of 'andesite' (Fig. 8A) show that the rhyolites are more depleted in LREE and Eu. The HREE abundances are about the same in both groups. Whether or not the rhyolites are derived from a highly fractionated melt of original andesitic to dacitic composition is uncertain. In theory, fractional crystallization of mineral phases from a dacitic melt should enrich the residual silicic liquid in both light and heavy REE and produce a negative Eu anomaly (Arth, 1976). The Freegold rhyolites show a negative Eu anomaly, but are not enriched in LREE or HREE although the LREE depletion may be the result of fractionation of LREE-rich accessory minerals. The lack of HREE enrichment in the rhyolite suggests that their origin is not simple fractional crystallization of a dacitic melt. Rhyolitic volcanism at Freegold Mountain may have resulted from a separate melting event which occurred after andesite-dacite intrusion.

ACKNOWLEDGMENTS

Logistic and technical support was partially provided by Archer, Cathro and Associates Ltd. We thank geologists Bob Cathro, Sandy Main, Jessie Duke and Kevin Capenhurst for their advice and discussions. Samples for radiometric dating were prepared by Kathrina Jager and Mike Franklyn, and analysed by Dave Jones in the laboratory of RHM. The technical assistance of Ota Mudroch is appreciated. We are grateful to Noreen Evans for drafting the figures. This project has been supported financially by Yukon Mineral Development Agreement funds under the supervision of WDG and by NSERC Operating Grants to JHC and RHM. Dave Sinclair reviewed the manuscript and provided many constructive comments which improved the content of this paper.

REFERENCES

Albuquerque, C.A.R.
1977: Geochemistry of the tonalitic and granitic rocks of the Nova Scotia southern plutons; Geochimica et Cosmochimica Acta, v. 41, p. 1-13.

Arth, J.G.
1976: Behavior of trace elements during magmatic processes-a summary of theoretical models and their applications; Journal of Research, U.S. Geological Survey, v. 4, p. 41-47.

Bostock, H.S.
1935: Carmacks District, Yukon; Geological Survey, Canada, Memoir 189, pp. 1-67.
1966: Notes on glaciation in central Yukon Territory; Geological Survey of Canada, Paper 65-36, 18 p.

Cole, J.W.
1979: Structure, petrology, and genesis of Cenozoic volcanism, Taupo Volcanic Zone, New Zealand - a review; New Zealand Journal of Geology and Geophysics, v.22 (6), p. 631-657.

Ewart, A.
1979: A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic, and related salic volcanic rocks, in *Trondhjemites, Dacites, and Related Rocks*, edited by F. Barker, Elsevier, Amsterdam, p. 13-121.

Ewers, G.R., and Keays, R.R.
1977: Volatile- and precious- metal zoning in the Broadlands geothermal field, New Zealand; Economic Geology, v. 72, p. 1337-1354.

Ewing, T.E.
1980: Paleogene tectonic evolution of the Pacific Northwest; Journal of Geology, v. 88, n. 6, p. 619-638.

Faure, G. and Powell, J.L.
1972: *Strontium Isotope Geology*. Springer-Verlag, New York. 188p.

Godwin, C.I.
1975: Alternative interpretations for the Casino Complex and Klotassin Batholith in the Yukon Crystalline Terrane; Canadian Journal of Earth Sciences, v. 12, p. 1910-1916.

Grond, H.C., Churchill, S.J., Armstrong, R.L., Harakal, J.E., and Nixon, G.T.
1984: Late Cretaceous age of the Hutshi, Mount Nansen, and Carmacks groups, southwestern Yukon Territory and northwestern British Columbia; Canadian Journal of Earth Sciences, v. 21, p. 554-558.

Henderson, P.
1982: Inorganic Geochemistry. Pergamon Press, New York.

Irvine, T.N. and Baragar, W.R.A.
1971: A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences, v. 8, p. 523-549.

Johnston, J.R.
1937: Geology and Mineral Deposits of Freegold Mountain, Carmacks District, Yukon; Geological Survey of Canada, Memoir 214, p. 1-21.

Le Couteur, P.C. and Tempelman-Kluit, D.J.
1976: Rb/Sr ages and a profile of initial Sr 87/ Sr 86 ratios for plutonic rocks across the Yukon Crystalline Terrane. Canadian Journal of Earth Sciences, v. 13, p. 319-330.

Lynch, G.V., and Pride, C.
1984: Evolution of a high-level, high-silica magma chamber: the Pattison pluton, Nisling Range alaskites, Yukon; Canadian Journal of Earth Sciences, v. 21, p. 407-414.

Mahood, G., and Hildreth, W.
1983: Large partition coefficients for trace elements in high-silica rhyolites; GCA, v. 47, p. 11-30.

Miller, C.F., and Mittlefehldt, D.W.
1982: Depletion of light rare-earth elements in felsic magmas; Geology, v. 10, p. 129-133.

Nash, W.P., and Crecraft, H.R.
1985: Partition coefficients for trace elements in silicic magmas; Geochimica et Cosmochimica Acta, v. 49, p. 2309-2322.

Peccerillo, A., and Taylor, S.R.
1976: Geochemistry of some calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey; Contributions to Mineralogy and Petrology, v. 58, p. 63-81.

Pride, M.J., and Clark, G.
1985: An Eocene Rb-Sr isochron for rhyolite plugs, Skukum area, Yukon Territory; Canadian Journal of Earth Sciences, v. 22, p. 1747-1753.

Reynolds, R.C.
1963: Matrix corrections in trace element analysis by X-ray fluorescence. Estimation of mass absorption coefficient by compton scattering; American Mineralogist, v. 48, p. 1133-1143.

Rodgers, J.W., Burchfiel, B.C., Abbot, F.W., Anepohl, J.K., Ewing, A.H., Koehnhken, P.J., Novitsky-Evans, J.M., and Talukdar, S.C.
1974: Paleozoic and Lower Mesozoic volcanism and continental growth in the western United States; Geological Society of America Bulletin, v. 85, p. 1913-1924.

Smith, M.J.
1982: Petrology and geology of high level rhyolite intrusives of the Skukum area, 105D SW, Yukon Territory in *Yukon Exploration and Geology 1981*, Department of Indian and Northern Affairs, Whitehorse, Yukon, p. 62-73.

Stevens, R.D., Delabio, R.N., and LaChance G.R.
1983: Age determinations and geological studies: K-Ar Isotopic Ages, Report 16; Geological Survey of Canada, Paper 82-2, 56 p.

Streckeisen, A.
1975: To each plutonic rock its proper name. Earth-Science Reviews., v. 12, p. 1-33.

Tempelman-Kluit, D.J.
1976: The Yukon Crystalline Terrane: Enigma in the Canadian Cordillera; Geological Society of America Bulletin, v. 87, p. 1343-1357.
1979: Transported cataclastite, ophiolite and granodiorite in Yukon: Evidence of arc-continent collision; Geological Survey of Canada Paper 79-14, 27 p.
1984: Geology of the Snag and Carmacks map sheets; Geological Survey of Canada, Open File 1101.

Tempelman-Kluit, D.J. and Wanless, R.K.
1975: Potassium- Argon age determinations of metamorphic and plutonic rocks in the Yukon Crystalline Terrane; Canadian Journal of Earth Sciences, v. 12, p. 1895-1909.

Turek, A., Riddle, C., and Smith, T.E.
1977: Determination of Rb and Sr by X-ray fluorescence in the measurement of radiometric ages; Canadian Journal of Spectroscopy, v. 22, No. 1, p. 20-24.

Weissberg, B.G.
1969: Gold-silver ore-grade precipitates from New Zealand thermal waters; Economic Geology, v. 64, p. 95-108.

Weissberg, B.G., Browne, P.R.C., and Seward, T.M.
1979: Ore metals in active geothermal systems, *in* Barnes, H.L. (ed.), Geochemistry of Hydrothermal Ore Deposits, Second Edition. John Wiley and Sons, New York, p. 739-780.

York, D.
1969: Least squares fitting of a straight line with correlated errors; Earth and Planetary Science Letter, v. 5, p. 320-324.

Yukon Exploration and Geology.
1983: Department of Indian and Northern Affairs, 317 p.

Role of structure in the emplacement of gold-quartz veins and rhyolite dykes at Freegold Mountain, Dawson Range, Yukon†

Brent I.A. McInnes[1], Wayne D. Goodfellow, and J.H. Crocket[2]
Mineral Resources Division

McInnes, B.I.A., Goodfellow, W.D. and Crocket, J.H., Role of structure in the emplacement of gold-quartz veins and rhyolite dykes at Freegold Mountain, Dawson Range, Yukon ; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 153-157, 1988.

Abstract

The Freegold Mountain area hosts several gold deposits which occur adjacent to the northwesterly trending Big Creek and Camp faults. Late Cretaceous rhyolite dykes and associated gold-quartz veins, e.g. the Laforma and Rambler deposits, have been emplaced in north-northeast-trending fault planes.

Two sets of fracture planes, oriented at 165°/70°E and 18°/80°W, show dextral and sinistral displacement, respectively. Rhyolite dykes and gold-quartz veins oriented predominantly north-northeast have been emplaced along the 18°/80°W extensional fracture systems. These fractures may be modelled as high-angle Reidel shears, although field measurements show that fracture orientations and fault movement have been complicated by changing stress fields from mid-Cretaceous to Tertiary time.

Résumé

La région de Freegold Mountain contient plusieurs gisements d'or qui se trouvent à côté des failles nord-ouest de Big Creek et de Camp. Des dykes de rhyolite de la fin du Crétacé et des filons de quartz aurifère associés, par exemple les gisements de Laforma et de Rambler, ont été mis en place dans des plans de failles orientés vers le nord-nord-est.

Deux ensembles de plans de fractures, orientés à 165°/70°E et 18°/80°W, montrent des déplacements respectivement dextres et sénestres. Des dykes de rhyolites et des filons de quartz aurifère orientés surtout nord-nord-est ont été mis en place le long des réseaux de fractures d'extension orientés selon 18°/80°W. Ces fractures peuvent avoir été modelées comme cisaillement de Reidel à angle élevé, bien que des mesures sur le terrain montrent que les orientations des fractures et le mouvement des failles ont été compliqués par un changement de champs de tension entre le milieu du Crétacé et le Tertiaire.

[1] Present address: Department of Geology, University of Ottawa, Ottawa, Ontario K1N 6N5
[2] Department of Geology, McMaster University, Hamilton, Ontario L8S 4M1
† Contribution to Canada-Yukon Mineral Development Agreement 1985-1989.

INTRODUCTION

The structural geology of the Freegold Mountain area is of interest in that most ore deposits, particularly vein deposits, are structurally controlled. Figure 1 shows the location of major structures and precious-metal-bearing veins and breccias in the Freegold Mountain area. The development of a gold deposit requires tremendous volumes of fluid flow to transport and deposit sufficient quantities of low solubility metals. Ground preparation by structural deformation is a prerequisite for the creation of high permeability, particularly in nonpermeable igneous rocks.

STRUCTURE

The orientation of known major fault structures in the study area are shown in Table 1.

The Big Creek fault has been documented by Tempelman-Kluit (1984) to cut through Big Creek Valley northwest of Freegold Mountain. The dextral displacement of a granite by this fault system is a minimum of 14 km. The fault has been interpreted by Tempelman-Kluit to bisect Freegold Mountain, although no physical evidence of such a major fault system was observed in the study area (Fig. 2 from McInnes et al., 1988). It is possible that the Camp fault is a splay or an offset extension (Sinclair et al., 1981) of the Big Creek fault and represents the plane of deformation in the Freegold Mountain area, although not enough data is available as to its sense of motion and displacement to verify this.

The Camp fault outcrops along the Freegold Mountain road just after the Laforma road turnoff (see McInnes et al., 1988, Fig. 2). The fault has brittely deformed the syenite, leaving it highly brecciated and friable. No markers have been identified to indicate the sense of displacement along this shear zone, but the occurrence of hornblendite on the south side of the fault zone suggests that some vertical movement has taken place, which has raised the cumulate zone of the syenite above the elevation of syenite to the north of the Camp fault. This evidence is speculative however since the cumulate hornblendite cannot be considered a well defined marker horizon.

Table 1. Orientation of major structural features at Freegold Mountain

Structure	Orientation	Direction and Displacement
Big Creek fault	130°	dextral, 14 km
Camp fault	130°	dextral?/vertical?
Pal fault	150°	dextral, 400 m
Laforma Vein/fault	22°	sinistral, 75 m
Rambler Vein/fault	32°	unknown

The Pal fault is a major structure against which the southern end of the Laforma vein ends abruptly. Rhyolite dykes near the Pal fault turn westward, parallel to the direction of fault movement. The dykes have intruded along curving splay fractures created during dextral movement on the Pal fault. Intrusion of rhyolitic magma into these fractures during faulting accounts for the lack of brittle deformation that would normally accompany drag folding.

In 1975, diamond drilling on the south side of the Pal fault intersected a quartz vein with mineralogy and gold grades similar to that of the Laforma Vein. This vein was interpreted to be the southern displaced portion of the Laforma Vein (Antoniuk, 1975). If so, about 400 m of dextral displacement has occurred on the Pal fault.

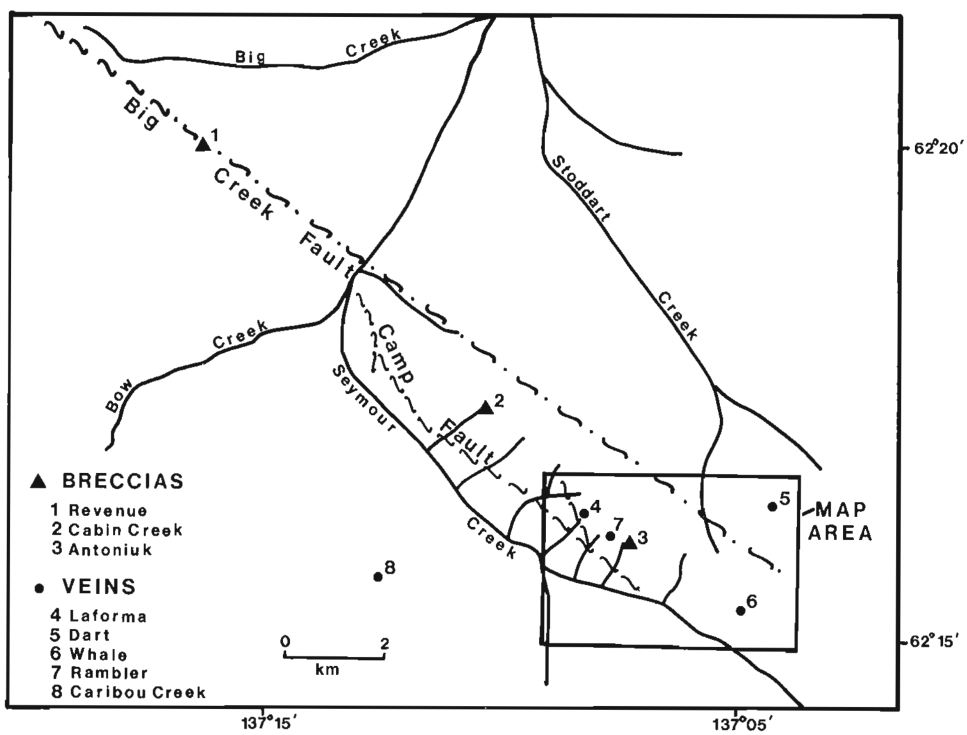


Figure 1. Location of gold-bearing veins and breccias with respect to major structural features.

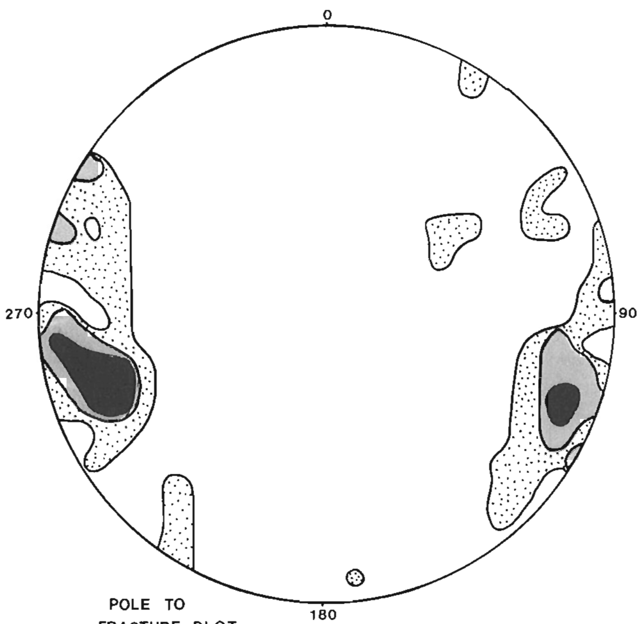


Figure 2. Pole to fracture plot of 139 fracture planes in study area.

The Laforma Vein was emplaced along a shear structure which has sinistrally displaced an andesite dyke (Beavan, 1963) about 75 m. The shear zone is highly brecciated, silicified and altered. Slickensides suggest that only strike-slip movement has occurred along this structure. The early, outer portions of the vein are sheared and the quartz is fractured and cemented by later silica. The later, central portion of the vein is characterized by inward-growing cockscomb quartz. Cockscomb texture is indicative of crystal growth in an open fissure and shows that extensional movement has also occurred on the Laforma fault.

Structural deformation in the study area

Figure 2 is a pole to fracture plot of 139 fracture and fault planes measured within the study area, the majority at outcrop scale. Figure 2 shows two distinct trends; a dominant orientation at 165/70E and a secondary trend of 18/80W. Figure 3 contains rose diagrams of dyke orientations within the study area. Figure 3A displays the cumulative orientation of 46 different dykes of varying composition. From this plot there are two principal directions, a north-northeast and a northeast trend. In order to characterize the structural control on dyke emplacement, rhyolite dyke orientations were measured. This places a temporal constraint on the structures studied since the timing of rhyolitic intrusion has been defined as Late Cretaceous (77.5 $\pm$ 6.2 Ma, McInnes et al., 1988).

Figure 3B is an isolated plot of rhyolite dykes within the Antoniuk Breccia, and it is apparent that a preferred orientation exists between 40° and 60°. These dykes are interpreted to have intruded through a semiconsolidated matrix of highly brecciated rock and therefore the alignment of the dykes within the breccia is probably dependent on the attitude of an inferred magma source below the breccia, and not controlled by regional stress conditions.

Figure 3C is a plot of remaining rhyolite dykes in the study area. These dykes show a dominant principal orientation between 0° and 20°, and two minor trends at approximately 100-120° and 140-160°. The orientation of dykes along a 0° and 20° trend, similar to the secondary fracture orientation on Figure 2, is interpreted to represent emplacement of rhyolites along secondary extensional fracture zones. Further evidence to suggest that extension occurs along these secondary fractures are the Laforma and Rambler gold-quartz veins (up to 2 m in width and displaying open-space filling textures) oriented at 22° and 32°, respectively. Furthermore, the permeability provided by extensional fractures and faults is a necessary prerequisite to fluid flow, mineral deposition and vein formation. On a more regional scale, rhyolite dykes emanating from the Nisling Range alaskite have a preferred northerly trend (Tempelman-Kluit, 1976). The similar orientation of rhyolite dykes at Freegold Mountain and the Nisling Range suggests a northerly oriented extensional fracture system may have persisted throughout the Dawson Range during Late Cretaceous to Tertiary in response to regional stress conditions.

Tensional and extensional processes operating in northern British Columbia (similar to those acting in Yukon) have been interpreted to have controlled northeast-trending normal block faulting (Gabrielse, 1985) and the emplacement of northerly trending lamprophyre dykes, and the peralkaline Stikine Lavas (Souther, 1977). Three occurrences of slickensides observed in the study area indicate that some fracture systems oriented north to northeast have had a vertical component of movement. Although no indication of the amount of displacement was evident, the presence of such features oriented north to northeasterly does indicate that block faulting may have occurred at Freegold Mountain.

Interpretation of structural deformation in the study area

Shearing within the competent rocks of the Freegold Mountain area has led to brittle deformation characterized by the abrupt offset of markers, and the occurrence of faults and fault breccias as defined by Ramsay (1980). Laboratory experiments conducted by Reidel in 1929 and later confirmed by Tchalenko (1968) using different material under brittle conditions, show that materials within a shear zone develop fracture systems in a systematic and orderly fashion. Figure 4a, redrawn from Roberts (1987) and O'Brien (1985), shows the orientation of shear fractures, and the direction of movement across them. The first fractures to form are the low-angle Reidel (R) and the high-angle Reidel (R') shears. The next to form are the reverse or pressure shears (P), followed by principal shear fractures (D). Extension fractures (T) are also formed during shearing. Their location is on a plane generally perpendicular to the X axis on a strain ellipsoid (principal stress direction = σ_1).

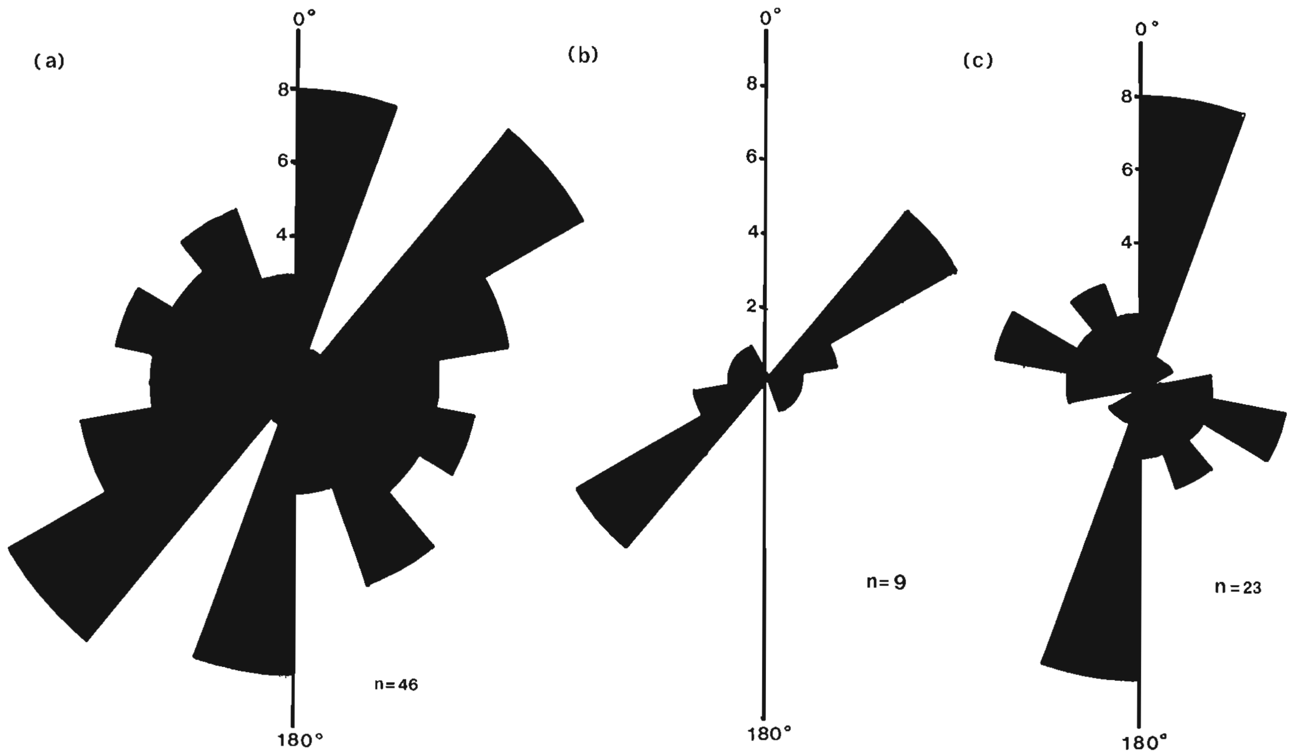


Figure 3. Rose diagrams of dyke orientations: (a) all dykes present in study area; (b) rhyolite dykes within Antoniuk Breccia; (c) rhyolite dykes in study area (excluding Antoniuk).

Since the Freegold Mountain area occurs between two megastructures where well documented shearing has occurred, it is possible that fractures and vein orientations within the area are controlled by conditions similar to those of the Reidel model. The area shows brittle deformation and shear development which would provide favorable conditions for Reidel shear development. Figure 4b shows the orientation of known fractures and shear fractures in the Freegold Mountain area. The Tintina fault and smaller faults in the area such as the Big Creek and Camp faults are designated as the major shear zone boundaries. The principal stress direction during Cretaceous deformation was 160° (Gabrielse, 1985). The orientation of fractures and shear zones in the Freegold Mountain area (Fig. 2; Table 1) do not compare favorably to a Reidel model of fracture orientation (Fig. 4a) since only one of the observed fracture orientations, at 18°, fits the predicted orientation of the high-angle Reidel shear fracture. Sinistral displacement along the Laforma vein/fracture system (which at 22°, represents the general 18 trend within error of measurement) is similar to that predicted by the model and may therefore be a high-angle Reidel fracture. None of the other observed shears, however, fit the model and it is possible that shearing at Freegold Mountain is not controlled by the Reidel model. The possible reasons for discrepancies between observed and predicted structures are:

1. The area between the principal bounding shear zones is too large to be modelled according to laboratory experiments.

2. A vertical component of movement along the shear zones affects the predicted orientation of fracture patterns.

3. Fracture patterns in the Freegold Mountain area are the result of non-uniform, continually changing stress conditions and do not reflect a state of constant deformation conditions.

4. Most of the stress is taken up along the major shear zones with low competency rocks and that the interior regions undergo a stress regime too low to produce Reidel shears.

The 18° fracture orientation is interpreted to have had both shear and extensional components and thus may represent a modified extension fracture (Fig. 4a). Fractures at 165° fracture orientation show dextral displacement and do not appear to be zones of major extension, although some dyke units do have this orientation. The Pal fault (150°) may be a member of this fracture family. If this is the case, then fractures and dykes with 165° orientation postdate those striking at 18°.

Gabrielse (1985) documented the change in general orientation of principal stress in the northern Cordillera using fold axes trends and the orientation of transcurrent faults in conjunction with their presumed ages. There appears to have been a change of σ_1 from northeast in pre-Albian time, to north-northwest in the middle Cretaceous, followed by north to northeast in Late Cretaceous to early Cenozoic time. If the Big Creek and Camp faults are subsidiary middle Cretaceous to Early Tertiary shear zones, parallel to the Tintina fault, they represent transcurrent faulting under a northwesterly principal stress direction. The timing of rhyolite dyke and vein emplacement along the 18° fracture orientation of Late

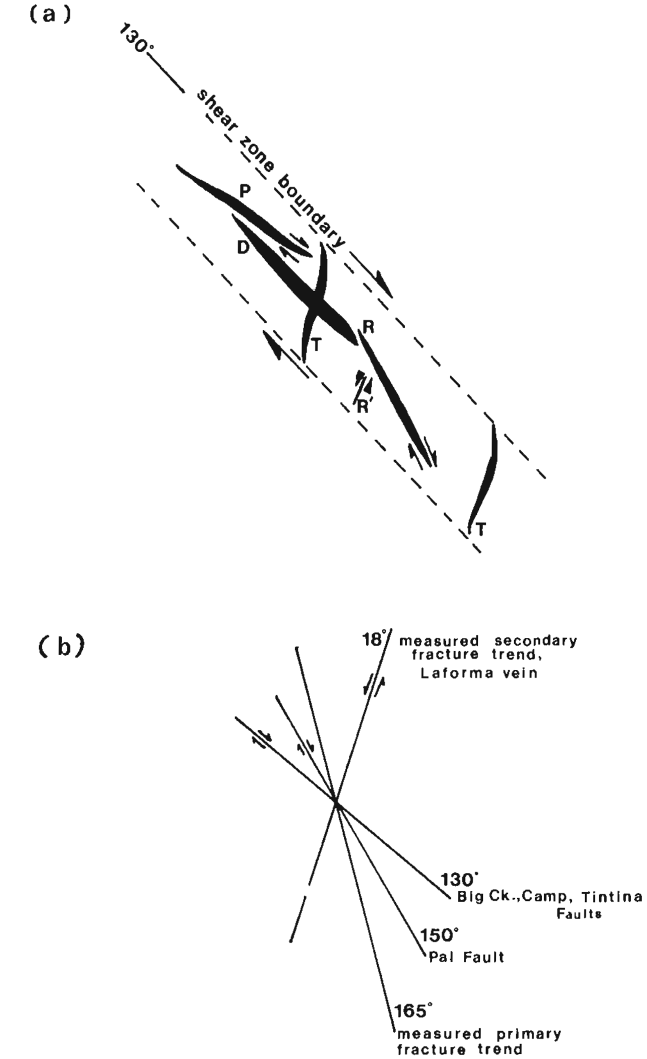


Figure 4 (a). Development of Reidel fractures in an area with shear zone boundaries (SZB) oriented at 130° (redrawn from Roberts, 1987); **(b).** Orientation of fracture planes and shear zones at Freegold Mountain.

Cretaceous (78 Ma) may represent regional σ_1 orientation to the northeast. Later offset of 18° fractures by movement on 165° fractures may have resulted from the reorientation of principal stress to a more northerly orientation.

Changing stress conditions through time may explain the orientation and crosscutting relationships of fracture zones observed in the study area, which are similar to those documented by Gabrielse (1985). The presence of non-unidirectional stress fields operating over long periods of time may explain why fracture orientations cannot be modelled as composite Reidel shears.

ACKNOWLEDGMENTS

We would like to acknowledge discussions with Lynn O'Donnell and Paul Clifford. Constructive criticism was provided by Dave Sinclair. We are grateful to Noreen Evans for drafting the figures. Logistical support for this field study was partly provided by Archer, Cathro and Associates Ltd., Whitehorse. This project has been supported financially by Yukon Mineral Development Agreement funds under the supervision of WDG and by NSERC Operating Grants to JHC.

REFERENCES

Antoniuk, T.
1975: A report on the 1975 diamond drilling program at the Laforma property, Mt. Freegold, Yukon. Private report, Rayrock Mines Ltd., *on file* Department of Indian and Northern Affairs, Whitehorse.

Beavan, A.P.
1963: Evaluation of Laforma Property, Ormsby Mines Ltd., Private Unpublished Report, Department of Indian and Northern Affairs, Whitehorse.

Gabrielse, H.
1985: Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia; Geological Society of America Bulletin, v. 96, pp. 1-14.

McInnes, B.I.A., Goodfellow, W.D., Crocket, J.H., and McNutt, R.H.
1988: Geological investigations at Freegold Mountain, Dawson Range, Yukon: Geology, geochemistry and geochronology of subvolcanic intrusions associated with gold deposits; *in* Current Research, Part E, Geological Survey of Canada Paper 88-1E.

O'Brien, B.H.
1985: The formation of veins in greenschist facies rocks and the early deformation of the Meguma Group, eastern Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 85-2, 35 p.

Ramsay, J.G.
1980: Shear geometry: a review; Journal of Structural Geology, v. 2, p. 83-99.

Roberts, R.G.
1987: Ore Deposit Models #11. Archean Lode Gold Deposits; Geoscience Canada, v. 14, no. 1, pp. 37-52.

Sinclair, W.D., Cathro, R.J., and Jensen, E.M.
1981: The Cash porphyry copper-molybdenum deposit, Dawson Range, Yukon Territory. Canadian Mining and Metallurgy Bulletin, v. 74, no. 832, p. 1-10.

Souther, J.G.
1977: Volcanism and tectonic environments in the Canadian Cordillera - a second look; *in* W.R.A. Barager, L.C., Coleman and J.M. Hall (eds.), Volcanic Regimes in Canada, Geological Association of Canada, Special Paper No. 16, p. 3-24.

Tchalenko, J.S.
1968: The evolution of kink-bands and the development of compressive textures in sheared clays; Tectonophysics, v. 6, p. 159-174.
1976: The Yukon Crystalline Terrane: Enigma in the Canadian Cordillera; Geological Society of America Bulletin, v. 87, p. 1343-1357.

Tempelman-Kluit, D.J.
1984: Geology of the Snag and Carmacks Map Sheets, Geological Survey of Canada, Open File 1101.

Conodont biostratigraphy of the Cache Creek Group in the Marble Range of south-central British Columbia

M.J. Orchard and J. Beyers[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Orchard, M.J. and Beyers, J., Conodont biostratigraphy of the Cache Creek Group in the Marble Range of south-central British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 159-162, 1988.

Abstract

Conodonts from the central and western belts of the group are Late Permian through Late Triassic in age; there are no limestones as old as the limestone olistolithes within the eastern belt of the Cache Creek Group, and no relationship between the two can be demonstrated. Upper Permian conodonts from the Marble Canyon Formation have Asiatic affinity. The age of the main limestone body extends into the Early Triassic in the north and therefore the limestone includes the Permian — Triassic boundary within it. Farther south, a transition from massive limestone to argillite occurs near the base of the Triassic. In the central and southern parts of the Marble Range, argillaceous Triassic sediments predominate, but clastic limestones are widespread and document a history of Triassic reworking.

Résumé

Les conodontes des zones centrale et occidentale du groupe datent du Permien supérieur au Trias supérieur. On ne trouve aucun calcaire aussi ancien que les olistolithes de calcaire de la zone est du groupe de Cache Creek, et aucune relation entre les deux ne peut être établie. Les conodontes du Permien supérieur de la formation de Marble Canyon ont une affinité asiatique. L'âge de la masse de calcaire principale remonte au Triassique inférieur dans le nord de sorte que le calcaire renferme la limite Permien-Trias. Plus au sud, il y a une transition du calcaire massif à l'argilite près de la base du Trias. Dans les parties centrale et méridionale du chaînon Marble, les sédiments argileux du Trias dominent, mais on trouve beaucoup de calcaires clastiques indiquant un remaniement du Trias.

[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

INTRODUCTION

This paper is a progress report on the study of conodont biostratigraphy of the Cache Creek Group in the Marble Range, south-central British Columbia. The Marble Range, located in Ashcroft and Bonaparte River map areas, forms the westernmost part of the Intermontane Belt. It is underlain largely by the Marble Canyon Formation (Duffell and McTaggart, 1952), which is synonymous with the central belt of the Cache Creek Group of Trettin (1980) and Monger and McMillan (1984). Fusulinids from the Marble Canyon Formation have 'Tethyan' affinity, which has led to the suggestion that the Cache Creek Group as a whole represents a far-travelled terrane accreted to Western North America.

The internal cohesion of the Cache Creek Group remains uncertain however, largely due to complex structure, poor outcrop, and limited fossil control. The discovery of conodonts (Orchard, 1981, 1984) and radiolarians (e.g. Cordey, 1986) in the Cache Creek Group provided the impetus to attempt to resolve the internal and external relationships of the group through detailed biostratigraphic research.

PREVIOUS WORK

Orchard (1984) summarized the conodont biostratigraphy of the eastern belt, or "melange unit" of the Cache Creek Group, partly based on the mapping of Shannon (1981). The chert/phyllite matrix of this belt includes Late Permian and Late Triassic conodont faunas, and radiolarians of Late and probable Middle Triassic age (Cordey, 1986). Carbonate olistoliths within the eastern belt are Late Pennsylvanian and Early Permian in age.

There is relatively little published paleontological data from the western belt of the Cache Creek Group per se. However, most sediments lying to the west of the Marble Canyon Formation, including the 'Pavilion beds', are Triassic in age (Rafek, *in* Trettin, 1980; Orchard, 1981).

The Marble Canyon Formation is well known for its Upper Permian fusulinids (*see* Trettin, 1980 for summary). Conodonts are generally uncommon in the limestone unit, particularly where fusulinids are abundant. Published accounts of other microfossils from the central belt of the Cache Creek Group are of Early and Late Triassic conodonts (Orchard, 1984) and Middle to Late Triassic radiolarians (Cordey, 1986).

CONODONT BIOSTRATIGRAPHY IN THE MARBLE RANGE

Recent work on the Cache Creek group has focused on four main localities (Fig. 1), from north to south: the Jesmond area (A), Pavilion Mountain (B), Marble Canyon (C) and Cornwall Hills (D). Each of these areas were known to contain productive lithologies from the reconnaissance sampling of K.R. Shannon, M.J. Orchard and N.M. Mortimer. During 1986 and 1987, about 300 samples were collected for conodont processing and of those processed, over one half have yielded conodonts.

A. Jesmond area

Limestone outcropping along the Jesmond fire-lookout access road is slightly to strongly recrystallized, and commonly dolomitized. Two separate sequences are recognized. The lower consists of at least 35 m of poorly bedded, partly silicified, dark grey limestone in which small, disarticulated crinoid stems are the only recognizable macrofossils. This limestone contains a Late Permian conodont fauna dominated by *'Diplognathodus' (?Iranognathus)* and *Hindeodus*, with fewer *Neogondolella*. The precise age of this fauna is uncertain because the principal elements of the fauna are new to North America. However, comparisons with successions in Transcaucasia and China suggest a very young Permian age.

The upper sequence, which is separated from the Permian section by non-exposure, comprises 84 m of almost flat lying, generally well-bedded, pale grey to white-weathering micrite. Some beds include algal laminates but other macrofossils are rare. Two conodont faunas are recognized in the upper sequence. An older fauna consists of relatively large and robust ramiform elements tentatively referred to *Ellisonia*, a genus that ranges through both the Permian and Triassic. Higher strata contain *Neospathodus* species of Early Triassic age.

B. Pavilion Mountain

Outcrop along the road to Pavilion Mountain includes central belt carbonates that are strongly recrystallized or metamorphosed to marble. Farther west, argillite is common and in places contains interbedded carbonate and limestone clasts. A carbonate interbed from a 42.5-m section, has yielded Late Triassic conodonts, whereas limestone clasts within the same section contain Early Triassic conodonts. This relationship suggests that Early Triassic strata were reworked during the Late Triassic.

C. Marble Canyon

The first account of conodonts from the Cache Creek Group was based on a locality in Marble Canyon (Orchard, 1981). This fauna was remarkable in providing the first record of Early Triassic strata in the entire Canadian Western Cordillera. It remains the richest, and perhaps the oldest, Triassic faunule recovered to date, and the only one in which elements of Permian aspect are also known. One of these Permian elements corresponds to the *'Diplognathodus'* that occurs at Jesmond. As noted by Orchard (1981), in the area of Marble Canyon, reworking of Permian limestones during the Early Triassic is implied. The Early Triassic sediments, which are dominantly argillites with thin black limestone interbeds, lie adjacent to massive Permian limestone and were formerly regarded as part of the Marble Canyon Formation. Late Triassic Strata outcropping farther to the west (MaCal *in* Orchard, 1981) are siliceous limestones that yield Late Triassic conodonts.

Permian conodont data from this area are sparse, but particularly interesting since the classic locality for *Yabeina* occurs nearby. Conodonts from within the main body of the Marble Canyon Formation near the Hat Creek road (Fig. 1) include *'Sweetognathus'* in association with Late Permian *Neogondolella*. The relationship of the former to the Early

Permian sweetognathids that are well known in western North America (including the Harper Ranch Group of Quesnel Terrane) is uncertain, but we suspect that the form evolved iteratively from diplognathodids by broadening of the carinal nodes. Similar *'Sweetognathus'* have not been described from North America but they do occur throughout the Late Permian shelf areas of Asia.

D. Cornwall Hills

Outcrop at Cornwall Hills has been included within the Marble Canyon Formation by Monger and McMillan (1984). The sediments exposed along the road to the lookout are extremely variable, consisting of grey radiolarian chert, carbonaceous tuff, mafic volcanics, dolomitized and recrystallized carbonate, and oolitic and brecciated limestones. One conodont faunule collected by K. Shannon from a limestone near the summit of Cornwall Hills contains *Epigondolella* and is thus Late Triassic (Orchard, 1984), but nearby a limestone conglomerate containing large clasts of oolitic limestone produced Early Triassic *Neopathodus* and a single specimen of *Platyvillosus* (unrecorded elsewhere in Western Canada). Other outcrops in this area expose mainly argillite and vocaniclastic material in which limestone clasts are common. As in the Pavilion Mountain area, these clasts sometimes include Early Triassic conodonts, but associated matrix has yet to be dated. Thin bedded limestones associated with argillites in the same area are both Early and Late Triassic in age, and bedded radiolarian chert is dated as Middle Triassic.

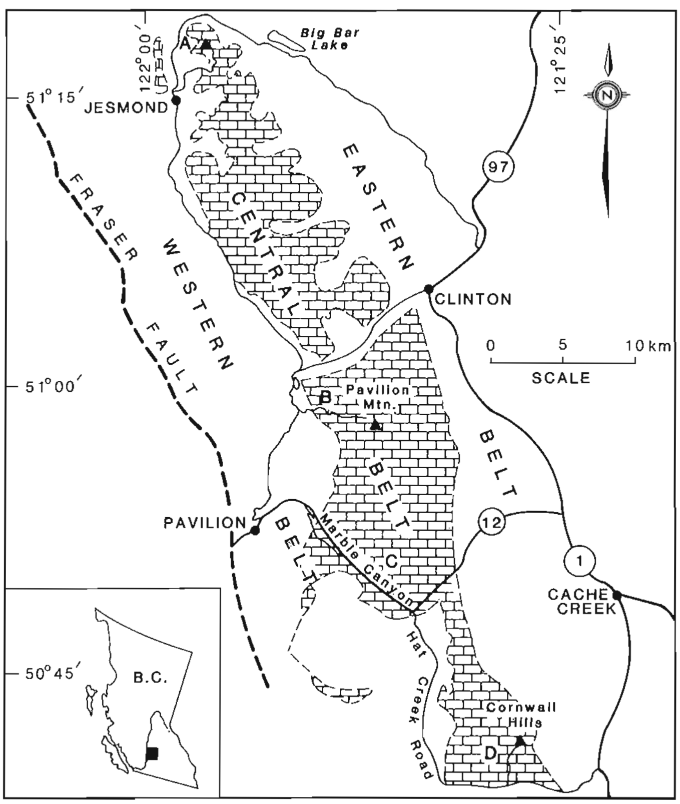


Figure 1. Outline map of the Cache Creek Group in Ashcroft and Bonaparte River map areas showing the location of principal localities mentioned in the text (based largely on Trettin, 1980).

CONCLUSIONS

1. Upper Permian conodonts from the Marble Canyon Formation are unlike those described elsewhere in North America, but are similar to forms known in Asia: Upper Permian *'Sweetognathus'*, typical of sequences in China, occurs in association with the Tethyan fusulinid *Yabeina*. Additional *'Diplognathodus' (?Iranognathus)* species are also new to North America.

2. Lower Triassic limestone overlies Upper Permian limestone at the north end of the Marble Range near Jesmond: the Permian — Triassic boundary therefore falls within the Marble Canyon Formation. In contrast, farther south in the Marble Canyon area, the boundary appears to be marked by an abrupt facies change, and there is some evidence that Late Permian conodonts were reworked during the Early Triassic.

3. Conodont-based correlations reveal that significant facies variations occur within the Cache Creek Group. Lower Triassic sediments in the central and western belts include thick algal limestones, argillites with thin black carbonates, coarse clastic limestone including oolitic limestone clasts, and volcaniclastics. Middle and Late Triassic sediments are chert, argillite and minor limestone, some of which appear to be reworked.

4. No pre-Upper Permian limestone source beds for the carbonate olistoliths of the eastern belt of the Cache Creek Group are identified in the Marble Canyon Formation. The possibility that the adjacent Quesnel Terrane to the east is the source of the olistoliths is given credence by the occurrence of coeval and conspecific Early Permian conodonts in both the olistoliths and the Harper Ranch Group, the Paleozoic basement of Quesnel Terrane (Orchard, 1987).

ACKNOWLEDGMENTS

Some of the costs of Beyers fieldwork and research were bourne by an NSERC Operating Grant. N. Mortimer is thanked for guiding us in the Pavilion area. We thank B. Forman, P. Forster, T. Dickey and R. Manley for assistance in the field. Christine Davis drafted Figure 1.

REFERENCES

Campbell, R.B. and Tipper, H.W.

1971: Geology of Bonaparte Lake map-area, British Columbia; Geological Survey of Canada, Memoir 363.

Cordey, F.

1986: Radiolarian ages from the Cache Creek and Bridge River complexes and from chert pebbles in Cretaceous conglomerates, southwestern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 595-602.

Duffell, S. and McTaggart, K.C.

1952: Ashcroft map-area, British Columbia; Geological Survey of Canada, Memoir 262.

Monger, J.W.H. and McMillan, W.J.

1984: Bedrock geology of Ashcroft (92I) map area; Geological Survey of Canada, Open File 980.

Orchard, M.J.
1981: Triassic conodonts from the Cache Creek Group, Marble Canyon, southern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 357-359.
1984: Pennsylvanian, Permian and Triassic conodonts from the Cache Creek Group, Cache Creek, southern British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 84-1B, p. 197-206.
1987: Conodont biostratigraphy and correlation of the Harper Ranch Group (Devonian — Permian), Ashcroft map area, southern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 743-749.

Shannon, K.R.
1981: The Cache Creek Group and contiguous rocks near Cache Creek, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 217-221.

Trettin, H.P.
1980: Permian rocks of the Cache Creek Group in the Marble Range, Clinton area, British Columbia; Geological Survey of Canada, Paper 79-17.

Northern Porcupine Creek anticlinorium and footwall of the Purcell Thrust, Northern Park Ranges, B.C.

G.A. Klein[1] and E.W. Mountjoy[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Klein, G.A. and Mountjoy, E.W., Northern Porcupine Creek anticlinorium and footwall of the Purcell Thrust, Northern Park Ranges, B.C.; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 163-170, 1988.

Abstract

The Purcell thrust fault emplaces a far-travelled structural slice of Precambrian basement gneisses and their possible cover rocks over Hadrynian Miette through Middle Cambrian strata of the Chatter Creek thrust sheet on the west limb of the Porcupine Creek Anticlinorium. The Porcupine Creek Anticlinorium and the Baker Glacier Syncline, two broad, open folds are the dominant structural elements in the footwall of the Purcell thrust fault, south of Hugh Allan Creek.

About 3100+ m of middle and upper Miette are involved in the core and flanks of the Porcupine Creek Anticlinorium. The Gog Group is about 1000 m thick on the west flank of the Porcupine Creek Anticlinorium but decreases to 700 m on the west flank of the Baker Glacier Syncline. It is overlain by up to 2000 m of massive Middle Cambrian carbonates in the southwestern part of the area.

Metamorphic grade rises westward from greenschist grade to amphibolite grade with kyanite-staurolite-bearing assemblages.

Résumé

La faille de charriage de Purcell met en place une tranche structurale lointaine de gneiss du socle précambrien et sa roche de couverture possible sur des couches de l'Hadrynien-Miette au Cambrien moyen de la nappe de charriage de Chatter Creek sur le flanc ouest de l'anticlinorium de Porcupine Creek. L'anticlinorium de Porcupine Creek et le synclinal de Baker Glacier, deux larges plis ouverts, sont les éléments structuraux dominants dans l'éponte inférieure de la faille de charriage de Purcell, au sud du ruisseau Hugh Allan.

On trouve environ 3100+ m de la formation tant moyenne que supérieure de Miette dans le noyau et les flancs de l'anticlinorium de Porcupine Creek. Le groupe de Gog a environ 1000 m d'épaisseur sur le flanc ouest de l'anticlinorium de Porcupine Creek, mais cette épaisseur diminue à 700 m sur le flanc ouest du synclinal de Baker Glacier. Il est recouvert d'une épaisseur allant jusqu'à 2000 m de carbonate massif du Cambrien moyen dans la partie sud-ouest de la région.

Les qualités des roches métamorphiques augmentent vers l'ouest d'une qualité schiste vert à une qualité amphibolite avec des assemblages contenant de la kyanite-staurolite.

[1] Department of Geological Sciences, McGill University,
3450 University Street, Montreal, Quebec H3A 2A7

INTRODUCTION

The study area (Fig. 1) forms a part of the Western Main Ranges and is bounded to the west by the Rocky Mountain Trench a major physiographic and structural feature which marks the boundary between the Western Main Ranges to the east and the Omineca Crystalline Belt to the west. It is accessible by helicopter from Valemount 70 km to the northwest.

Previous work in the area includes reconnaissance mapping by Campbell (1968), and by Price and Mountjoy (1970) (Operation Bow-Athabasca) and M.Sc. thesis research and mapping by Craw (1977), Leonard (1985) and Oke (1982).

Field mapping in 1986 and 1987 was at a 1:50 000 scale.

The Porcupine Creek Anticlinorium (PCA), a major regional structure, extends through the study area and appears to terminate either just south or north of Hugh Allan Creek. The study of the evolution of this structure is one of the principal objectives of the present project. Previous research on the Porcupine Creek Anticlinorium to the south of the study area includes the works of Balkwill (1972), Craw (1977), Ferri (1984), Gardner (1977), and Mielliez (1972).

STRATIGRAPHY

The area is underlain by Hadrynian to Cambrian Miette and Gog Group and unnamed Middlle Cambrian strata (Fig. 2). The exposed stratigraphic sequence is about 5000 m thick.

Miette Group

Middle Miette

In this area the upper Miette and only the upper part of the middle Miette outcrop. A minimum of 1500 m of middle Miette strata occur on the flanks and in the core of the PCA but only the uppermost 600 to 800 m are well exposed as compared to about 2500 m exposed immediately north of Hugh Allan Creek (Mountjoy and Forest, 1986). Typical middle Miette Group strata consist of 20-100-m-thick composite grit units and interbedded green or grey pelites and slates. A typical individual grit unit is characterized by basal, unsorted pebble conglomerates grading upward into medium- to coarse-grained psammites. Graded beds provide useful way-up criteria.

The uppermost 100-200 m are transitional to the upper Miette Group with pelites, semipelites and psammites increasing upsection.

A reddish calcareous grit-psammite unit (about 20-40 m thick) interbedded with green semipelites and psammites is exposed on two ridges on the west flank of the PCA about 1000 m below the top of the middle Miette (Marker "B" in Fig. 2, 4b). A second marker is a brownish sandy carbonate that occurs within a 100-m-thick green pelite about 1500 m below the top of the middle Miette (Marker "A"). Another carbonate marker occurs on the faulted northeast limb of the PCA (Marker "C"). Its exact stratigraphic position is not certain but could be a lower lateral equivalent of Marker "B". It consists of 2-3 m of black micritic limestone laterally alternating with brown dolomitic sandy carbonate. It is associated with a thick green pelite and a black pelite with abundant pyrite porphyroblasts. Markers C and B appear to correlate with the widespread carbonate that occurs in the upper part of the middle Miette to the north.

Upper Miette Group

A continuous 1650-m-thick section of upper Miette Group exposed on the west flank of the PCA was measured in detail, and is divisible into four units. The structural deformation in this section is minor. The basal unit consists of 580 m of monotonous grey, brown weathering pelites. Towards the top are minor beds of psammites, semipelites and sandy carbonates. A second unit consists of 440 m of grey limestones, sandy dolomitic carbonates, calcareous pelites and grits. A third unit includes about 360 m of grey, brown weathering chloritoid and/or garnet slates and schists. The uppermost unit, 270 m thick, is characterized by the first appearance of quartz sandstones in the upper Miette Group. It consists of brown weathering interbedded pelites and quartzites. The proportion and thickness of quartzites increase upwards.

Gog Group

A 1200-m-thick sequence on the west flank of the PCA is assigned to the Lower Cambrian Gog Group on the basis of a lithologically distinct three-fold division, relative thicknesses and stratigraphic position above the upper Miette. No fossils were found in this sequence due to the high grade of metamorphism. The lowest unit has a minimum thickness of 800 m and consists primarily of quartzites and is assigned to the McNaughton Formation. It is overlain by carbonates, pelites and quartzites of the Mural Formation which in turn are overlain by quartzites of the Mahto Formation.

The predominant lithology of the McNaughton Formation is a medium- to coarse-grained, light coloured, cross-bedded quartzite. Greenish, reddish and black sands and minor recessive pelitic horizons are also present. The contact with the underlying upper Miette Group is apparently conformable and was placed at the first thick light grey quartzite, which at a distance is easily distinguished from the more brownish weathering interbedded quartzites and pelites of the upper Miette Group. The McNaughton Formation thins rapidly westward from a minimum of 800 m on the west flank of the PCA to about 360 m in the core and on the west flank of the Baker Glacier Syncline (Fig. 4a, 4b).

The overlying Mural Formation is a relatively incompetent horizon sandwiched between two competent units that has experienced intense ductile folding. Its thickness varies between 50 and 120 m. It is mainly interbedded carbonates, calcareous pelites, pelites, quartzites and two distinct mappable coarsely crystalline, grey marbles each between 10 to 25 m thick.

The Mahto Formation varies between about 180 and 250 m. It is formed by brown weathering, slightly recessive, well-bedded quartzites and thinner interbeds of dolomitic sandy carbonates.

Middle Cambrian (?) carbonates

More than 2000 m of mainly massive carbonates and subordinate pelites conformably overlie Mahto strata in the Baker Glacier Syncline, south of Baker Creek. A basal 200 m thick argillaceous unit was observed and may correlate with the Tsar Creek argillite first recognized by Fyles (1960). It consists of light yellow, fissile pelites, semipelites and carbonates. The basal unit is overlain by a 700- to 800-m-thick sequence of alternating 10- to 70-m-thick bands of: 1) brown-weathering, thinly interbedded black carbonate, dolomitic and pelitic layers; and 2) massive grey or white marbles. These lithologies are similar to the ones described by Craw (1977) as the Kinbasket Formation. South of Dawson Creek this sequence is overlain by massive, cliff-forming, light brown or grey carbonates at least 1000 m thick. The whole sequence is stratigraphically equivalent to but differs lithologically from the Middle Cambrian Chancellor Group

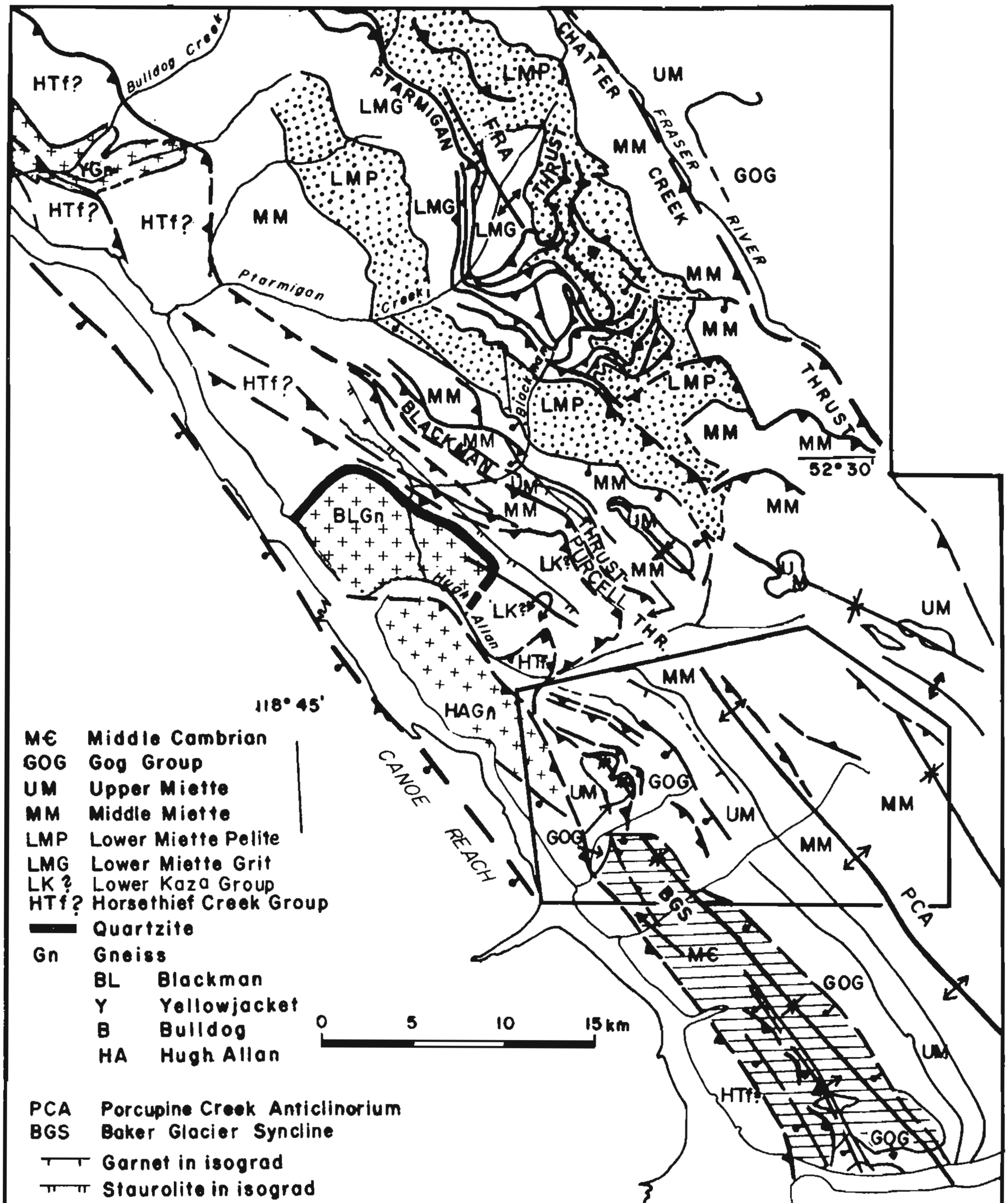


Figure 1. Regional compilation map of the Park and Selwyn Ranges, B.C., with location of the study area. Information modified from Mountjoy and Forest (1986) and Craw (1977).

exposed along strike to the southeast. These massive cliff-forming marbles are more characteristic of the Middle and Upper Cambrian carbonate formations of the eastern Main Ranges. The change from carbonate to shale facies marks the western margin of an extensive carbonate platform termed the Kickinghorse Rim by Aitken (1971). This platform margin trends more westerly and is oblique to the northwest structural trend. The facies change observed near the Wood River fits the trend and appears to be the continuation of this platform margin.

STRUCTURE

The structure in the Chatter Creek thrust sheet is dominated by two major elements which are from east to west: the Porcupine Creek Anticlinorium (PCA) and the Baker Glacier Syncline (BGS). The Purcell thrust forms the western boundary of the Chatter Creek thrust sheet (see Fig. 1, 3, 4a, 4b). This fault was previously mapped by Price and Mountjoy (1970), Leonard (1985), and Mountjoy and Forest (1986) (see Mountjoy, 1988 further details).

Porcupine Creek Anticlinorium

The east flank of the PCA is formed by an east-dipping (30°-40°) panel of middle Miette Group strata (Fig. 2c). The structure is characterized by open, upright northeast-verging folds and northeast-dipping thrust faults of small displacement. The core of the PCA is structurally complicated (Fig. 4b). Two west-dipping thrust faults are clearly related to the tightening of the large-scale upright folds. Overturning of folds and thrust faults associated with the Porcupine Creek Anticlinorium has been documented in several studies to the south (Balkwill, 1972; Gardner, 1977; Ferri, 1984; and Craw, 1977). In the study area minor overturning of structures was observed only in some locations in the core and does not appear to be as significant as it is to the south. The displacements on thrust faults in the core of the PCA are uncertain. If the correlation of middle Miette carbonate markers in the core is correct displacement was minor.

Middle Miette Group, upper Miette Group and Gog Group strata occur on the west flank of the PCA which is characterized by steeper dips (about 50-60°) and intense, localized bedding parallel shear. Large-scale folds and faults in the exposed middle and upper Miette Group strata are minor.

Three foliations are present across the PCA (Fig. 5). 1) A penetrative cleavage (S3) is developed as a slaty cleavage in pelitic units and as a fracture cleavage in more competent lithologies such as grits and psammites. It is axial planar or fanned with respect to the prominent northeast-verging folds (F3). 2) Southwest- and northeast-dipping crenulations overprint the penetrative cleavage, the southwest-dipping one being better developed and more common. 3) "Late" northeast-verging tight kink folds associated with southwest-dipping axial planar crenulations were observed in upper Miette Group rocks on the west flank of the PCA.

Further mapping is required to determine whether the Porcupine Creek Anticlinorium can be correlated with an anticline recognized by Leonard (1985) north of Hugh Allan Creek. See Mountjoy (1988) for interpretations and problems concerning the continuity of these structures and the Blackman thrust across Hugh Allan Creek. A possible southeast continuation of the Blackman thrust is the Fort thrust (Figs 3, 4b).

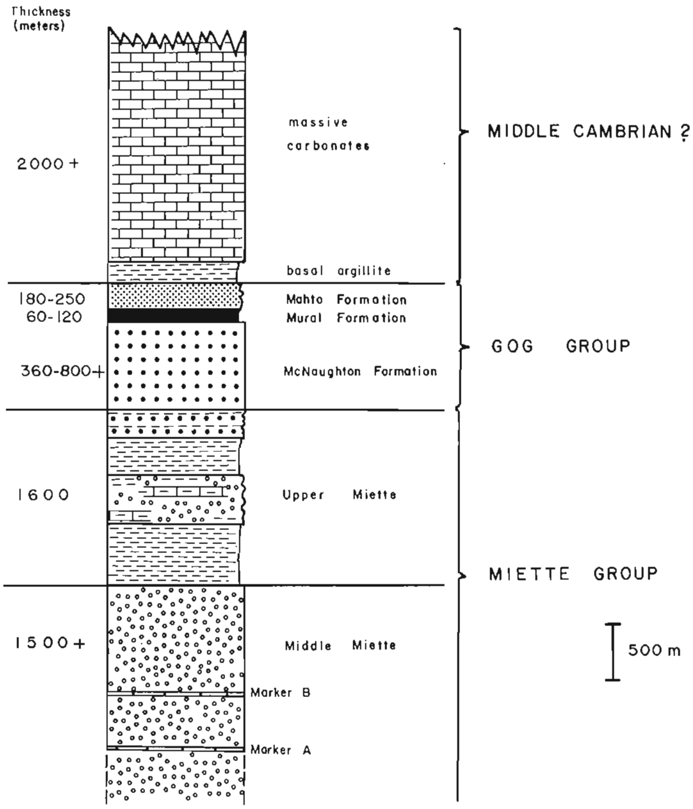


Figure 2. Composite stratigraphic column (note: maximum thicknesses are shown).

Thrusts on the west flank of the PCA

Four southwest-dipping thrust faults separate the west flank of the PCA from the Baker Glacier Syncline, north of Baker Creek (Fig. 4a). These are from east to west: Peak thrust, Little Peak thrust, Crevasse thrust and Gusty thrust faults (these names are informal). The total displacement on these faults is about 3.6 km. The Peak thrust juxtaposes a complexly folded and faulted slice of McNaughton quartzite over relatively undeformed southwest-dipping McNaughton and Mural strata. Displacement on this fault is about 2 km as measured on cross-section A-B (Fig. 4a). Small-scale structures observed in the hanging wall differ from the footwall. A near bedding-parallel tectonic shear fabric occurs in a local, narrow zone in the hanging wall quartzites and has caused significant stretching of quartz pebbles. This fabric is folded by small-scale southwest-verging recumbent folds. The timing relationships between these fabrics and the foliations observed in the remainder of the study area are uncertain.

The Little Peak thrust has a displacement of about 0.5 km and it carries a slice of southwest-dipping McNaughton, Mural and Mahto strata over McNaughton quartzites. Thrust faulting appears to be related to tightening and breaking up of large-scale upright folds. To the west, the Crevasse thrust fault carries a complexly folded and faulted slice of McNaughton, Mural and Mahto strata. It has an approximate displacement of 1 km. The lower part of this slice consists of a series of small southwest-dipping (50-70°) thrust faults spaced about 50 m apart with offsets on the order of 10-20 m. These faults involve the uppermost McNaughton quartzites and the lower pelitic horizon of the Mural and appear to be rooted in several large-scale upright to recumbent, open to isoclinal folds outlined by the lower Mural Marble.

Baker Glacier Syncline

This syncline was previously mapped by Price and Mountjoy (1970) and Craw (1977). North of Baker Creek upper Miette Group through uppermost Gog Group strata occur in the core and the west flank of this structure (Fig. 4a). The

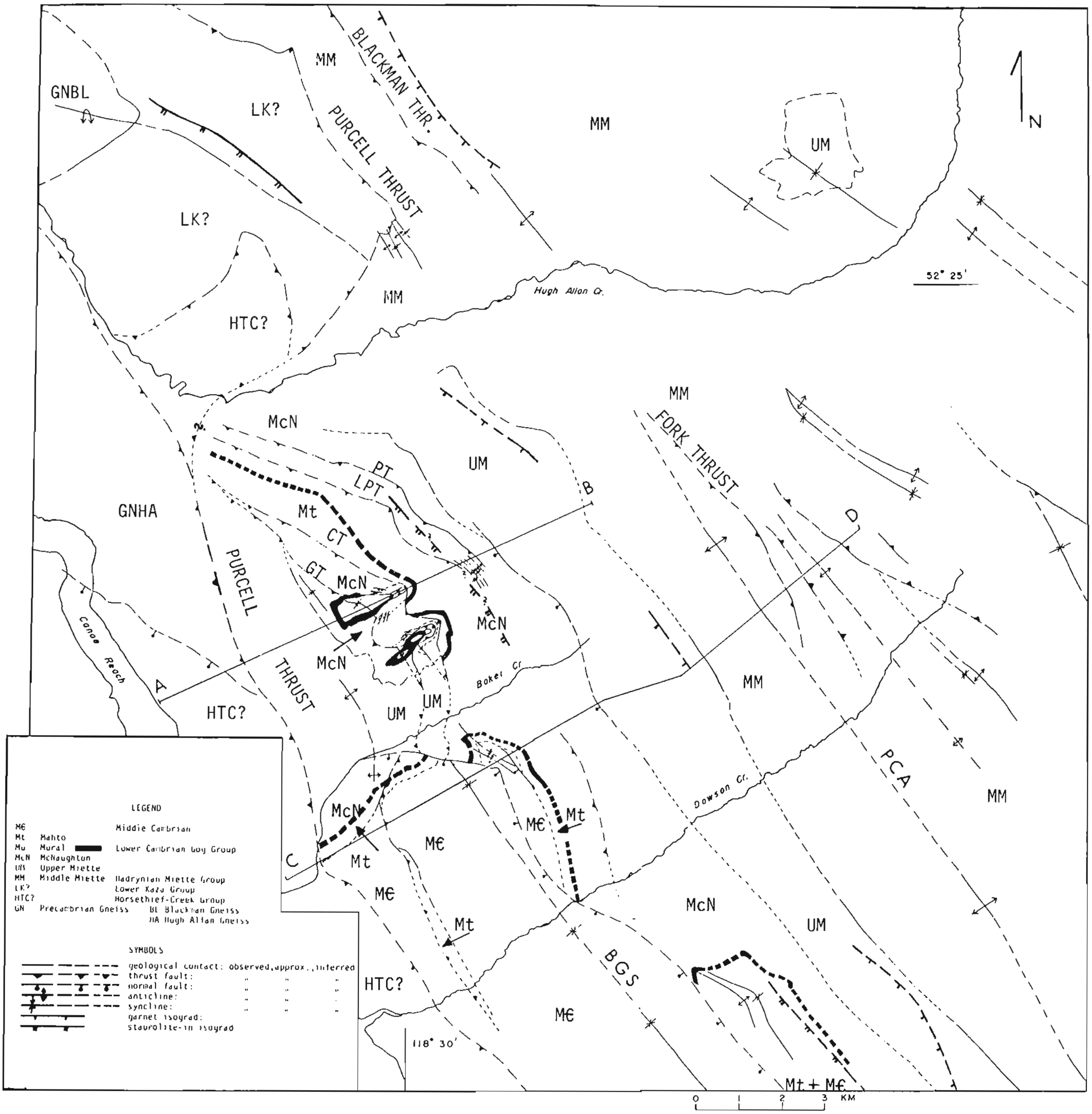


Figure 3. Detailed geology of the northern Park Ranges, British Columbia, compiled from unpublished Bow-Athabasca data and Craw (1977), Leonard (1985), and Oke (1982). PT — Peak Thrust, LPT — Little Peak Thrust, CT — Crevasse Thrust, GT — Gusty Thrust.

structure to the south of Baker Creek changes drastically (contrast Fig. 4a and 4b). South of Baker Creek the predominant structure is a southwest-dipping normal fault which cuts the east flank of the syncline and downdrops a thick section of Middle Cambrian(?) carbonates on the west against Gog Group strata on the west. Smaller normal faults are common in both the hanging wall and the footwall. Only one of the four thrust faults present to the north of Baker Creek could be mapped southward and it appears to merge with the normal fault. This may indicate that this thrust was utilized by the later normal fault giving a possible explanation for its relatively low dip. A gentle (20-30°), northeast-dipping thrust fault with a displacement of about 300 m cuts a broad anticline immediately west of the Baker Glacier Syncline. On a large scale the underlying upper and middle Miette Group layers do not appear to be significantly disrupted by the observed faults.

The earliest foliation observed across the BGS is a near bedding parallel schistosity (S1). It is best developed in pelites and calcareous pelites and prominent porphyroblasts that lie in this schistosity are muscovite, biotite and calc-silicates. No associated folds were observed. The schistosity is folded by northeast-verging recumbent and upright folds (F2 and F3) with associated crenulations. Fracture and solution cleavages (F3) are locally developed in quartzites and marbles respectively.

Purcell thrust

The Purcell thrust juxtaposes the Hugh Allan gneiss and possible Horsethief-Creek Group strata onto the west flank of the Baker Glacier Syncline (Fig. 2a). To the north of Hugh Allan Creek the fault carries the Blackman Anticline with the Blackman gneiss and Hadrynian cover rocks over middle Miette Group grits of the Blackman thrust sheet. The fault zone is covered along and to the south of Hugh Allan Creek. Strongly sheared grits assigned to the upper Miette Group were observed in one locality in the immediate footwall of the Purcell thrust south of Hugh Allan Creek. This fabric might reflect high strain conditions related to the emplacement of the Purcell basement thrust sheet. Similarly the shear fabric observed in the hanging wall of the Peak thrust may

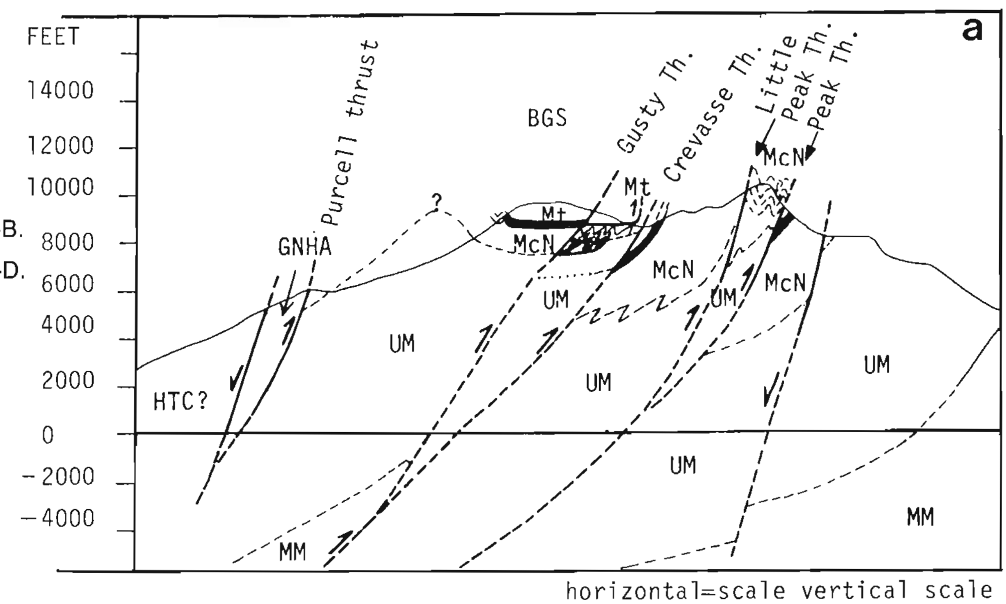
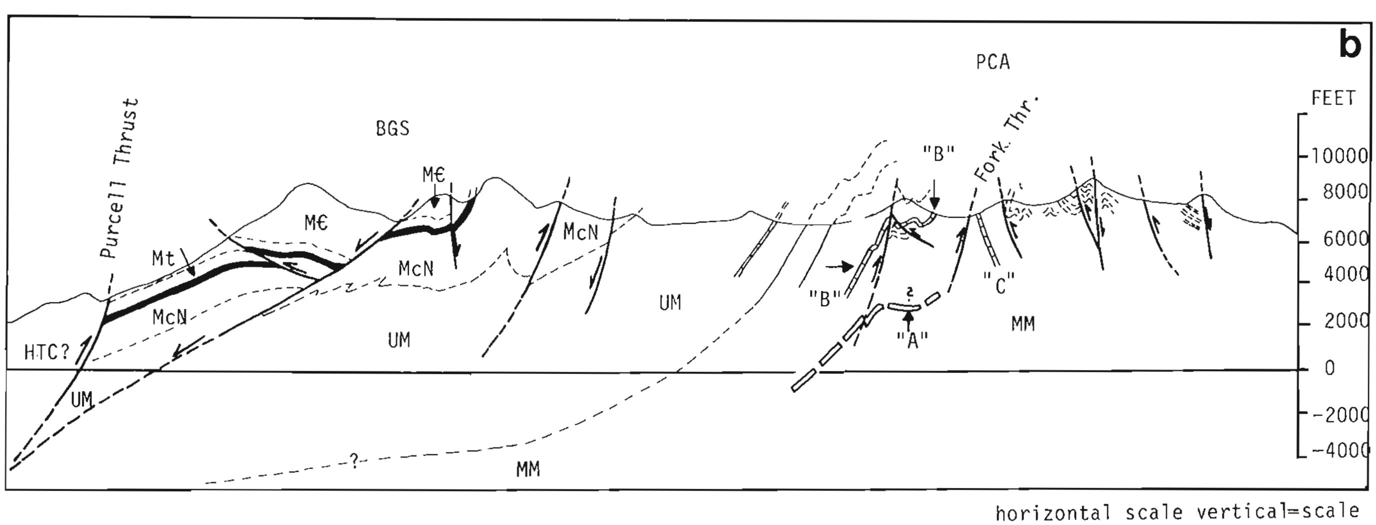


Figure 4

(a) Cross-section along line A-B.

(b) Cross-section along line C-D.



be the result of movement along the Purcell fault. No evidence for ductile deformation such as mylonitic fabrics were observed. The staurolite-in isograd is offset about 4 km by the Purcell thrust along Hugh Allan Creek. This indicates at least some post-metamorphic movement along this fault (see Mountjoy, 1988).

Late structures

Transverse foliations near the Rocky Mountain Trench have been noted previously by Forest (1985), Leonard (1985) and McDonough (1984), among others. A northwest-dipping crenulation cleavage (St) strikes about 075° in the study area. It was observed from the Rocky Mountain Trench up to 15 km to the east occurring on the east flank of the PCA. This foliation crenulates the penetrative cleavage (F3). The timing relationship to F4 is not known.

SUMMARY AND CONCLUSIONS

Five deformational events are superimposed in the study area (Table 1). The structure is dominated by the Porcupine Creek Anticlinorium and the Baker Glacier Syncline which are large F3 structures that were probably initiated during F2. The penetrative cleavage, a conjugate set of crenulations (both considered S3 in this study) and thrust faults are related to the progressive deformation of these structures. Folds and foliations produced in the early stages of formation were tightened and rotated during later stages and overprinted by younger foliations. However no significant overturning was produced. The very tight folds and associated thrust faults observed between the Porcupine Creek Anticlinorium and the Baker Glacier Syncline north of Baker Creek appear to die out southward suggesting that these structures may be related to the movement on the Purcell thrust.

Mapping along Hugh Allan Creek confirmed the presence of the Purcell thrust which separates two distinctly different stratigraphic and structural units. The earliest deformation resulted in detachment of cover from basement. If indeed the strata above the Blackman gneiss are Lower Kaza Group and if a thick Horsethief Creek sequence underlies the Kaza Group as has been suggested this requires the tectonic removal of underlying Horsethief Creek strata. Initially the Purcell thrust transported the Hugh Allan and Blackman gneisses and overlying strata a considerable distance eastwards onto Western Main Ranges middle Miette through Middle Cambrian strata. Renewed motion on the fault was minor and post-metamorphic (Mountjoy, 1988).

Several important problems remain to be solved in this area such as: 1. the nature of the heat source that produced the high grade metamorphism in the footwall of the Purcell fault. 2. The stratigraphic position of possible Lower Kaza strata overlying the Blackman gneiss. 3. The origin of the right angle bend of the Purcell thrust along Hugh Allan Creek. 4. The origin of the early bedding parallel schistosity S1 and the northwest dipping transverse crenulation St.

Table 1. Structural summary

Fold phase & foliations	Structural Domaines — West — Baker Glacier Syncline (BGS)	Porcupine Cr. Ant. (PCA) — East
S1		
F2 — S2	X	
F3 — S3	X	X
F4 — S4		X
Ft — St	X	X

Explanation:

S 1 =	— bedding — parallel schistosity
F 2 =	— northeast-verging, isoclinal, recumbent folds — first thrusting event
S 2 =	— axial planar southwest-dipping crenulations
F 3 =	— northeast-verging open, upright folds — second thrusting event
S 3 =	— penetrative cleavage (slaty, fracture or solution) — southwest-dipping crenulation — northeast-dipping crenulation
F 4 =	— northeast-verging kink folds
S 4 =	— axial planar southwest dipping crenulations
S t =	— northwest-dipping crenulation (post F3)

ACKNOWLEDGMENTS

Financial support for field and laboratory work is provided by an EMR Research Agreement (71-04-87) and Mountjoy's NSERC grant (A2128). The authors thank Phil Simony for helpful discussions. Special thanks go to the people from Yellowhead Helicopters: Garry, Nikki and Todd and to Brian Hannis for excellent expediting. Keith Mountjoy helped immeasureably in the mapping and enjoying of these mountains during two summers.

REFERENCES

Aitken, J.D.
1971: Control of lower Paleozoic sedimentary facies by the Kickinghorse Rim, Southern Rocky Mountains of Alberta; *in* Bulletin of Canadian Petroleum Geology, v. 19, p. 557-569.

Balkwill, H.R.
1972: Structural geology, lower Kicking Horse River Region, Rocky Mountains, British Columbia; *in* Bulletin of Canadian Petroleum Geology, v. 20, no. 3, p. 603-105.

Campbell, R.B.
1968: Canoe River (83D), British Columbia; Geological Survey of Canada, Map 15-1967, scale 1:250,000; (part of GSC Open File 290).

Craw, D.
1977: Metamorphism, structure and stratigraphy of the Southern Park Ranges (Western Rocky Mountains), British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta.

Ferri, F.
1984: Structure of the Blackwater Range, British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta.

Forest, R.C.
1985: Structure and metamorphism of Ptarmigan Creek area, Selwyn Range, British Columbia; unpublished M.Sc. thesis, McGill University, Montreal.

Fyles, J.T.
1960: Geological reconnaissance of the Columbia River between Bluewater Creek and Mica Creek; British Columbia Ministry of Mines, Annual Report, 1959, p. 95-105.

Gardner, D.A.C.
1977: Structural geology and metamorphism of calcareous lower Paleozoic slates, Blaeberry River — Redburn Creek Area, near Golden, British Columbia; unpublished Ph.D. thesis, Queen's University, Kingston, Ontario, 220 p.

Leonard, R.
1985: Variable structural style, stratigraphy, total strain and metamorphism adjacent to the Purcell thrust near Blackman Creek, B.C.; unpublished M.Sc. thesis, McGill University, Montreal, 250 p.

McDonough, M.R.
1984: Structural evolution and metamorphism of basement gneisses and Hadrynian cover, Bulldog Creek area, British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta.

Mielliez, F.
1972: Structural of the southern Solitude Range, British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta.

Mountjoy, E.W.
1988: The Hugh Allan (Purcell) Fault at Hugh Allan Creek a low-angle west-dipping trust fault; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1 E.

Mountjoy, E.W. and Forest, R.
1986: Revised structural interpretation, Selwyn Range between Ptarmigan and Hugh Allan creeks, British Columbia — an antiformal stack of thrusts; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 177-183.

Oke, C.
1982: Structure and metamorphism of Precambrian basement and its cover in the Mt. Blackman area, British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta.

Price, R.A. and Mountjoy, E.W.
1970: Geological structure of the Canadian Rocky Mountains between Bow and Athabasca rivers, a progress report; Geological Association of Canada, Special Paper 6, p. 7-26.

Structural geology of part of the Main Ranges near Jasper, Alberta

Roland G. Dechesne[1] and Eric W. Mountjoy[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Dechèsne, R.G. and Mountjoy, E.W., Structural geology of part of the Main Ranges near Jasper, Alberta; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 171-176, 1988.

Abstract

Two main deformational phases occur in the Main Ranges near Jasper, Alberta. The earlier produced low-angle thrust faults and associated folds. Steep to upright faults and folds overprint the earlier structures. In the Meadow Creek area, second generation thrust faults cut previously overturned strata and place younger strata onto older. Because of these later faults, the status of the Meadow Creek Formation is in doubt.

Low-angle thrust faults of the Jasper area (including the Simpson Pass Thrust) may have been produced during the same event that caused the low-angle, syn-metamorphic, faults in the Selwyn Range to the west. Later steep structures in both areas may represent a single regional event.

Résumé

On trouve deux grandes failles de déformation dans les chaînons minces près de Jasper en Alberta. La plus ancienne a produit des failles de charriage d'angle faible et des plis associés. Des failles et des plis abrupts verticaux se superposent aux structures plus anciennes. Dans la région de Meadow Creek, des failles de charriage de deuxième génération coupent des couches renversées antérieurement et placent des couches plus jeunes sur les plus vieilles. À cause de ces failles plus récentes, l'état de la formation de Meadow Creek est mal défini.

Les failles de charriage d'angle faible de la région de Jasper (y compris la faille de Simpson Pass) ont pu se produire pendant le même événement qui a causé les failles synmétamorphiques d'angle faible dans le chaînon Selwyn à l'ouest. Des structures abruptes plus récentes dans les deux régions pourraient provenir d'un même événement régional.

[1] Department of Geological Sciences, McGill University, 3450 rue University, Montreal, Quebec H3A 2A7

INTRODUCTION

In addition to field work in the Fraser River Anticlinorium, field work in 1987 was carried out in portions of the Jasper map-area (83D/16, Fig. 1, 2) to elucidate the relative timing of two major faults, the Monarch and Simpson Pass thrusts, and related structures. This project was undertaken for three main reasons:

1) recently, Brown et al. (1986) have suggested that the Pauline and Monarch thrusts in the Mount Robson area (Mountjoy, 1980) represent the easternmost exposure of structures related to a proposed duplex within basement gneisses of the Omineca Crystalline belt,

2) our observations, in 1986, of multiple deformation within the immediate hanging wall of the Simpson Pass Thrust,

3) our mapping of a large folded thrust in the Ptarmigan Creek area of the Selwyn Range to the southwest (Mountjoy and Forest, 1986; Dechesne, unpublished work) which indicates that the Ptarmigan Creek Fault Zone has a larger displacement than can be accommodated on the Chatter Creek Thrust and therefore must be connected to structures farther northeast.

In addition, when these data are incorporated into a regional cross-section through the Jasper-Yellowhead structural culmination they will provide constraints on the structural style within deep levels of regional cross-sections in adjacent areas and in the Omineca Hinterland.

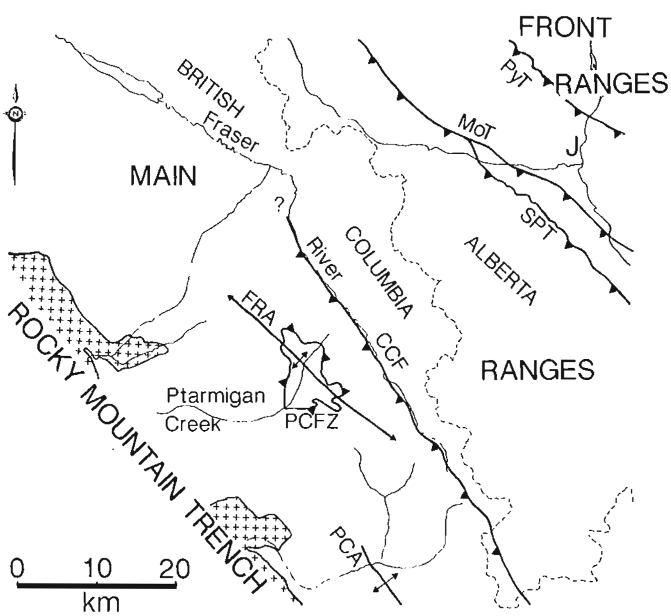


Figure 1. Simplified regional geological map including the study area near Jasper. Shown are Jasper, Alberta (J), Pyramid Thrust (PyT), Monarch Thrust (MoT), Simpson Pass Thrust (SPT), Chatter Creek Fault (CCF), Ptarmigan Creek Fault Zone (PCFZ), Fraser River Anticlinorium (FRA), and the Porcupine Creek Anticlinorium (PCA). Basement gneisses shown in cross pattern.

PREVIOUS WORK

The Jasper area was mapped on a semi-reconnaissance basis during Project Bow-Athabasca (Price, 1967; Price and Mountjoy, 1966, 1970; Mountjoy and Price, 1985). Particularly detailed mapping has been done by H.A.K. Charlesworth and his students was undertaken in the Athabasca River and Miette River valleys near Jasper (Fig. 2; Charlesworth et al., 1967). The region to the north has been mapped by Mountjoy (1962, 1980) and the area to the south by Mountjoy and Price (in press).

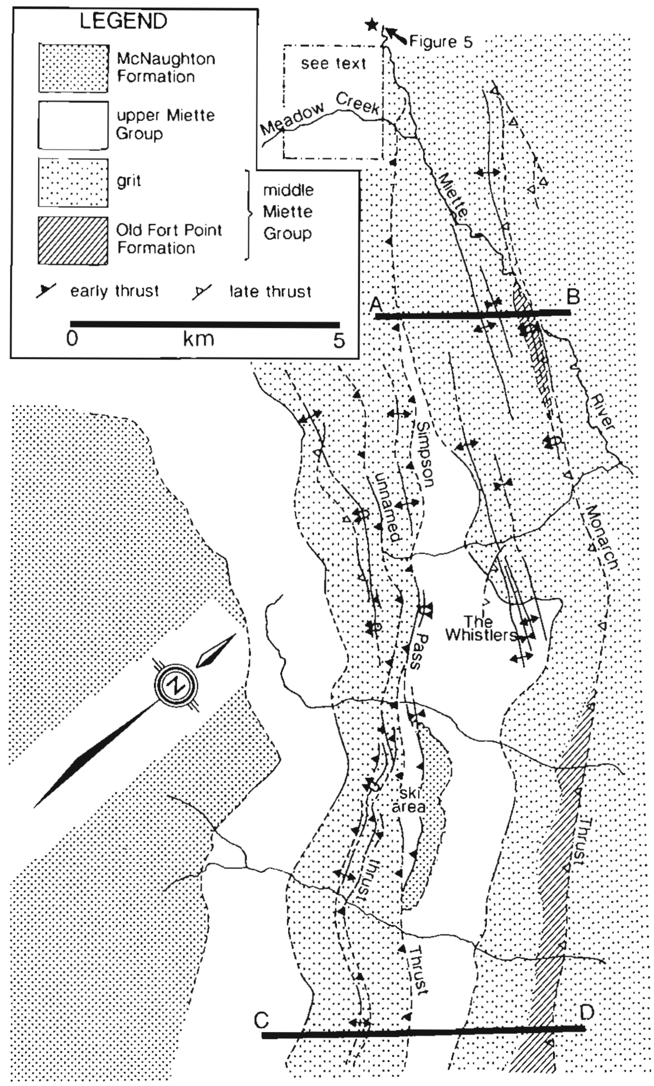


Figure 2. Detailed geological map of the region southwest of Jasper. The series of upright folds near The Whistlers are late folds, all other folds shown are early folds associated with the early faults. A-B and C-D are lines of cross-sections illustrated in Figure 4. The Meadow Creek area is discussed in the text. Star indicates location of outcrop sketch shown in Figure 5.

GEOLOGICAL SETTING

The Monarch and Simpson Pass thrusts outcrop in the eastern part of the Main Ranges of the Canadian Rocky Mountains. Farther south, the Simpson Pass Thrust delineates the eastern margin of the Main Ranges (Price and Mountjoy, 1970; Mountjoy 1970, 1976), but at the latitude of Jasper, the Pyramid Thrust forms this boundary (Fig. 1). In the Jasper area, the Main Ranges are dominated by exposures of Hadrynian (late Proterozoic) Miette Group and Lower Cambrian (and older?) Gog Group (Fig. 3; Mountjoy, 1962). The contact between the two groups is sharp and is locally known to be disconformable (Teitz and Mountjoy, 1985). Based on the correlation presented by Carey and Simony (1985), the Old Fort Point Formation (Charlesworth et al., 1967) is placed within the middle Miette Group in this paper (Fig. 3) and not below it as Mountjoy and Price (1985) have shown. More work is necessary to more clearly document the lateral relationships of these rocks. The quartz arenites of the McNaughton Formation (Mountjoy and Aitken, 1963; Young, 1978) of the Gog Group have been deformed into a series of open, regional scale folds separated by thrust faults (Mountjoy and Price, 1985), whereas the granule to pebble conglomerates, poorly sorted arenites and interbedded slates of the Miette Group have been tightly folded (Charlesworth et al., 1967). Mountjoy (1970, 1976) and Mountjoy and Price (1985) recognized that major faults that cut Gog Group strata could also be traced into Miette Group rocks, contrary to Charlesworth et al. (1967), who found only a few faults within the Miette Group during their mapping.

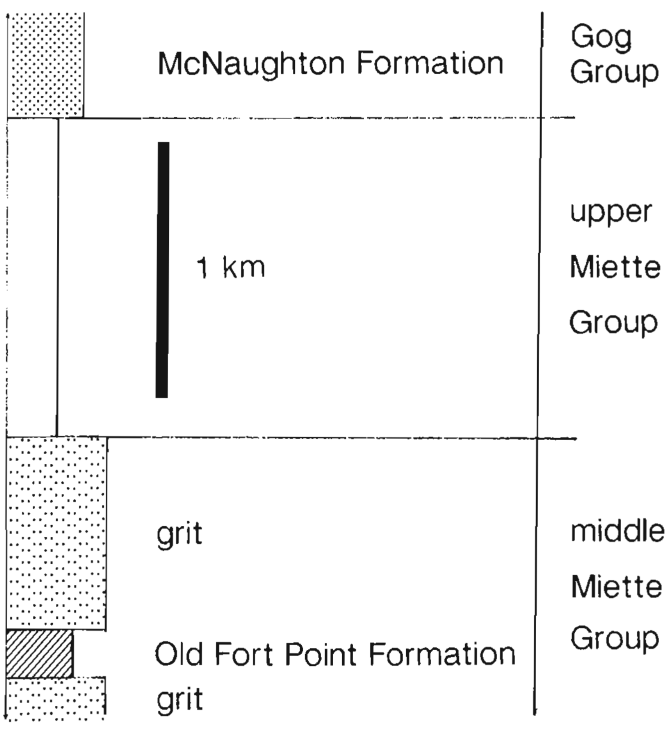


Figure 3. Generalized stratigraphic column exposed within the study area (after Charlesworth et al., 1967).

STRUCTURAL GEOLOGY

Early faults and folds

Two separate large thrust faults can be traced from the Marmot Ski area towards the Miette River (Fig. 2, 4). The more easterly is the Simpson Pass Thrust, the other is unnamed. Near these faults, Miette Group strata are deformed into a series of overturned tight folds. Within the fault zones, strata are dominantly overturned. Quartz veining is associated with folded and faulted conglomerates and sandstones but slates and carbonates were deformed ductilely. Thick conglomerate packages within the Middle Miette Group are dismembered and shuffled with adjacent slates. In several locations, folds are ripped limb from limb, leaving isolated fold closures. Microfabrics indicate that deformation took place at or near the metamorphic peak, which was sub-biotite greenschist grade. The phyllite to slaty cleavage in pelites is axial planar to folds associated with the faults. Conglomerate contains an anastomosing foliation defined by mica and chlorite and slightly flattened clasts. Mylonitization within McNaughton Formation quartz arenites has produced a bleached quartz-rich rock that contains shearbands and anastomosing shear zones.

Late faults and folds

Later thrust faults can be found in both the hanging wall and footwall of the Simpson Pass Thrust. In Highway 16 roadcut exposures of the Simpson Pass Thrust sheet, small thrust faults and hanging wall antiforms have been superimposed onto a previously overturned panel. These faults place younger rocks onto older strata. The earlier overturning is due to folds associated with the Simpson Pass Thrust. Another late minor thrust, in the footwall of the Simpson Pass Thrust, also exposed along Highway 16, cuts down stratigraphically in its direction of transport (northeastward). Associated en echelon quartz veins in slates indicate that deformation within the slates was less ductile than at the metamorphic peak. Within the fault itself, the veins were rotated and boudinaged and the regional schistosity is folded.

The Monarch Thrust cuts across the structural fabric of the region both in its hanging wall and footwall (Mountjoy and Price, 1985). The immediate footwall of the thrust is exposed along Highway 16 and clearly shows veined slates with folded foliation. In this outcrop two generations of quartz veins cut conglomerate. An early, subvertical set is boudinaged, and a later generation of en echelon veins did not experience the earlier deformation. This suggests that there was two stages of motion on the Monarch Thrust.

The structure of the Monarch Thrust sheet includes a northeasterly overturned tight anticline cored by the Old Fort Point Formation with axial planar slaty cleavage, and at higher structural levels, on The Whistlers, upright folds that fold the preexisting foliation. Locally, a subvertical crenulation cleavage can be found with these later folds. A late southwest verging thrust fault related to the upright folds was found on The Whistlers (Fig. 2).

Southwest verging kink folds documented by Charlesworth et al. (1967) may be related to the late thrust faults, especially the late, southwest verging fault in the Monarch Thrust sheet, but they may be even later. No evidence has been found to distinguish between these two possibilities.

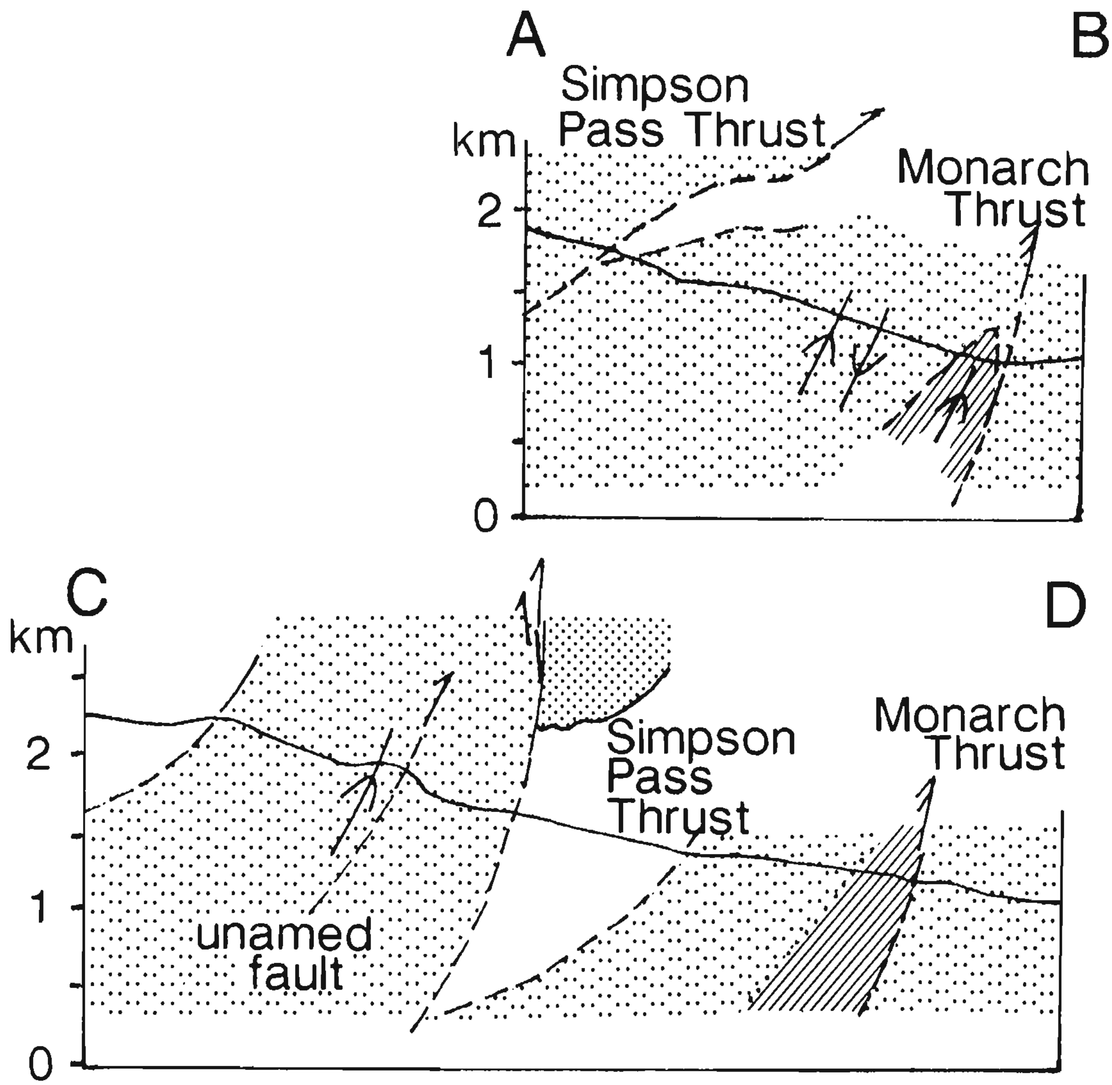


Figure 4. Structural cross-sections of the study area. Lines of section shown in Figure 2. Arrows with single heads represent early faults while those with double heads denote late faults. Note the steep dip of the Simpson Pass Thrust where it ramped through the McNaughton Formation (section C-D).

DISCUSSION OF THE MEADOW CREEK FORMATION

Charlesworth et al. (1967) mapped a folded sequence of pelites and conglomerates in the Meadow Creek valley which they felt underlay the Old Fort Point Formation. They assigned the name Meadow Creek Formation to these strata. Later, Mountjoy (1970, 1976) and Mountjoy and Price (1985) ascribed the pelites and conglomerates to middle Miette Group strata overlying the Old Fort Point and felt that their contact with the Old Fort Point Formation was a normal fault.

In the course of the present mapping, the contact relations of these rocks were reexamined. Overturned northeasterly-facing Old Fort Point Formation are structurally overlain by overturned northeasterly-facing conglomerate and pelite. The contact between the grits and the Old Fort Point Formation is not exposed across a gap in outcrop of at least 50 m. The top of the conglomerate package grades stratigraphically upwards into interbedded graded sandstones, siltstones and pelites. These strata may be stratigraphically lower than the Old Fort Point Formation, but it is also possible that they represent strata younger than the Old Fort Point Formation and are structurally emplaced into their present position. Second generation thrust faults that place younger strata onto older strata are common, not only in the Meadow Creek valley, but also along strike to the northwest.

In the hanging wall of the Simpson Pass Thrust, along Highway 16, 30 to 40 m of grit and pelite appears to be older than Old Fort Point Formation (Fig. 5). In this region, right way up grit and pelite are thrust onto right way up Old Fort Point Formation along an early thrust; as no evidence has been found for an earlier deformational event, the hanging wall of the thrust fault must contain rocks that are stratigraphically lower than the Old Fort Point Formation. Horses of limestone pebble conglomerate (member C of Charlesworth et al., 1967) and pink limestone (member B) occur in the fault zone structurally above their equivalents in the footwall of the thrust fault. These imply that the Old Fort Point

Formation in the hanging wall must be even higher up, thus overlying the grit and pelite. Because of poor exposures away from the highway and Meadow Creek, it has not yet been possible to trace these units along strike; consequently no detailed structure-map of this area is presented in this paper. More work is necessary to resolve the precise stratigraphic relationships of the coarse clastic rock in this area relative to the Old Fort Point Formation.

STRUCTURAL GEOLOGY: DISCUSSION AND REGIONAL PICTURE

In the Main Ranges near Jasper, two distinct episodes of compression can be documented. The earlier one produced major low-angle faults such as the Simpson Pass and Moose Pass thrusts and may have initiated the Monarch Thrust, while the later deformation reactivated the Monarch Thrust and produced steeper faults.

In the Ptarmigan Creek area of the Selwyn Range to the west (Fig. 1), the two main deformational events cannot be related using a modified Sanderson (1982) fold and thrust belt model and, at the scale of that range, can be treated as separate phases (Mountjoy and Forest, 1986; Dechesne, unpublished data). In the Jasper area more work is needed to determine if the two faulting events can be related by the Sanderson (1982) model, or can be treated as two independent events.

The earlier main deformational event of the Selwyn Range, which produced the Ptarmigan Creek Fault Zone and the event that produced the Simpson Pass Thrust, are tentatively interpreted to be related. Later events in both areas are also correlated. These correlations imply that the later deformational event is unrelated to the earlier one on the scale of the Main Ranges.

The net slip of the early Ptarmigan Creek Fault Zone (PCFZ) and associated structures (about 28 km) is much larger than that of the late Chatter Creek Fault (about 3 km); consequently, the PCFZ must be lined with faults that outcrop farther east.

Linking the Simpson Pass Thrust directly to the Ptarmigan Creek Fault Zone is premature in light of resolved structural and stratigraphic problems in the Selwyn Range (Dechesne and Mountjoy, unpublished data) and in the Jasper area.

The Monarch Thrust appears to have been initiated during the earlier event. If the first deformational event in the eastern Main Ranges is the same as the one that produced the PCFZ, and if the PCFZ is similar to age to synmetamorphic structures west of the Rocky Mountain Trench (as suggested by similar relationships with the metamorphic peak), then possibly Brown et al. (1986) are correct in relating the Pauline and Monarch thrusts to basement tectonics further west.

CONCLUSIONS

Two main deformational phases are recognized in the Main Ranges near Jasper, Alberta. The earlier produced low-angle thrust faults and associated folds. A strong foliation is related to these structures. Steep to upright faults and folds overprint the earlier structures. Locally, a crenulation cleavage was produced. In the Meadow Creek area, second generation thrust faults that cut previously overturned strata place younger strata onto older. It thus is possible that the Meadow Fault Formation of Charlesworth et al. (1967) represents strata that overlie the Old Fort Point Formation and are not older strata than the Old Fort Point Formation. However, strata older than the Old Fort Point Formation may outcrop along Highway 16, west of Meadow Creek.

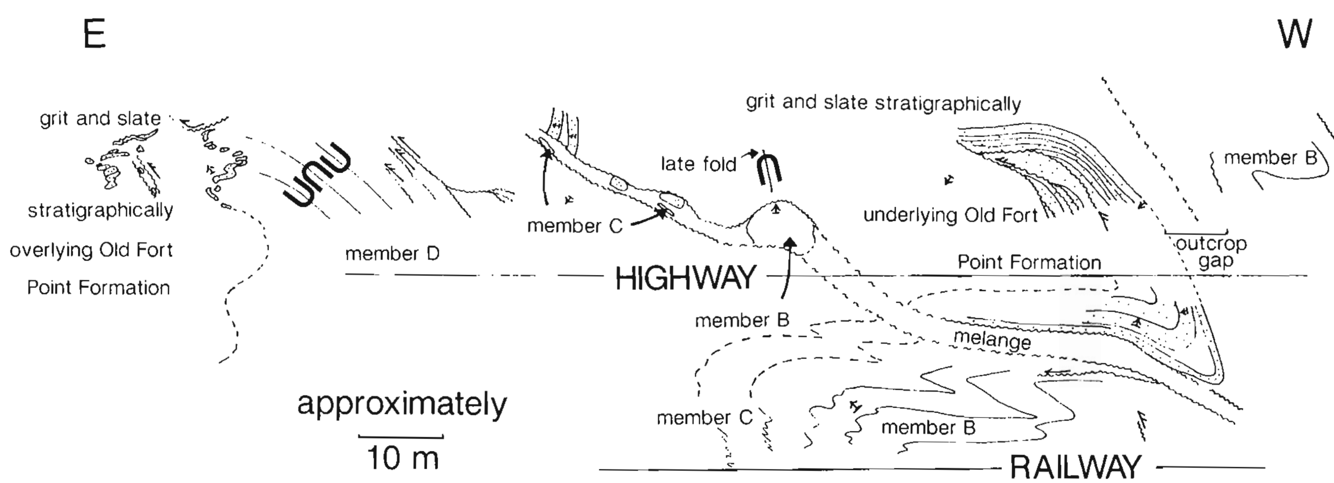


Figure 5. Composite field sketch of area indicated in Figure 2. Scale varies slightly across this view. Arrows with single heads represent early faults while those with double heads denote late faults. The melange occurs within an early large fault zone. As can be seen in this view, only 30 to 40 m of strata can be documented in the hanging wall of this fault zone, and the upper contact with the Old Fort Point Formation is not exposed. The outcrop gap may conceal a west-side-down normal fault that down drops the Old Fort Point Formation in the hanging wall of the early thrust, or a late west-side-up thrust that cuts the early fault and places Old Fort Point Formation of the footwall at highway level. Small arrows with flat bases indicate stratigraphic tops. Members within the Old Fort Point Formation after Charlesworth et al. (1967).

Low-angle thrust faults of the Jasper area (including the Simpson Pass Thrust) are believed to have developed during the same event that produced the low-angle, syn-metamorphic, Ptarmigan Creek Fault Zone (PCFZ) in the Selwyn Range to the west. Later steep structures in both areas may represent a single regional event as well.

The Monarch Thrust may be related to basement tectonics further west, as suggested by Brown et al. (1986). However, it is unlikely that the Monarch Thrust is the easternmost extent of this deformation.

REFERENCES

Brown, R.L, Journeay, J.M., Lane, L.S., Murphy, D.C., and Rees, C.J.
1986: Obduction, backfolding and piggyback thrust in the metamorphic hinterland of the southeastern Canadian Cordillera; Journal of Structural Geology, v. 8, p. 255-268.

Charlesworth, H.A.K., Weiner, J.L., Akehurst, A.J., Bielenstein, H.U., Evans, C.R., Griffiths, R.E., Remington, D.B., Stauffer, M.R., and Steiner, J.
1967: Precambrian geology of the Jasper Region; Research Council of Alberta, Bulletin 23, 74 p.

Carey, J.A. and Simony, P.S.
1985: Stratigraphy, sedimentology and structure of Late Proterozoic Miette Group, Cushing Creek area, B.C; Bulletin of Canadian Petroleum Geology, v. 33, p. 184-203.

Mountjoy, E.W.
1962: Mount Robson (southeast) map-area, Rocky Mountains of Alberta and British Columbia; Geological Survey of Canada, Paper 61-31, 114 p.
1970: Geology of the Main Ranges between Tete Jaune, Cache and Jasper; *in* Edmonton Geological Society 1970 Field Conference, p. 47-107.
1976: Edson to Valemount — the Rocky Mountain Front and Main Ranges along Highway 16 in the Jasper area; *in* Geological Association of Canada Field Trip Guidebook, p. 4-42.
1980: Mount Robson map-area, Alberta and British Columbia; Geological Survey of Canada, Map 1499A.

Mountjoy, E.W. and Aitken, J.D.
1963: Early Cambrian and Late Precambrian paleocurrents, Banff and Jasper National Parks; Bulletin of Canadian Petroleum Geology, v. 11, p. 161-168.

Mountjoy, E.W. and Forest, R.
1986: Revised structural interpretation, Selwyn Range between Ptarmigan and Hugh Allan Creeks, British Columbia — an antiformal stack of thrusts; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 177-183.

Mountjoy, E.W. and Price, R.A.
1985: Jasper (83 D/16) geological map and cross-sections, 1:50 000 scale; Geological Survey of Canada, Map 1611A.
— Amethyst Lakes (83 D/9) geological map and cross-sections, 1:50 000 scale; Geological Survey of Canada (in press).

Price, R.A.
1967: Operation Bow-Athabasca, Alberta and British Columbia; *in* Report of Activities, Part A, May to October 1966, Geological Survey of Canada, Paper 67-1A, p. 106-112.

Price, R.A. and Mountjoy, E.W.
1966: Operation Bow-Athabasca, Alberta and British Columbia; *in* Report of Activities, Part A, May to October 1965, Geological Survey of Canada, Paper 66-1A, p. 116-121.
1970: Geological structure of the Canadian Rocky Mountains between Bow and Athabasca rivers, a progress report; Geological Association of Canada, Special Paper 6, p. 7-26.

Sanderson, D.J.
1982: Models of strain variation in nappes and thrust sheets: a review; Tectonophysics, v. 88, p. 201-233.

Teitz, M. and Mountjoy, E.W.
1985: The Yellowhead and Astoria carbonate platforms in the Late Proterozoic upper Miette Group, Jasper, Alberta; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 341-348.

Young, F.G.
1978: The lowermost Paleozoic McNaughton Formation and equivalent Cariboo Group of eastern British Columbia: piedmont and tidal complex; Geological Survey of Canada, Bulletin 288, 60 p.

Geology and geochronometry of the Eagle plutonic complex, Hope map area, southwestern British Columbia

C.J. Greig[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Greig, C.J., Geology and geochronometry of the Eagle plutonic complex, Hope map area, southwestern British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 177-183, 1988.

Abstract

The Cretaceous Eagle plutonic complex consists of three map units that have a common intrusive and structural history. Early(?) Cretaceous foliated to gneissic granodiorite, on the east margin, is a pervasively deformed syntectonic pluton containing planar fabrics which parallel intense foliations in rocks of the Upper Triassic Nicola Group to the east. Variably deformed late Early Cretaceous muscovite granite, mainly restricted to the west margin of the complex, forms large and small, latest syn- or post-tectonic intrusions. The third unit, a heterogeneous gneiss complex, occurrs along the contact between granodiorite and muscovite granite and is composed of material from both units. The Eagle complex was uplifted in the mid- to Late Cretaceous, and was cut by numerous brittle faults during the early Tertiary.

Résumé

Le complexe plutonique d'Eagle du Crétacé est composé de trois unités qui ont un passé intrusif et structural commun. La granodiorite feuilletée à gneissique du Crétacé inférieur (?), sur la marge est, est un pluton syntectonique déformé par pénétration qui renferme des structures planaires parallèles à d'intenses schistosités dans les roches du groupe de Nicola du Trias supérieur à l'est. Du granite à muscovite de la fin du Crétacé inférieur, déformé de façon variable et limité principalement à la marge ouest du complexe, forme de grosses et petites intrusions syn- ou post-tectoniques plus récentes. La troisième unité, un complexe de gneiss hétérogène, gît le long du contact entre la granodiorite et le granite à muscovite, et est composé de matériaux provenant des deux unités. Le complexe d'Eagle a été soulevé au cours du Crétacé moyen à supérieur, et a été coupé par de nombreuses failles fragiles pendant le Tertiaire inférieur.

[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

INTRODUCTION

Mapping at 1:25 000 scale of the Eagle plutonic complex (the "Eagle complex") was undertaken during 1986 and 1987 to determine its intrusive and structural history. Fieldwork and continuing geochronologic, petrographic and geochemical studies will form part of an M.Sc. thesis at the University of British Columbia.

The Coquihalla highway and an extensive network of logging roads provide access to the study area, which is centred on the highway tollbooth, 55 km from Hope (Fig. 1).

Although the Eagle complex hosts no known significant mineral occurrences in the study area, several properties along its margins have been the subject of considerable base and precious metals exploration. Cretaceous to Tertiary faults appear to have been the primary control for the occurrences and could provide the focus for future exploration.

REGIONAL SETTING

The Eagle complex forms the southern part of the Mount Lytton-Eagle complex, an elongate north-northwest-trending plutonic complex that extends 200 km south from near Lytton (50°30') to south of the forty-ninth parallel. It forms the westernmost part of the Intermontane Belt and is one of a number of northwest trending litho-tectonic elements that dominate the regional structural grain where the Coast, Cascade and Intermontane belts meet in southwestern British Columbia (Fig. 1).

Uplift during late Early Cretaceous to early Tertiary time provides the disparate parts of the Mount Lytton-Eagle complex with their regional structural integrity. The northern half of the complex, the Mount Lytton plutonic complex (Monger, 1981), extends south to 50°N. It is of early Mesozoic age, is locally crosscut by Triassic-Jurassic plutons and is thought to represent a lower structural level of the Upper Triassic Nicola volcanic arc (Monger, 1985). The southern half of the Mount Lytton-Eagle complex, the Eagle plutonic complex, is a late syn- to post-tectonic intrusive complex of Early(?) and Early Cretaceous age. It is bounded on the east by a syn-deformational intrusive contact with the Upper Triassic Nicola Group, and bounded on the west by the Pasayten fault, which separates it from the predominantly sedimentary rocks of the Methow trough of Jurassic to Tertiary age.

GEOLOGY OF THE COUNTRY ROCK ENVELOPE

Upper Triassic Nicola Group

Upper Triassic Nicola Group rocks underlie the east margin of the study area and are part of a belt of strongly deformed, amphibolite grade schistose rocks whose foliation trends N 160 degrees with remarkable consistency, from south of the forty-ninth parallel almost as far north as Merritt (Rice 1947). Primary fabrics are rarely preserved within the study area (Fig. 2), but 5 km east of the contact, where the intensity of deformation and metamorphic grade decrease, primary textures are well preserved. Undeformed Nicola Group rocks comprise heterogeneous and discontinuous mafic lava, flow breccia, pyroclastic rocks and greywacke, lesser dacite, rhyolite, argillite, limestone and conglomerate and abundant greenstone (Eastwood, 1961).

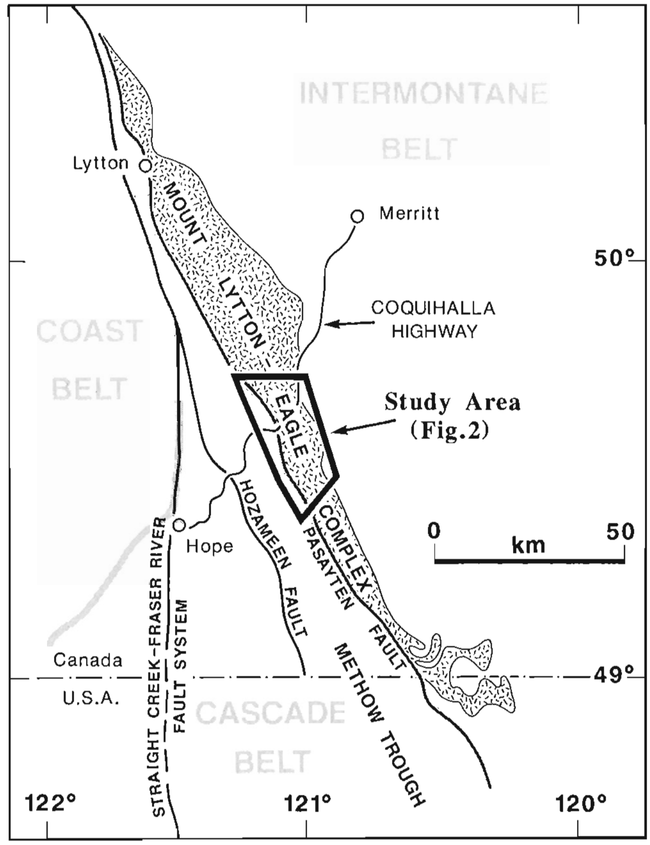


Figure 1. Geological and physiographic belts, major litho-tectonic elements and location of the study area. After Roddick et al. (1979).

Metamorphosed and deformed Nicola rocks near the eastern margin of the Eagle complex are more homogeneous. Rock types, typically pyritic and rusty-weathering, include light to dark green schistose biotite amphibolite, strongly banded greenstone, white coarse-grained marble, white sericitic schist, and black, well-layered siliceous amphibolite. Within 2 km of the contact, a uniform northwest-trending, southwest-dipping foliation is well developed and metamorphic grade rises from sub-greenschist or greenschist facies to amphibolite facies. Mylonitic textures are common and most intense in the strongly layered greenstone, where streaky white and pale to dark green layers alternate to produce a striped appearance.

Upper Triassic(?) hornblende diorite-metabasalt

Greenschist grade hornblende (quartz) diorite and subordinate metabasalt occur along the west margin of the Eagle complex. Widespread chlorite and magnetite alteration products of mafic minerals and crosscutting chlorite-epidote veinlets are characteristic. Metabasalt is dark green, massive, fine-grained and displays rare amygdaloidal and porphyritic textures. Diorite is heterogeneous in grain size as well as development, intensity and orientation of gneissic fabric (Fig. 3). Abundant fine-grained "greenstone" inclusions within diorite suggest that it intrudes metabasalt.

The contact between the diorite-metabasalt unit and rocks of the Eagle complex is faulted. Contrasting brittle and ductile fault fabrics along it suggest a compound history.

Age control for this unit is poor. Metabasalt is similar to Upper Triassic Nicola Group rocks to the east, as noted by Rice (1947) for similar rocks south of the map area. Uranium-lead zircon dating of the diorite is underway and preliminary results suggest an intrusive age of Late Triassic, with significant lead loss in the Early Cretaceous (P. van der Heyden, pers. comm., 1987).

GEOLOGY OF THE EAGLE PLUTONIC COMPLEX

Work to date indicates that the Eagle complex consists of three units that have a common deformational and intrusive history. Two of the units are distinct plutonic bodies and consist of foliated to gneissic biotite granodiorite of probable latest Jurassic to earliest Cretaceous age, and muscovite granite of probable mid-Cretaceous age. A heterogeneous gneiss complex commonly separates the granodiorite and the muscovite granite. The proposed subdivision and nomenclature

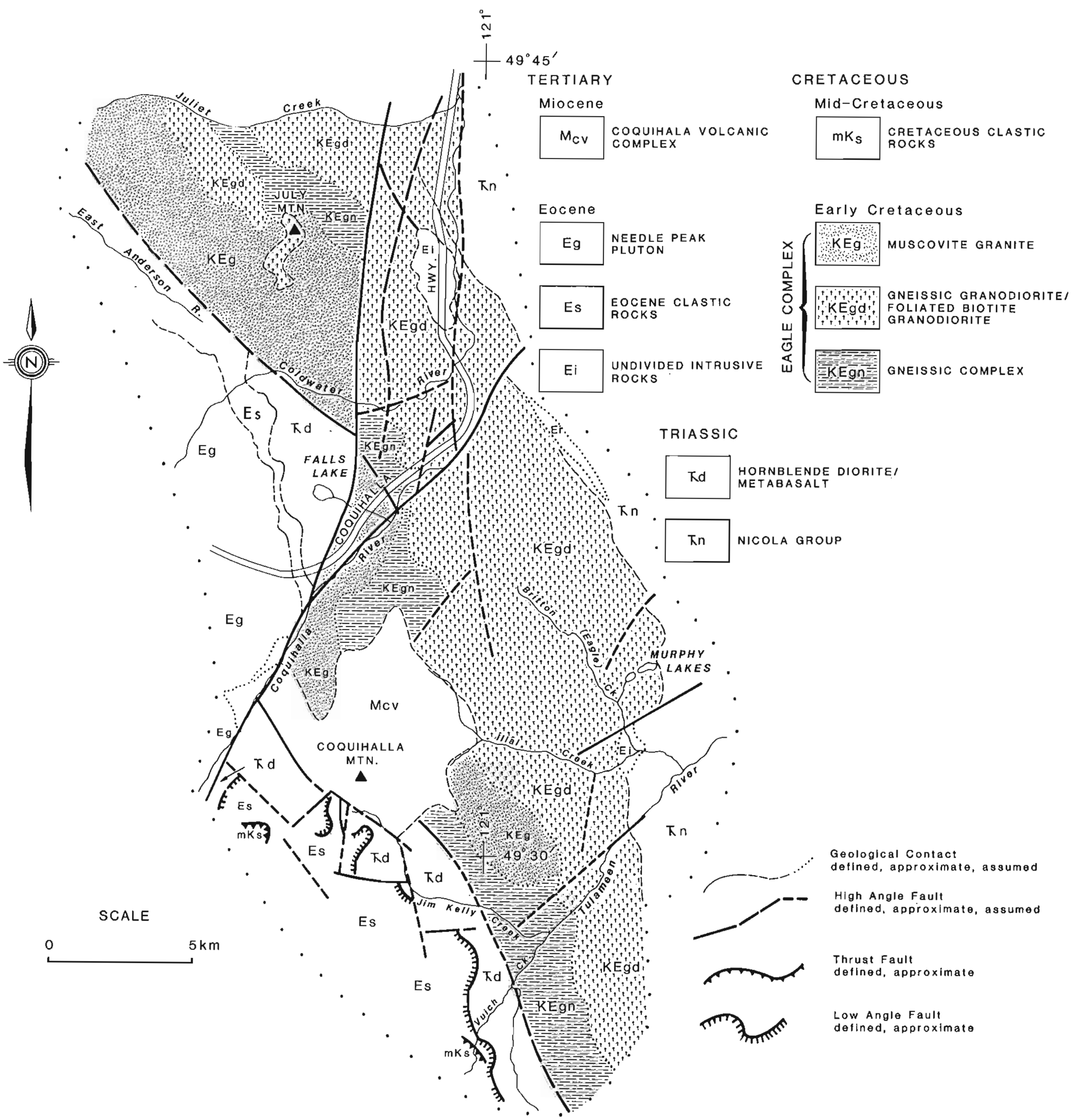


Figure 2. Geological sketch map. Patterned areas indicate units of the Eagle plutonic complex.

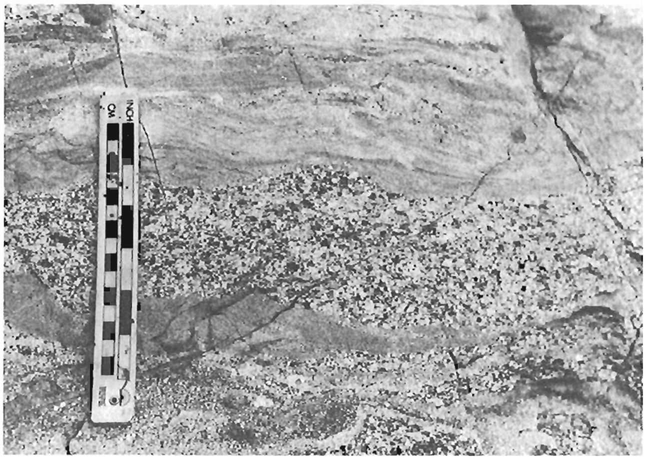


Figure 3. Upper Triassic(?) hornblende diorite, 1.5 km south of Falls Lake.

differs in detail but not in intent from the original definitions of Dawson (1879), Camsell (1913), Cairnes (1924), Rice (1947) and Monger (1970).

Early(?) Cretaceous foliated to gneissic biotite granodiorite

Gneissic to well-foliated hornblende biotite granodiorite underlies much of the eastern half of the map area and is the most extensive map unit within the Eagle complex. Intense, widespread foliation and the presence of primary epidote are characteristic. The ''granodiorite'' unit is of probable latest Jurassic to earliest Cretaceous age and may represent a late syn-tectonic intrusion relative to fabrics developed in adjacent rocks of the Nicola Group.

Two sub-units are recognized. Foliated biotite granodiorite is the contact phase with Nicola Group rocks along the eastern margin. To the west, toward the gneiss complex, gneissic granodiorite is developed. Foliated biotite granodiorite grades into gneissic granodiorite; changes in orientation or intensity of fabric are gradational or caused by late brittle faulting. Mesocratic, light grey to white weathering, medium-grained (hornblende)-epidote-biotite granodiorite to tonalite characterizes both sub-units. Hornblende is locally the dominant mafic mineral. Gneissic granodiorite is typified by narrow (average less than 1 cm), biotite-rich folia within equigranular biotite granodiorite (Fig. 4). It is more hornblende-rich and has finer-grained biotite than the foliated biotite granodiorite to the east. Where discrete biotite-rich folia are lacking, its equigranular texture may make it difficult to discern the fabric.

The characteristic structural grain and the intrusive relations involving the foliated to gneissic granodiorite suggest late synkinematic intrusion into the Nicola Group. Concordantly foliated biotite granodiorite sills in Nicola Group schistose amphibolite and marble are commonly boudinaged (Fig. 5). Weakly foliated granodiorite commonly contains intensely foliated country rock inclusions which are generally oblate and concordant with the foliation in the pluton. Foliations in more intensely deformed granodiorite and Nicola Group rocks at the contact are parallel. Remarkable concordance of planar fabrics in the granodiorite with foliations in Nicola Group rocks occurs over a strike length of approximately 100 km along their contact. Planar fabrics parallel the contact as well as the regional trend of the elongate Eagle complex, which suggests that intrusion had a strong regional tectonic control.

Stratigraphic age of the granodiorite unit is poorly constrained. New K-Ar and Rb-Sr isotopic dates range from 100-120 Ma (Aptian to Early Albian), confirming the earlier work (Wanless et al., 1967; Roddick and Farrar, 1972). The dates might be interpreted as reset due to later intrusion of muscovite granite. The Early(?) Cretaceous age for the unit is currently being tested by U-Pb geochronometry.

Early Cretaceous muscovite granite and pegmatite

Mid-Cretaceous muscovite-bearing granite is the youngest unit in the Eagle complex and is mainly restricted to the west margin. It forms several large intrusions and numerous cogenetic stocks, dykes and sills which intrude other units

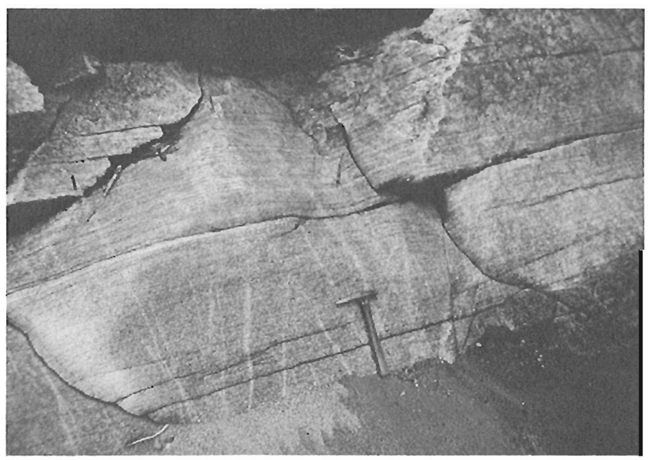


Figure 4. Gneissic granodiorite of the Eagle complex, Tulameen River.

Figure 5. Boudinaged sills of the Early(?) Cretaceous foliated granodiorite within amphibolitic schist of the Nicola Group, 1.5 km northwest of Murphy Lakes.

in the Eagle complex. On the west margin, it is faulted against Triassic(?) hornblende diorite and metabasalt and Eocene clastic rocks. Unlike rocks of the gneiss complex and the granodiorite unit, phases of the muscovite granite are not invariably deformed and are interpreted as latest syn- or post-tectonic intrusions.

Three relatively large and homogeneous bodies of biotite muscovite granite to quartz monzonite intrude along the western margin of the Eagle complex in the study area. All are probably related and may have been physically continuous prior to Tertiary faulting and volcanism. Their white to pale grey weathering colours mirror their leucocratic nature. Although the bodies most commonly contain two micas, muscovite is more abundant than biotite and is locally the only mica present. The granite is typically medium grained but grades into aplitic to pegmatitic varieties in zones of low strain. Common accessory minerals include hornblende and pinkish-red garnet. Planar fabrics within the three largest bodies of muscovite granite are variable in orientation and intensity. The northernmost body exhibits a northwest-trending, moderately steep northeast-dipping foliation that increases in intensity toward the southwest (toward the Pasayten fault) to become a protomylonite. Micas and, less commonly, ribboned quartz grains outline the planar fabric. Along the northeast margin of the body, and within the more poorly exposed bodies to the south, foliation intensity is weaker and massive textures more common. The variety in intensity and orientation of fabric in muscovite granite indicates it is less deformed than the foliated to gneissic granodiorite.

Small, muscovite-rich, discordant intrusions are widespread in the gneiss complex and occur as dykes in granodiorite. Pegmatitic muscovite granite and pink pegmatite are distinguished. Pegmatitic muscovite granite is more abundant and very similar to pegmatitic varieties in the large muscovite granite plutons. Pink pegmatites, characterized by pink potassium feldspar, are generally smaller (averaging 15 cm thick, ranging up to 2 or 3 m wide), more homogeneous, and have a wider distribution than the pegmatitic muscovite granites.

The broad zone of textural heterogeneity and mixed intrusive relations which marks the contact between the older granodiorite and younger muscovite granite intrusions defines part of the gneiss complex. The zone is characterized by all varieties of muscovite granite in numerous intrusive geometries with the granodiorite, such as agmatite, concordant lit-par-lit intrusions, crosscutting apophyses and development of enigmatic hybrid zones between the two units.

Potassium-argon (104-106 Ma on muscovite, and 97-100 Ma on biotite) and Rb-Sr dates suggest a late Early Cretaceous age for the unit. Both varieties of pegmatites yield younger (89-91 Ma) K-Ar dates which suggest either a difference in cooling rate between large and small intrusions or that the pegmatite stocks are younger and unrelated to the muscovite granite.

Gneiss complex

The gneiss complex, exposed as a discontinuous belt through the central and western Eagle complex, is characteristically heterogeneous. Constituent protoliths are recognizable but their discontinuous distribution prohibits map-scale subdivision of the gneiss complex. Well-layered orthogneiss, genetically related to gneissic granodiorite to the east, is interlayered with subordinate amphibolite and rare calc-silicate rocks. Intense layering, localized folding, and isolated occurrences of hybrid phases suggest a complicated history. The gneiss complex also includes the heterogeneous contact zone between the Jura-Cretaceous foliated to gneissic granodiorite and mid-Cretaceous muscovite granite described above.

Orthogneiss is most common and its closely spaced fabric and its composition are similar to that in the granodiorite to the east. Centimetre-scale discontinuous layering is defined by alternate leucocratic feldspar- and quartz-rich and subordinate narrower hornblende- and biotite-rich layers (Fig.6). The orthogneiss also alternates with and locally appears to intrude metre-scale biotite amphibolite layers. More commonly, however, contacts are characterized by the appearance of plagioclase augen and abundant discrete shear-related(?) layers in the orthogneiss. Rare, decimetre-scale marble and calc-silicate pods form a discontinuous layer concordant with gneissosity. Their form is related to deformation of the surrounding orthogneisses. Their presence, together with that of isolated exposures of boudined and/or injected amphibolite layers, proves that at least some of the bands in the gneiss complex were formed from older non-plutonic rocks.

CRETACEOUS AND TERTIARY STRATA AND TERTIARY INTRUSIONS

Cretaceous clastic rocks

On the southwest margin of the study area, finely laminated black shales, interbedded with lesser chert-muscovite sandstones along Vuich Creek, have yielded late Albian to Cenomanian (approximately 100 Ma to 90 Ma: mid-Cretaceous) palynomorphs (G.E. Rouse, pers. comm., 1987). A short distance downstream, Middle Eocene rocks structurally beneath them indicate that post-Middle Eocene eastward-directed thrust faulting has occurred in the area. Two kilometres to the west of Vuich Creek, clastic rocks correlative with the Cretaceous strata were studied by

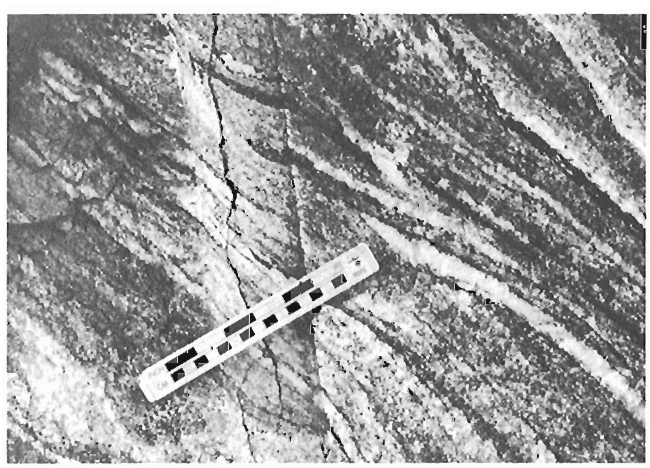


Figure 6. Discontinuous layers in gneiss complex, Coquihalla highway, 4 Km northeast of Falls Lake.

MacLean (1986). She found immature chert-muscovite sandstone and chert pebble conglomerate interbedded with subordinate mudstone and siltstone, which she interpreted to have formed in an alluvial fan environment with a western provenance. At least a partial eastern source for the clastic rocks is suggested, however, by the presence of abundant (up to 40 %) detrital muscovite in all rock types, and by their close proximity to muscovite-bearing granitic rocks of the Eagle complex. This further suggests that uplift of the Eagle complex occurred by late Early to earliest Late Cretaceous time.

Undivided Eocene intrusions

The contact between the Eagle complex and the Nicola Group to the east appears to have localized Tertiary intrusions and faults. Felsic to intermediate post-tectonic porphyritic dykes, sills and stocks are especially common near the contact, as are brittle fracturing, alteration and mineralization. There are three map-scale intrusions of note. Underlying the valley of the Coldwater River is the Keystone stock, an unfoliated, equigranular, medium-grained, hornblende biotite quartz diorite of early Tertiary age (W.J. McMillan, pers. comm., 1986) which intrudes rocks of the Eagle complex. The Keystone stock is itself cut by a younger multiple-phase, steeply-plunging, pipe-like intrusive breccia which carries base and precious metals mineralization (Saleken, unpublished company report, 1979).

Southeast, across the fault underlying the Coquihalla River valley, is an elongate composite intrusion described by Camsell (1913) as a "Granite Porphyry". It is a post-tectonic, high-level complex of porphyritic dykes which intrude along the Eagle/Nicola contact. Near its north end, at the Independence mineral property, it is associated with copper-gold mineralization. A late, unaltered dyke from this property yielded a K-Ar age of 55 Ma. Similar porphyritic sills and dykes, commonly associated with mineralization, occur to the south along the Eagle complex-Nicola Group contact.

At the confluence of Britton (formerly Eagle) and Illal creeks, another post-tectonic stock straddles the Eagle complex-Nicola Group contact. This stock forms exposures which Camsell (1913) described as his "type" Eagle granodiorite. Although it is similar in composition to the gneissic granodiorite of the Eagle complex, it is much less biotite-rich and has none of the planar fabric which characterizes the Eagle complex. It is an unfoliated, light- to dark-grey (at the contacts), weakly porphyritic biotite hornblende granodiorite. At its west contact, it crosscuts gneissic granodiorite of the Eagle complex and at its agmatitic east contact, it contains randomly oriented blocks of schistose Nicola Group rocks.

Eocene clastic rocks

Middle Eocene clastic rocks, previously assigned to the Cretaceous (Cairnes, 1924), are exposed along the length of the west side of the study area and are characterized by the presence of typically dark red grit. Rocks from a good section along Vuich Creek yielded Middle Eocene palynomorphs (G.E. Rouse, pers. comm., 1987).

The grit is commonly thick-bedded and poorly-sorted, with angular to subrounded clasts of leucocratic muscovite-bearing granitic rocks in a finer-grained groundmass. Although most commonly dark red in colour, pale mauve, buff or light green varieties may be interbedded. Local red thin-bedded gritty siltstone and coarse conglomerate with a red grit matrix also occur. Interbedded with, and in places more abundant than grit, are dark grey, thinly-bedded argillaceous rocks and subordinate lighter-grey sandstone and siltstone.

South of Coquihalla Mountain, the Eocene clastic rocks overlie Triassic(?) hornblende diorite and metabasalt on a west-dipping low angle fault of uncertain nature. The orientation of this fault and the presence of younger rocks on older suggest a possible west-side-down low angle normal fault. Intrusion of the 46 Ma Needle Peak pluton into similar rocks north of the Coquihalla River tightly constrains this deformation to Middle Eocene time. On Vuich Creek, late Albian to Cenomanian (G.E. Rouse, pers. comm., 1987) clastic rocks are thrust eastward onto the Middle Eocene rocks. This suggests that the timing and style of structures in this area are complex.

Needle Peak pluton

Distinctive granitoid peaks with well-developed exfoliation joints underlie the west-central margin of the map-area. First described by Cairnes (1924) and referred to the Cretaceous, they were renamed Needle Peak pluton by Monger (1970) and assigned an Eocene age based on a K-Ar date of 40 Ma (Wanless et al., 1967). The rocks consist of massive, light grey, medium- to coarse-grained biotite hornblende granite to granodiorite which commonly contains distinctive euhedral, pinkish potassium feldspar phenocrysts. Along its east and northeast contacts, the Needle Peak pluton clearly intrudes and produces a prominent hornfels in Middle Eocene(?) sedimentary rocks. Its southeast contact, closely paralleling the Coquihalla River valley, is a fault that juxtaposes both older (hornblende diorite and muscovite granite) and possibly younger (pyroclastic and rhyolitic rocks of the Coquihalla volcanic complex) rocks with the pluton. New K-Ar isotopic ages on hornblende and biotite are concordant at 46 Ma and are interpreted as the intrusive age of the pluton.

Coquihalla volcanic complex

The Miocene Coquihalla volcanic complex (Berman, 1979; Berman and Armstrong, 1980), underlies Coquihalla Mountain and the ridges radiating outward from it. It consists of undeformed calc-alkaline felsic to intermediate extrusive and intrusive rocks of which pale-weathering, flaggy, rhyolitic pyroclastic rocks are the most extensive. Pyroclastic rocks nonconformably overlie rocks ao the Eagle complex and are intruded by andesitic to dacitic domes, dykes and sills, and by a late quartz diorite stock which forms the core of Coquihalla Mountain. Concordant K-Ar and Rb-Sr isotopic ages of 23 Ma suggest an earliest Miocene age.

GEOLOGICAL EVOLUTION OF THE EAGLE PLUTONIC COMPLEX

Based on work to date, the geological history of the Eagle plutonic complex may be:

1. In Early(?) Cretaceous time, granodiorite of the Eagle complex intruded and was strongly deformed together with rocks of the Upper Triassic Nicola Group, to produce on the east side of the complex a strong west-dipping, regional foliation.

2. Muscovite granite of late Early Cretaceous age intruded the granodiorite and related rocks of the gneiss complex and was itself weakly deformed in the waning stages(?) of the deformation which affected the older granitic rocks.

3. During mid- to Late Cretaceous time the Eagle complex was uplifted along the Pasayten fault to become a source terrane for the Jackass Mountain and Pasayten groups to the west and the Spences Bridge Group to the east.

4. In Early Eocene time, high-level intrusions and brittle faults were localized along the east margin of the Eagle complex. By the Middle Eocene, the Eagle complex was again supplying detritus west to the Methow trough. This was short-lived, however, as Middle Eocene clastics were involved in possible west-directed normal faulting as well as east-directed thrust faulting before being intruded by the Needle Peak pluton at 46 Ma.

5. Brittle deformation dominated in post-Eocene time, and may have controlled the emplacement of the Coquihalla volcanic complex and intrusion of breccias into the Keystone stock. Faulting in post-earliest Miocene time downdropped the Coquihalla volcanic complex against the Needle Peak pluton across a northeast-trending high angle fault.

ACKNOWLEDGMENTS

Fieldwork was funded by the Geological Survey of Canada and directed by J.W.H. Monger, Argon, potassium and uranium-lead analyses were performed by J. Harakal, D. Runkle and P. van der Heyden, respectively. All laboratory costs were funded by an NSERC operating grant to R.L. Armstrong. Thanks are due to: R.L. Armstrong for thesis supervision, R.G. Anderson for advice and encouragement, B. Greig, M. Gunning and K. Hancock for assistance in the field, J. Harakal, D. Runkle, and P. van der Heyden for guidance in the laboratory, G.E. Rouse for palynological work, P. Krauss for photographic work, C. Davis for drafting and P. Christopher, G. Richards and A.E. Soregaroli for access to private company reports.

REFERENCES

Berman, R.G.
1979: The Coquihalla volcanic complex, southwestern British Columbia; unpublished M.Sc. thesis, University of British Columbia, 169p.

Berman, R.G. and Armstrong, R.L.
1980: Geology of the Coquihalla volcanic complex, southwestern British Columbia; Canadian Journal of Earth Sciences, v.17, p. 985-995.

Cairnes, C.E.
1924: Coquihalla area, British Columbia; Geological Survey of Canada, Memoir 139, 187 p.

Camsell, C.
1913: Geology and mineral deposits of the Tulameen District, B.C.; Geological Survey of Canada, Memoir 26, 188 p.

Dawson, G.M.
1879: Report on exploration in the southern portion of British Columbia; Geological Survey of Canada, Report of Progress for 1877-78, p. 1B-173B.

Eastwood, G.E.P.
1961: Tulameen: Lawless Creek area; *in* British Columbia Minister of Mines, Annual Report, 1960, p. 42-55.

MacLean, M.
1986: Provenance and depositional setting of the Pasayten Group, Treasure Mountain, southwestern British Columbia; unpublished B.Sc. thesis, University of British Columbia, 68 p.

Monger, J.W.H.
1970: Hope map-area, west half (92H W1/2), British Columbia; Geological Survey of Canada, Paper 69-47, 75 p.
1981: Geology of parts of western Ashcroft map-area, southwestern British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 185-189.
1985: Structural evolution of the southwestern Intermontane Belt, Ashcroft and Hope map areas, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 349-358.

Rice, H.M.A.
1947: Geology and mineral deposits of the Princeton map-area, British Columbia; Geological Survey of Canada, Memoir 243, 136 p.

Roddick, J.C. and Farrar, E.
1972: Potassium-argon ages of the Eagle granodiorite, southern British Columbia; Canadian Journal of Earth Sciences, v. 9, p. 596-599.

Roddick, J.A., Muller, J.E., and Okulitch, A.V.
1979: Fraser River, British Columbia-Washington; Geological Survey of Canada, Map 1386A.

Wanless R.K., Stevens, R.D., Lachance, G.R., and Edmonds, C.M.
1967: Age determinations and geologic studies, K-Ar isotopic ages; Geological Survey of Canada, Paper 66-17.

Eastern margin of the Coast Plutonic Complex, Mount Waddington map area, B.C.

Margaret E. Rusmore[1] and G.J. Woodsworth
Cordilleran and Pacific Geoscience Division, Vancouver

Rusmore, M.E. and Woodsworth, G.J., Eastern margin of the Coast Plutonic Complex, Mount Waddington map area, B.C.; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 185-190, 1988.

Abstract

A Late Cretaceous complex fold and thrust system is exposed in the Niut Range east of the Coast Plutonic Complex. The Upper Carnian and Lower Norian basalts and sediments formed in an arc setting and are overlain by shallow-marine carbonates and volcaniclastic sandstone, and correlate with coeval rocks in Stikinia. Lower Cretaceous clastic sediments and an enigmatic volcanic unit of presumed Early Cretaceous age are also involved in the thrusting.

Northwest-trending, gently southwest-dipping thrust faults imbricate the units, creating a 30 km wide thrust belt. Elongation lineations within the thrusts plunge gently southwest, and are interpreted to be parallel to the transport direction. Northeast-directed, rather than southwestward, thrusting is supported by the northeast-vergence of several large folds, and by thrusts that steepen and cut upsection to the northeast.

Résumé

Un réseau de plis et de failles complexes du Crétacé supérieur est exposé dans le chaînon Niut à l'est du complexe plutonique de Coast. Les basaltes et les sédiments du Carnien supérieur et du Norien inférieur ont formé un arc et sont recouverts par des roches carbonatées de fond marin peu profond et du grès volcaniclastique, et sont corrélés avec des roches contemporaines dans Stikinia. Des sédiments clastiques du Crétacé inférieur et une unité volcanique énigmatique présumée du Crétacé inférieur sont aussi en jeu dans le réseau de failles.

Des failles de charriage de direction nord-ouest et de faible pendage sud-ouest imbriquent les unités, créant une zone de charriage de 30 km de large. Des linéations d'élongation dans la zone de charriage plongent doucement vers le sud-ouest et seraient parallèles à la direction de transport. La direction nord-est plutôt que sud-ouest du charriage est confirmée par la tendance vers le nord-est de plusieurs grands plis et par des poussées qui soulèvent et coupent la section supérieure au nord-est.

[1] Department of Geology, Occidental College, Los Angeles CA, U.S.A. 90041

INTRODUCTION

The Niut Range in the northeastern part of Mount Waddington map area (southwest of the Yalakom Fault) straddles the boundary between the Intermontane Belt on the east and the Coast Belt to the west (Fig. 1). In this area, the Intermontane Belt is underlain predominantly by Upper Triassic and Lower to Upper Cretaceous sedimentary and volcanic strata that have been deformed by southwest-dipping thrust faults and northwest-trending transcurrent faults (Tipper, 1969). To the west, these rocks are in contact with mainly plutonic and high grade metamorphic rocks of the Coast Belt (Roddick and Tipper, 1985); these rocks are presumed to be largely Mesozoic and Tertiary in age.

The present project is designed to gain a better understanding of the stratigraphy and structure of this well exposed and complex area, and to answer questions raised but not answered by previous work. In particular, the stratigraphy, tectonic setting, and regional significance of the Upper Triassic strata have been controversial, with the rocks being variously assigned to Wrangellia, Stikinia or the Cadwallader terrane. The geometry of the thrust sheets, the nature, amount, and age of movement of the thrusts, and the relation between thrusting and transcurrent faulting are uncertain. Also unknown is the nature of the boundary between the Coast and Intermontane belts in this region. For example, it is unclear whether stratigraphy and structures in the Intermontane Belt can be traced west into the high grade metamorphic and plutonic rocks of the Coast Plutonic Complex, as is the case in Whitesail Lake map area 300 km northwest (van der Heyden, 1982) or whether the boundary is simply an intrusive contact. Work to date has consisted largely of mapping at 1:20 000 scale in the Intermontane Belt, mainly in the area bounded by Mosley Creek, Homathko River, and the Tchaikazan Fault. We stress that the conclusions reached in this paper are tentative and must be confirmed by further work.

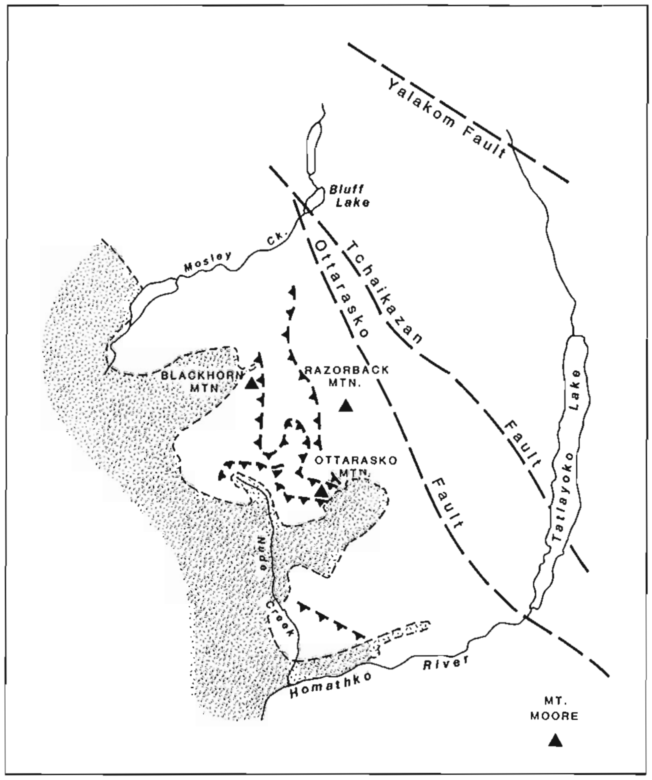


Figure 1. Index map of the Niut Range, showing major faults and the approximate eastern limit of plutonic and metamorphic rocks of the Coast Plutonic Complex (dashed). After Tipper (1969) and Roddick and Tipper (1985).

STRATIGRAPHY

Stratified rocks in the area consist of Upper Triassic volcanic and sedimentary strata, Lower Cretaceous clastic rocks, and a basalt to rhyolite volcanic unit of assumed Early Cretaceous age. No complete sections of any of the units are known. Because of the severe deformation, the relations between most of the units are speculative, and the true thicknesses are unknown.

Upper Triassic strata

Upper Triassic rocks can be divided into four informal units. Three units are Carnian and Early Norian in age and may be facies of each other; the other unit is Late Norian and was probably deposited on the older units.

The most extensive Carnian to Early Norian unit, here informally called the Mt. Moore volcanics, consists predominantly of augite porphyry basalt breccia and volcaniclastic sandstone, minor tuff, and rare basalt flows and limestone. Good exposures of this unit occur in the area around Mt. Moore, but the stratigraphy is complicated by offsets on low- and high-angle faults. Rocks of this unit are, in general, dark greenish-grey to maroon and vary greatly in texture and appearance. A diagnostic feature is the presence of conspicuous and abundant clinopyroxene, as phenocrysts in the breccias and flows, and as detrital grains in the sedimentary rocks. Plagioclase phenocrysts are commonly present but tend to be smaller and less abundant than the clinopyroxene. Conodonts from one interbed of limestone from the Mt. Moore area are Late Carnian (M.J. Orchard, pers. comm., 1981). In the Mt. Moore area, this unit is equivalent to Unit 1 of Tipper (1969). Rocks exposed northwest of BLuff Lake were also assigned by Tipper to Unit 1; however, their field and thin section appearance indicates they are not part of the Mt. Moore volcanics. Instead they may be part of the Upper Cretaceous Kingsvale Group.

The second unit is restricted to the Mt. Moore area, where it is equivalent to Tipper's Unit 3. The rocks are mainly sandstone and siltstone with rare pebbly sandstone and shaly limestone. Clinopyroxene clasts, presumably derived from the Mt. Moore volcanics, are common in the sandstone. We found no diagnostic fossils in this unit, although Tipper (1969) suggested a Carnian(?) and Early Norian age on the basis of several collections of Halobia.

The third unit consists of maroon and green tuffaceous shale, lapilli tuff, minor limestone, and rare volcaniclastic sandstone. The unit outcrops west and northwest of Razorback Mountain, where it was mapped as Unit 5a by Tipper (1969). No diagnostic fossils have been found; the presence of lapilli tuff suggests the unit was deposited during eruption of the Mt. Moore volcanics, thus it is probably Carnian to Early Norian in age.

The Upper Norian unit is found mainly in poorly exposed areas west of Bluff Lake, where it is roughly equivalent to units 5 and 6 of Tipper (1969). The rocks are mainly shallow-marine limestone, and interbedded volcaniclastic sandstone and maroon and green shale. The clastic rocks appear to be derived from an older basaltic source. Conodonts from limestone interbedded with maroon shale are Late Norian (M.J. Orchard, pers. comm., 1987) , an age in agreement with the presence of Monotis in Unit 5 (Tipper, 1969).

The three Carnian and Lower Norian units probably accumulated in an island arc setting. Clinopyroxene compositions from the Mt. Moore volcanics indicate that the basalts are calc-alkaline to tholeiitic and similar to basalts present in modern island arcs (Wilmanns, 1987). Whole-rock chemical analyses also support an arc setting, although the data are more scattered. We interpret the Carnian(?)-Lower Norian clinopyroxene-bearing sandstone unit as a local facies of the Mt. Moore volcanics. The age of the maroon and green shale-tuff unit is uncertain but, if it is Carnian to Late Norian, it too may be a distal, lateral equivalent of the Mt. Moore volcanics. Middle Norian strata are unknown from the area. Evidence of active volcanism is absent from the Upper Norian strata; the arc may have been quiescent in Upper Norian time, or the locus of volcanism may have shifted elsewhere.

Rocks of the Niut region have been variously correlated with those of Wrangellia, Stikinia, and the Cadwallader terrane. Our results suggest that the Upper Triassic rocks are part of Stikinia. The rock types, reconstructed stratigraphy, and inferred tectonic setting of the Niut Range units are similar to coeval rocks in Stikinia (Rusmore et al., 1987). Specifically, the Mt. Moore volcanics resemble parts of the Upper Karnian to Lower Norian Savage Mountain Formation of the Takla Group in northern Stikinia (Monger, 1977). Clinopyroxenes from the Takla Group (J.W.H. Monger, pers. comm., 1987) closely resemble those from the Mt. Moore volcanics (Wilmanns, 1987) and support this correlation. The other Carnian-Lower Norian units are too poorly understood to compare to specific formations, but both are lithologically similar to rocks in the Takla Group. The Upper Norian limestone and shale unit may be equivalent to Upper Norian limestone of the Sinwa Formation in northeastern Stikinia (Monger, 1980).

Although both the Cadwallader terrane and the Upper Triassic rocks in the Niut Range are inferred to have formed in or near an island arc, differences in rock types preclude their correlation. Basalt in the Cadwallader terrane is aphyric or contains abundant plagioclase phenocrysts, and clastic rocks contain granitic clasts as well as volcanic clasts eroded from an older arc (Rusmore, 1987). These differences may reflect changes within one arc or may indicate that the Cadwallader terrane is a separate Upper Triassic arc.

The Mt. Moore volcanics are chemically and petrographically unlike Upper Triassic rocks of Wrangellia. Basalt in Wrangellia is typically aphryric or plagioclase porphyritic and chemically resembles modern within-plate basalt or back- or forearc basalt erupted in an extensional setting (Davis and Plafker, 1985). These characteristics suggest that the rocks in the Niut Range are not correlative with Wrangellia.

Lower Cretaceous strata

Lower Cretaceous clastic sediments, equivalent to Unit 12 of Tipper (1969), are the dominant rocks south of Ottarasko Mountain. These rocks are dominantly fine grained sandstone, siltstone, and shale, but well stratified and locally crossbedded conglomerate is present. Much of the unit where we examined it may have formed in a shallow marine to deltaic setting. The unit is Hauterivian in age; Lower and Middle Hauterivian ammonites were collected by Tipper (1969), and an ammonite found in this study is Late Hauterivian in age (J.A. Jeletzky, pers. comm., 1987).

Variations in clast compositions serve to divide the conglomerates into two types. One type, found only south of Ottarasko Mountain, contains 75 to 85 % volcanic clasts, two-thirds of which are andesitic. In the other type, exposed on and around Razorback Mountain, most clasts are felsic volcanic and quartzose granitoid rocks; andesitic clasts are rare. Sandstone compositions seem to show this same variation, but only a few samples have been examined petrographically. Rocks that appear to be mylonites in hand specimens and deformed granitoid rocks, although uncommon, are present as clasts in both conglomerate types. These clasts and the abundance of granitoid clasts in some conglomerates are intriguing hints that the absence of Jurassic strata from the region may reflect deformation and uplift in Jurassic time.

The structurally highest rocks on Blackhorn and Ottarasko mountains consist of a varied suite of volcanic rocks that are here informally called the Ottarasko volcanics. Some of these rocks were mapped as Unit 1a by Tipper (1969). Most of the unit is dacite to andesite; basalt and rhyolite are subordinate but locally abundant. The unit consists mainly of poorly stratified, unsorted to poorly sorted volcanic breccia with few recognizable flows. No fossils have been found in this unit, and its stratigraphic relations with other units are unknown. It may be equivalent to Unit 13 of Tipper (1969), which he thought to be Hauterivian in age. The Ottarasko volcanics strongly resemble Lower Cretaceous volcanics that one of us (GJW) has seen in the Rivers Inlet, Bella Coola and Whitesail Lake map areas along the east side of the Coast Plutonic Complex. Volcanic clasts in the Hauterivian sediments are lithologically similar to the Ottarasko volcanics, suggesting that Ottarasko volcanics were their source. This evidence is consistent with an Early Cretaceous age for the Ottarasko volcanics, but this suggestion must remain little more than a guess. U-Pb dating of the volcanic rocks is underway in an attempt to resolve the matter.

STRUCTURE

Northeasterly verging thrust faults and spectacular recumbent folds are the main structures in the area. The thrust belt is continuous for 35 km along strike before passing out of the area mapped. Closely spaced thrusts bound thin slices of volcanic rocks, limestone,and clastic rocks north of Ottarasko Mountain and west of Razorback Mountain. South and east of this area, Lower Cretaceous sedimentary strata outcrop extensively and form mountain-scale, recumbent or gently inclined tight to isoclinal folds that are bounded by thrusts. Throughout the area, the thrusts strike northwest to north; small segments strike northeast. Dips are generally 10 to 35° southwest or west, although dips locally reach 60° on ramp portions of the thrusts.

Where exposed, the thrusts are marked by zones of highly strained phyllite, limestone, sandstone or conglomerate. Clasts in sandstone, conglomerate, and lapilli-rich phyllite are strongly elongated within and near the thrusts. The orientation of these lineations is remarkably consistent. Along the 35 km of the thrust belt examined, the lineations plunge gently southwest or, rarely, northeast (Fig. 2). The uniformity of the lineation directions suggests that little deformation has occurred since thrusting, although the thrust belt could have been tilted as one large block. In addition to the lineated rocks, the thrusts also typically contain phyllite and marble with a penetrative cleavage that is parallel to the attitude of the thrusts. In a few outcrops, clasts in the sandstones are flattened as well as elongated, and define a foliation parallel to the cleavage in the phyllite and marble. Most flattening fabrics are symmetric; rotated clasts were seen in only one outcrop where they suggest the direction of transport is to the northeast.

Several thrust sheets of Lower Cretaceous clastic rocks lie west of the Ottarasko fault. Clastic rocks between the thrusts commonly form nearly recumbent, tight to isoclinal folds that are overturned to the east or northeast; folds have axial planes inclined 5-25° west or southwest, and plunge gently northwest to southwest (Fig. 2). The largest exposed

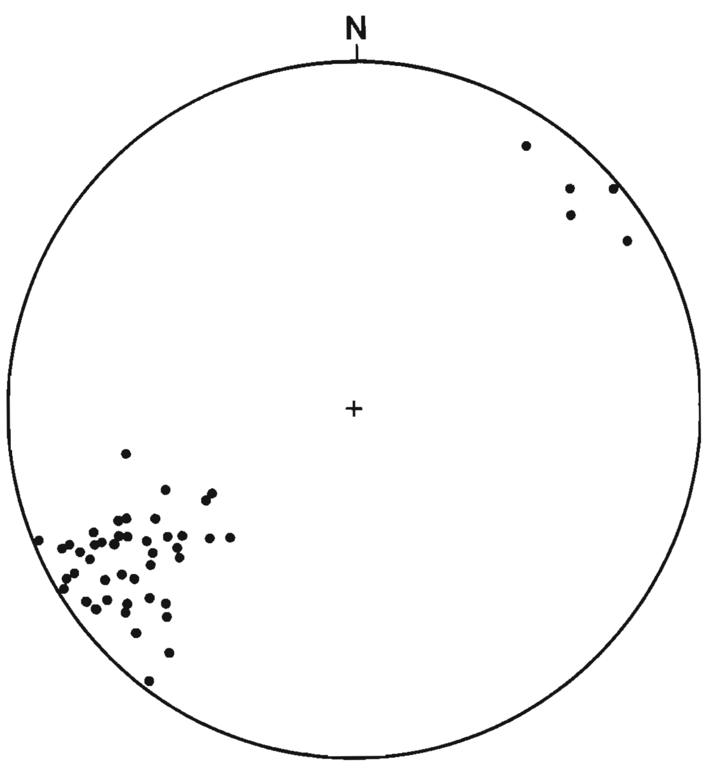


Figure 2. Stereographic projection of elongation lineations from the Niut Range.

Figure 3. Upper Triassic basalts thrust over Lower Cretaceous sediments on the southwest side of Ottarasko Mountain. The thrust is marked by a light coloured band of intensely deformed Upper Triassic limestone.

Figure 4. Highly imbricated lenses of Upper Triassic strata structurally overlain by Lower Cretaceous(?) Ottarasko volcanics (lighter, massive rocks that make up the upper third of the section). Looking northwest to the ridge 3 km west of Razorback Mountain.

tight folds have half-wavelengths of about 700 m. In outcrop, the clastic rocks typically appear undeformed; sedimentary structures and clast shapes are well preserved. Only in the hinge regions is a weak cleavage present in the shale.

Thrusts bearing the Upper Triassic Mt. Moore volcanics in their upper plate mark the western and southern edge of extensive exposures of Lower Cretaceous clastic rocks (Fig. 3). West of these thrusts, the Lower Cretaceous clastic rocks occur only as small thrust-bounded lenses. In the southern part of the map area, greenschist facies metavolcanic breccias are juxtaposed against the clastic rocks along a south-dipping thrust. West of Razorback Mountain, thin lenses of Upper Triassic rocks form an imbricate zone about 400 m thick that dips 20-40° to the southwest (Fig. 4). A few slices of Lower Cretaceous clastic rocks are also present in this imbricate zone. Andesitic to dacitic "sills" occur as boudins several metres long oriented parallel to the cleavage in the surrounding phyllites. Boudinaged plagioclase phenocrysts define a gently southwest-plunging elongation lineation that parallels lineations throughout the imbricate zone. Boudin necks are perpendicular to this lineation. To place an older limit on the age of the thrusting, we collected one of the deformed sills for U-Pb dating on zircon.

Five or more thrust-bound sheets of Ottarasko volcanics structurally overlie the imbricate zone west of Razorback Mountain. Each sheet is bounded by a layer of Lower Cretaceous(?) cleaved black shale and sandstone that presumably marks a thrust horizon. Maroon shale and marble occur in a few of these horizons. If the Ottarasko volcanics are Lower Cretaceous, then the western thrusts place younger rocks over older (Upper Triassic) strata. Our work to date leads us to suspect that this relationship results from the presence of a profound angular unconformity between the Upper Triassic strata and the Ottarasko volcanics, although out-of-sequence thrusting could explain the structural order. We consider it unlikely that the faults are low angle normal faults, as they are indistinguishable from structurally lower thrusts.

Field evidence suggests that the thrusts moved from southwest to northeast. Most fold axes lie at high angles to the elongation lineation (Fig. 5), suggesting the transport direction is parallel to the lineation. Northeast-directed, rather than southwestward, thrusting is supported by the northeast vergence of several very large folds, and by thrusts that steepen and cut upsection to the northeast. The one outcrop where we observed rotated clasts also indicates transport to the northeast.

The thrust belt may include rocks as young as Late Cretaceous. Volcanic rocks of the Kingsvale Group are juxtaposed against Lower Cretaceous clastic rocks to the west by the Ottarasko fault, mapped by Tipper (1969) as a high-angle strike slip fault. However, east of Razorback Mountain, cleaved phyllite in the Ottarasko fault zone dips 30-60° to the southwest, and contains gently southwest-plunging elongation lineations. These features suggest but do not prove that the Ottarasko fault is part of the thrust system and not a transcurrent fault. If so, the Kingsvale Group is the structurally lowest plate, and thrusting is Late Cretaceous or younger.

The thrusts are older than a quartz diorite pluton that intrudes a thrust south of Ottarasko Mountain. Three zircon fractions gave a concordant U-Pb date of 68 $\pm$ 0.3 Ma (R.R. Parrish, pers. comm., 1987). Thrusting is thus probably Late Cretaceous in age, and certainly no older than Late Hauterivian.

The thrusts dip southwesterly under the Coast Plutonic Complex which lies only a few kilometres west of the area mapped. West of Nude Creek, metamorphic rocks locally contain staurolite and have elongation lineations that plunge gently to moderately southwest (GJW, unpubl. data). This geometry suggests that the Coast Plutonic Complex may be the highest grade and structurally highest plate in the thrust system.

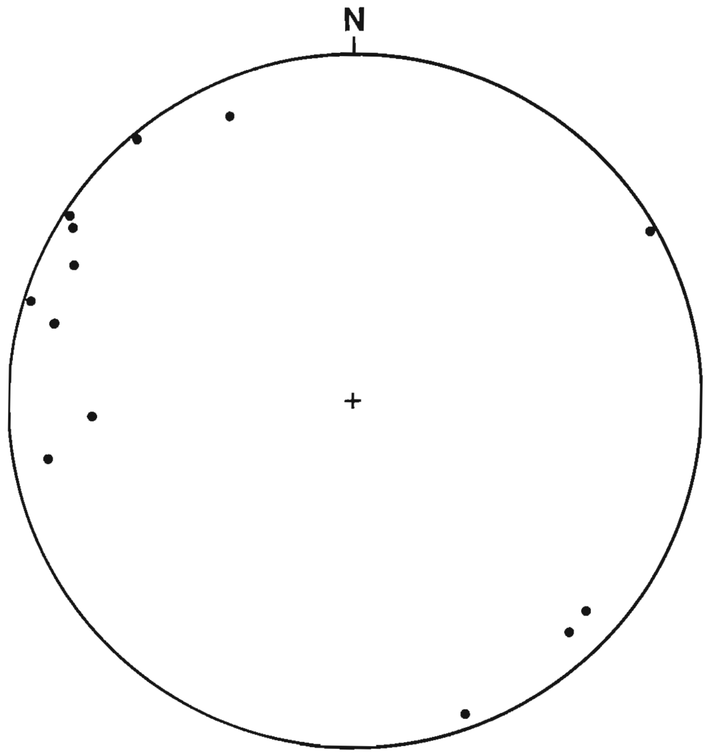


Figure 5. Stereographic projection of fold axes from the Niut Range.

As a final note, we point out that Late Cretaceous deformation is also characteristic of the Atna Peak area on the east edge of the Coast Plutonic Complex southeast of Terrace, B.C. (G.J. Woodsworth and E.D. Ghent, unpubl. data) and in the Mt. Raleigh area within the eastern Coast Plutonic Complex (Woodsworth, 1979). Like the Niut Range, these areas are characterized by elongation lineations that plunge gently to moderately southwest or northeast.

ACKNOWLEDGMENTS

Fieldwork for this project is funded jointly by the Geological Survey of Canada (GJW) and by a grant from the Petroleum Research Fund, administered by the American Chemical Society (MER). We thank Felix St. Augustine, Eric Wilmanns, and David Woodsworth for cheerful assistance in the field. Eric Wilmanns also contributed microprobe data from his Senior thesis. Mike King of White Saddle Air Services provided outstanding flying; Audrey King and Jen King gave us gracious hospitality at Bluff Lake.

REFERENCES

Davis, A. and Plafker, G.
1985: Comparative geochemistry and petrology of Triassic basaltic rocks from the Taku terrane on the Chilkat Peninsula and Wrangellia; Canadian Journal of Earth Sciences, v. 22, p. 183-194.

Monger, J.W.H.
1977: The Triassic Takla Group in McConnell Creek map-area, north-central British Columbia; Geological Survey of Canada, Paper 76-29, 44 p.

1980: Upper Triassic stratigraphy, Dease Lake and Tulsequah map areas, northwestern British Columbia; *in* Current Research, Part B, Geological Survey of Canada, Paper 80-1B, p. 1-9.

Roddick, J.A. and Tipper, H.W.
1985: Geology, Mount Waddington (92N) map area; Geological Survey of Canada, Open File 1163.

Rusmore, M.E.
1987: Geology of the Cadwallader Group and the Intermontane — Insular superterrane boundary, southern British Columbia; Canadian Journal of Earth Sciences, v. 24.

Rusmore, M., Woodsworth, G.J., and Wilmanns, E.
1987: Stratigraphy and structure of rocks along the eastern margin of the Coast Plutonic Complex west of Chilko Lake, British Columbia; Geological Society of America, Abstracts with Programs, v. 19, p. 446.

Tipper, H.W.
1969: Mesozoic and Cenozoic geology of the northeast part of Mount Waddington map-area (92N), Coast District, British Columbia; Geological Survey of Canada, Paper 68-33, 103 p.

van der Heyden, P.
1982: Tectonic and stratigraphic relations between the Coast Plutonic Complex and Intermontane Belt, west-central Whitesail Lake map area, British Columbia; unpublished MSc thesis, University of British Columbia, 172 p.

Wilmanns, E.G.
1987: Compositions of the Moore Peak clinopyroxenes and their tectonic implications; unpublished BA thesis, Occidental College, California, 31 p.

Woodsworth, G.J.
1979: Metamorphism, deformation, and plutonism in the Mount Raleigh pendant, Coast Mountains, British Columbia; Geological Survey of Canada, Bulletin 295, 58 p.

Paleomagnetism of lake sediment cores from McLeod Lake and McBride map areas, central British Columbia

E.A. Fuller[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Fuller, E.A., Paleomagnetism of lake sediment cores from McLeod Lake and McBride map areas, central British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 191-195, 1988.

Abstract

Lake sediment cores were taken from six lakes using a pneumatic coring device (Mackereth corer). Of these, cores from McLeod and Narrow lakes were sampled and specimens analyzed using a spinner magnetometer. The resulting paleomagnetic inclinations are presented (natural remanent magnetism (NRM) and after magnetic cleaning at 20 mT). Magnetic stability tests on pilot samples, using Zijderveld graphs, indicate that the magnetism is stable and that these lake sediments have high potential for secular variation work.

Trends of turning points along a generalized secular variation line correlate between the three measured cores although the absolute values are shifted. In the Narrow Lake core a magnetically disturbed zone corresponds with a silty clay layer with organic debris.

Résumé

Des carottes de sédiments lacustres ont été prélevées dans six lacs au moyen d'une carotteuse pneumatique Mackereth. De celle-ci, les carottes des lacs McLeod et Narrow ont été triées et des échantillons ont été analysés au moyen d'un magnétomètre rotatif. Les inclinaisons paléomagnétiques résultantes sont présentées (magnétisme rémanant naturel (MRN) et après nettoyage magnétique à 20 mT). Des essais de stabilité magnétique sur des échantillons de référence, basés sur des diagrammes de Zijderveld, indiquent que le magnétisme est stable et ces sédiments lacustres conviendraient bien à des travaux sur les variations séculaires.

Il existe une corrélation étroite entre les tendances des points de virage le long d'une ligne de variation séculaire généralisée et les trois carottes mesurées même si les valeurs absolues sont décalées. Dans la carotte du lac Narrow, une zone de perturbation magnétique correspond à une couche de silt argileux contenant des débris organiques.

[1] Department of Geology, University of Western Ontario, London Ontario N6A 5B7

INTRODUCTION

Recent lake sediments can record past variations in the geomagnetic field. These perturbations, called Holocene secular variations, can be determined by measuring magnetism of samples taken from lake-sediment cores. The resulting data, commonly declination and inclination, are graphed against depth to show secular variation and to correlate one record with another. This paper provides the preliminary results of paleomagnetic work on three cores from central British Columbia; it is a feasibility study.

The objective is to study Holocene sedimentation in selected lakes of central British Columbia by correlating the bottom sediments within- and between-lakes. Research of this type has been done in other parts of Canada; for example in the Great Lakes (Mothersill, 1979, 1981, 1982, 1984a,b; Anderson, 1976; Dodson, 1977), northern Alberta (Turner, 1982a), the Arctic (Retelle, 1985) and Vancouver Island (J.S. Mothersill, pers. comm., 1987). This is the first lake sediment paleomagnetic study in central British Columbia.

During the 1987 field season cores were taken from five lakes in McLeod Lake map area and one lake in McBride map area (Fig. 1). The lakes were chosen based on accessibility, sufficient depth and potential for fine grained sediment. Depth requirements were constrained by the pneumatic coring device. Textures of the sediments may preclude their suitability for acquiring depositional remanent magnetism. Fine grained sediments appear to be best suited for paleomagnetic lake sediment work (Barendregt, 1981). Lakes with bedrock sources of detrital magnetite in their watershed are preferred. In the present case the source of magnetite is from the mafic volcanic rocks of the Slide Mountain and Takla groups (Campbell et al., 1973; Muller and Tipper, 1969).

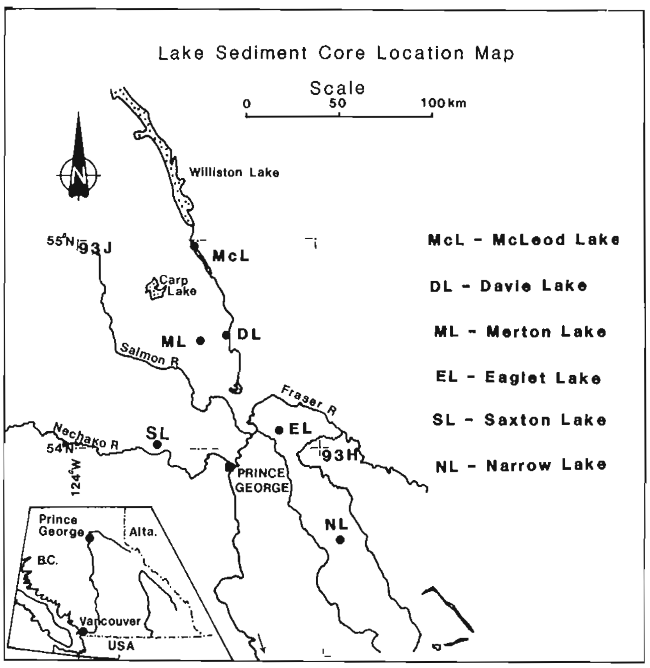


Figure 1. Location of lakes cored for paleomagnetic measurements in central British Columbia.

PROCEDURE

The cores were collected from a small inflatable boat using a Mackereth corer (Fig. 2) capable of obtaining 6 m of continuous core in plastic pipe of 5 cm internal diameter. The coring method followed that of Turner (1982b) and a description of the operation of the corer is given by Mackereth (1958, 1969).

Partial cores were collected from Eaglet Lake, Davie Lake, McLeod Lake, Saxton Lake, and Narrow Lake. A complete core was collected from Merton Lake.

The laboratory work was conducted at Geological Survey of Canada facilities at the Pacific Geoscience Centre (PGC), Sidney, B.C. where the core tubes were marked, split and sampled at 3 cm spacing from top to bottom. Rare intervals with organic debris were not sampled for study.

Magnetic measurements were obtained with a Schonstedt spinner magnetometer connected to an IBM personal computer. Specimen measurement using the Softsed computer program generated declination, inclination, field intensity and statistical data. However, because the coring device was not oriented on the lake bottom, the declination data are arbitrarily set and inclination data were not corrected for possible nonvertical attitudes of the corer. In this paper only the inclination data is presented. Core logging included measurement of the angles between the core axis and bedding to indicate deviations from the vertical. A correction can be applied to help compensate for this error (E. Irving, pers. comm., 1987).

Because this is a feasibility study, only cores most likely to contain sufficient magnetite and hence remnant magnetism were measured. In this case the Narrow Lake core NL87-01 was chosen. Measurements on 113 samples were made to determine if the material was sufficiently magnetized for measurement and if the measurements had sufficient precision to be statistically useful (Tarling, 1983).

The stability of the remanent magnetism was tested using step-wise alternating field (AF) demagnetization along

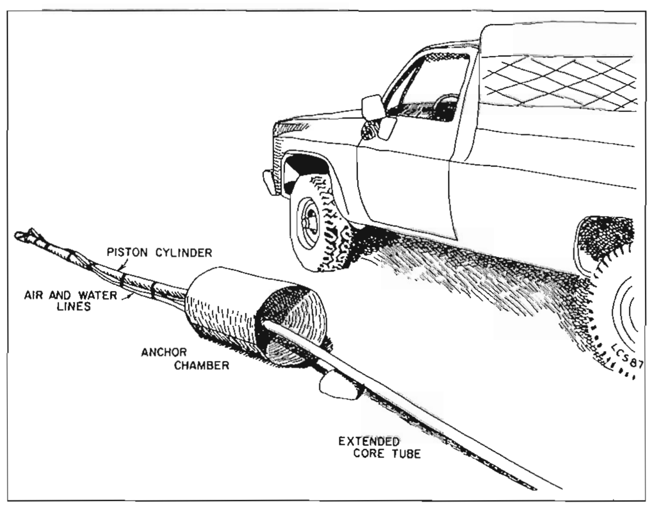


Figure 2. Mackereth corer with fully extended core tube; drawn from a photograph.

three perpendicular axes in increments from 5 mT to 90 mT on a pilot group of six samples each from NL87-01 and NL87-02. The components of the resultant magnetic vector for each applied alternating field are plotted against the magnetic intensity ratio, where initial NRM intensity is one, shown on orthogonal plots (Zijderveld graphs, Fig. 3). Stability is indicated by the linearity of the path over a range of applied magnetic fields.

The other samples were measured after cleaning at the end points of the linear range. The resulting plots of inclination (Fig. 4), generated from commercial software (Symphony and Lotus 1-2-3), indicate natural remanent magnetism (NRM) and magnetically cleaned sample magnetism. Turning points (locii on a generalized curve corresponding to swings about a maximum or minimum inclination) were identified and labelled using Greek letters following the convention of Mackereth (1971) (Fig. 5).

RESULTS

In the Narrow Lake cores the linear demagnetization path, for the two sets of pilot samples, falls between 20 and 60 milliteslas (mT) (Fig. 4) suggesting that the magnetism is stable (hard) and that whole core demagnetization can be carried out at 20 mT and 60 mT. The lake sediment paleomagnetic records for Narrow Lake show general agreement in inclination between cores from the same lake. In detail, the top metre for each core exhibits a uniform trend with an abrupt break at 100 cm. At this discontinuity there is a marked disruption in inclination data which persists to 150 cm in NL87-01 and to the end of NL87-02 at 200 cm. From the base of these scattered data NL87-01 regains a smooth trend to 300 cm. Stratigraphically the core (NL87-01) contains an organic debris layer at the base of the disruption and sparse organic debris upward in the section.

Beneath 300 cm NL87-01 becomes disorganized in inclinations coinciding with a change in core-bedding plane angle from 80 to 60°.

The McLeod Lake core (McL87-01) record is very smooth and well defined throughout its length (2.39 m). A second core (McL87-02) was collected but has not been analyzed. Both cores were taken from a deep part of the lake (20 m) near the mouth of McLeod River.

The striking similarity between inclination records for McLeod Lake core and Narrow Lake core (NL87-01) from 25 cm to 220 cm provides strong evidence of correlation from lake to lake. An increase in inclination in the McLeod Lake core below 220 m was not noted in the Narrow Lake core. The discrepancy may result from faster sedimentation in Narrow Lake indicated by constancy in inclination with depth.

CONCLUSIONS

The Narrow Lake sediments have a hard magnetization, presumably acquired at the time of deposition or post-depositionally. Samples cleaned at 20 mT show a tighter path of magnetic inclination. Correlation between two cores from the same lake (Narrow Lake) appears to be valid based on the distribution of data points; scattered data points lie at the same depth with less scattered points above and below

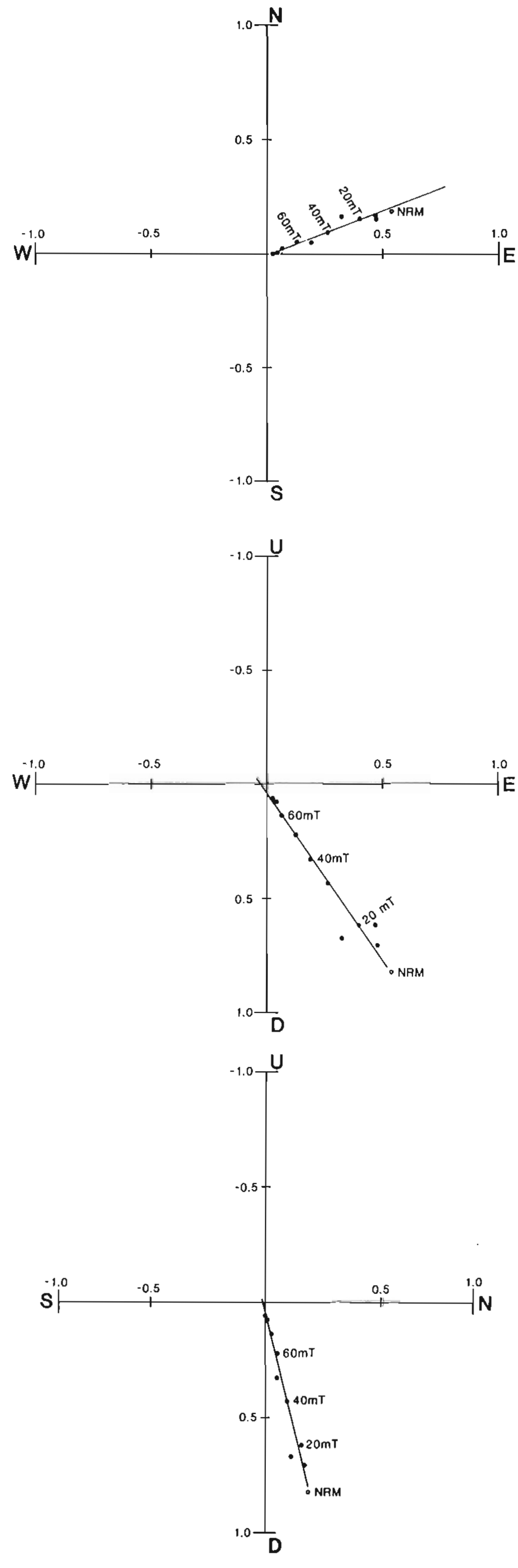


Figure 3. Orthogonal plots of a pilot specimen from 105 cm depth in NL87-01 core. The alternating field (AF) demagnetization shows a single component of magnetization. U and D refer to up direction (negative) and down direction (positive) respectively; East (E) and North (N) are positive, and West (W) and South (S) are negative.

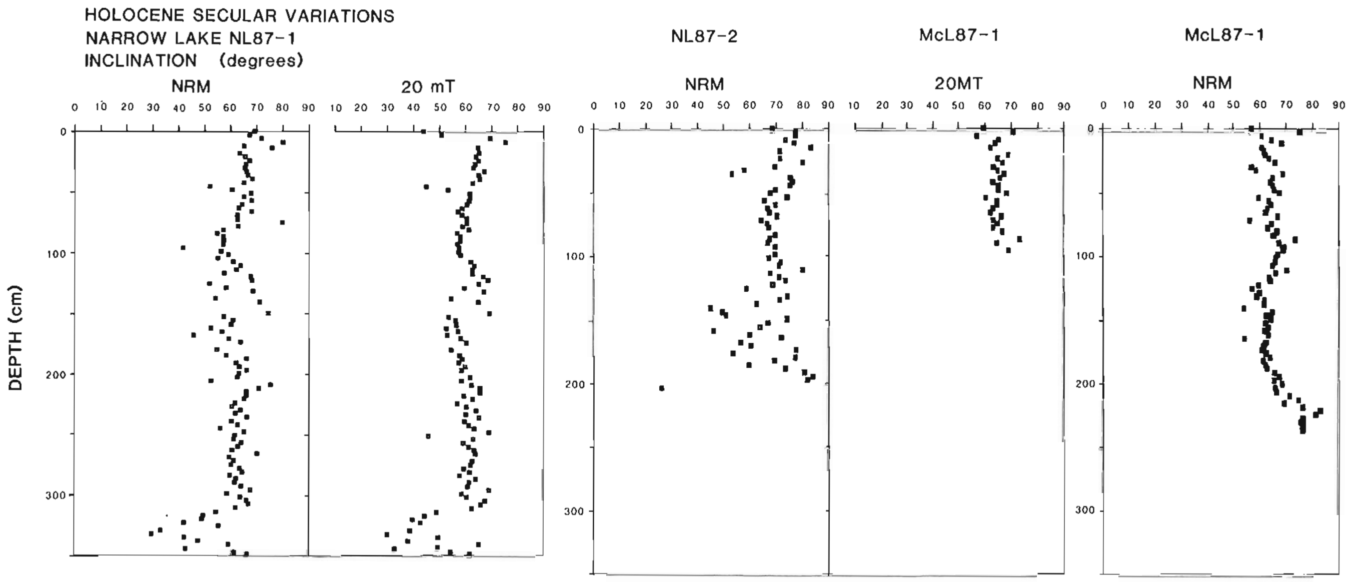
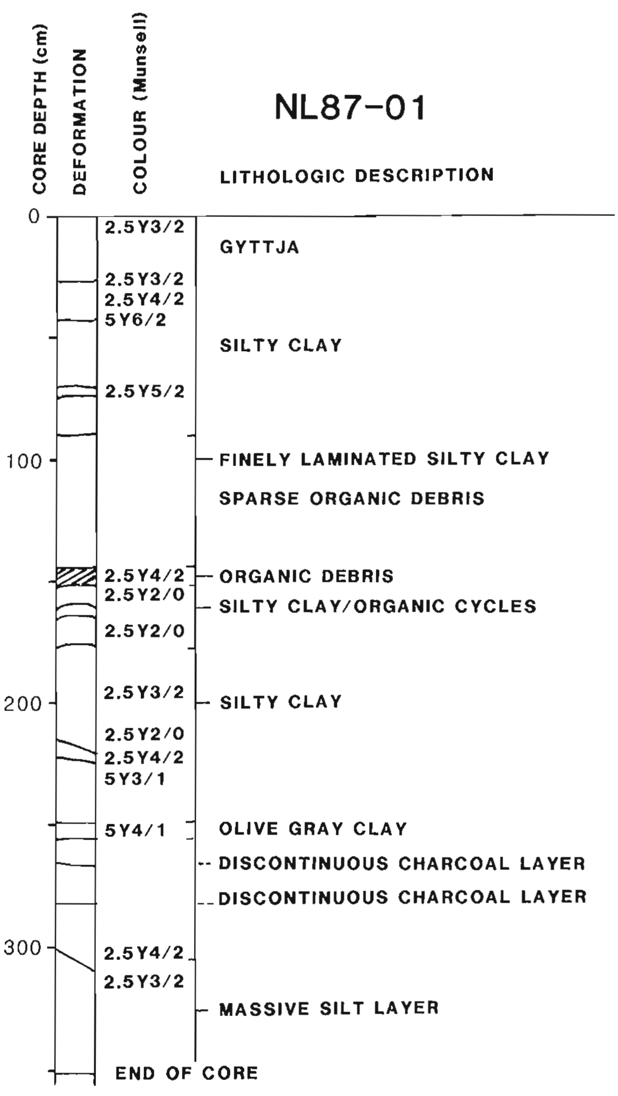


Figure 4. Inclination records for Narrow Lake cores NL87-01, NL87-02, and McLeod Lake core McL87-01. NRM = Natural Remanant Magmatism, 20 mt = after subjected to 20 mt alternating field.



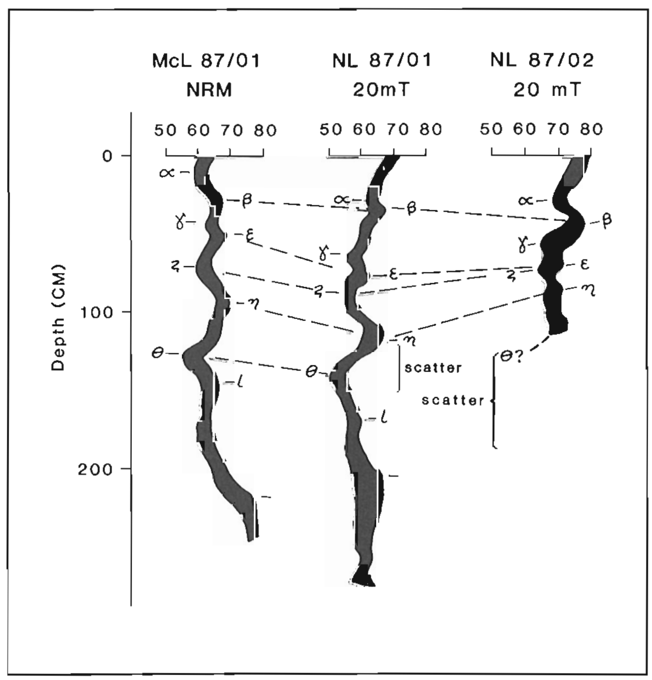


Figure 6. Correlation of lake sediment paleomagnetic records using Mackereth (1971) method of matching inflection points.

Figure 5. Core log of NL87-01 showing location of organic debris where the paleomagnetic record is disrupted. Also shown is the extent of bedding deformation caused by the coring process.

this disruption. The magnetic record for McLeod Lake (NRM) is very well defined and qualitatively the inclination variation down the core length correlates with that from Narrow Lake.

The coring method and sample measurement were successful in obtaining records of changes in paleomagnetism for lake sediment cores. Where the data are scattered the sediment is presumed to have undergone post-depositional reorganization of mineral grains. The process responsible is not known but inferred to be from compaction or mass movement.

ACKNOWLEDGMENTS

The Quaternary aspects of McLeod Lake map area were carried out as part of the regional mapping project supervised by L.C. Struik who assisted with most of the coring. The Mackereth corer used was built at the University of Alberta under the guidance of Gillian Turner and Ian Gough and was loaned by Ian Gough and Ted Evans (both of the Physics Department, University of Alberta). The British Columbia Ministry of the Environment at Prince George and Victoria supplied information on lake bathymetry and composition of lake bottom dredge samples. Ted Faulkner, District Geologist for Prince George, B.C. Ministry of Energy, Mines and Petroleum Resources supplied logistical support and regional expertise. Ted Irving and Jane Wynne as well as several GSC staff at the Pacific Geoscience Centre provided technical instruction and use of the paleomagnetic laboratory and computer facilities.

REFERENCES

Anderson, T.W.
1976: Late Quaternary paleomagnetic stratigraphy from east-central Lake Ontario; *in* Current Research, Part C, Geological Survey of Canada, Paper 76-1C, p. 203-206.

Barendregt, R.W.
1981: Dating methods of Pleistocene deposits and their problems; VI, Paleomagnetism; Geoscience Canada, v. 8, p. 56-64.

Campbell, R.B., Mountjoy, E.W., and Young, F.G.
1973: Geology of the McBride map area, British Columbia; Geological Survey of Canada, Paper 72-35, 104 p.

Dodson, R.E.
1977: Paleomagnetic records of secular variation from Lake Michigan sediment cores; Earth and Planetary Science Letters, v. 34, p. 387-395.

Mackereth, F.J.H.
1958: A portable core sampler for lake deposits; Limnology and Oceanography, v. 3, p. 181-191.
1969: A short core sampler for subaqueous deposits; Limnology and Oceanography, v. 14, no. 1, p. 145-151.
1971: On the variation in direction of the horizontal component of remanent magnetization in lake sediments; Earth and Planetary Science Letters, v. 12, p. 332-338.

Mothersill, J.S.
1979: The paleomagnetic record of the late Quaternary sediments of Thunder Bay; Canadian Journal of Earth Sciences, v. 16, no. 5, p. 1016-1023.
1981: Late Quaternary paleomagnetic record of the Goderich Basin, Lake Huron; Canadian Journal of Earth Sciences, v. 18, no. 3, p. 448-456.
1982: Late Quaternary stratigraphic sequence of the Goderich Basin: texture, mineralogy, and paleomagnetic record; Journal of Great Lakes Research, v. 8, no. 3, p. 578-586.
1984a: The use of paleomagnetic curves for chronostratigraphic correlation of late Quaternary fluvial, estuarine and lacustrine stratigraphic sequences in Nipigon Bay, Lake Superior, Ontario, Canada; *in* Geochronology of Recent Deposits, a selection of papers presented to a Symposium on the Geochronology of Recent Deposits as part of the 11th International Association of Sedimentologists' Congress, ed. J.A. Robbins; Chemical Geology, v. 44, 1-3, p. 243-252.
1984b: Paleomagnetic columns; a method for time parallel correlation and absolute dating of late Quaternary sequences of the Great Lakes area; *in* Correlation of Quaternary Chronologies, ed. W.C. Mahaney; Geobooks, Norwich, United Kingdom.

Muller, J.E. and Tipper, H.W.
1969: Geology of the McLeod Lake map area, British Columbia; Geological Survey of Canada, Map 1204A.

Retelle, M.J.
1985: Glacial geology and Quaternary marine and lacustrine stratigraphy of the Robeson Channel area, northeastern Ellesmere Island, N.W.T., Canada; unpublished PhD thesis, University of Massachusetts, Amherst, 243 p.

Tarling, D.H.
1983: Palaeomagmatism: Principles and Applications in Geology, Geophysics and Archaeology; Chapman and Hall, London, United Kingdom, 379 p.

Thompson, R. and Oldfield, R.
1986: Environmental Magmatism; Allen and Unwin, Boston, Massachusetts, 227 p.

Turner,
1982a: A geomagnetic secular variation study (3100-19500 bp) in western Canada; The Geophysical Journal of The Royal Astronomical Society, v. 71, no. 1, p. 159-171.
1982b: Mackereth corer operating manual; unpublished manuscript, University of Alberta, Physics Department, Edmonton, Alberta, 26 p.

Trace fossils and stratigraphy of the Precambrian-Cambrian boundary sequence, upper Harper group, Ogilvie Mountains, Yukon

P.S. Mustard[1], J.A. Donaldson[1], and R.I. Thompson
Cordilleran and Pacific Geoscience Division, Vancouver

Mustard, P.S., Donaldson, J.A., and Thompson, R.I., Trace fossils and stratigraphy of the Precambrian-Cambrian boundary sequence, upper Harper group, Ogilvie Mountains, Yukon; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 197-203, 1988.

Abstract

The informally named Harper group includes up to 2500 m of sedimentary and volcanic strata deposited during Late Proterozoic extension tectonics along the western margin of North America. The upper Harper group unconformably overlies Proterozoic dolostones, except in the Mt. Harper area where it conformably overlies the Harper Volcanic Complex (751 Ma). Clastic dolostones predominate, except in the stratigraphically highest map unit, in which abundant quartz wacke and rare chert pebble conglomerate are interbedded with dolomitic wacke. The Harper group is disconformably overlain by dolostone that contains sparse Early Cambrian Archaeocyathids near the base.

Trace fossils occur at several localities in the top 50 m of the Harper group. Ichnogenera include Planelites, Rusophycus, Cruziana, Arenicolites, Diplocraterion *and possibly* Chondrites. Rusophycus *and* Cruziana *suggest an Early Cambrian age. This find is significant in terms of both regional correlation and our understanding of late Precambrian-Cambrian evolution of the western North America margin.*

Résumé

Le groupe de Harper, non formellement reconnu, comprend jusqu'à 2500 m de couches sédimentaires et volcaniques qui ont été déposées le long de la marge occidentale de l'Amérique du Nord durant son extension vers la fin du Protérozoïque. La partie supérieure du groupe de Harper repose en discordance sur des dolomies d'âge protérozoïque, sauf dans la région du mont Harper, où elle repose en concordance sur le complexe volcanique de Harper (750 Ma). Les dolomies clastiques prédominent, sauf dans l'unité cartographique qui est stratigraphiquement la plus élevée. À l'intérieur de cette dernière, des wackes quartziques abondantes se trouvent interstratifiées avec de rares conglomérats à galets silicieux. Une unité de dolomie qui renferme de rares Archéocyatides (d'âge cambrien inférieur à intermédiaire) vers la base, repose en discordance stratigraphique sur le groupe de Harper.

Des traces de fossiles apparaissent à plusieurs localités à l'intérieur des 50 derniers mètres du groupe de Harper. Les ichnogenres comprennent: Planelites, Rusophycus, Cruziana, Arénicolites, Diplocratérion *et peut-être* Chondrites. *La présence de* Rusophycus *et* Cruziana *indique la possibilité d'un âge cambrien inférieur. Cette découverte est importante à l'égard des corrélations régionales aussi bien que de notre compréhension de l'évolution de la marge occidentale de l'Amérique du Nord à la fin du Précambrien et au début du Cambrien.*

[1] Ottawa-Carleton Geoscience Centre, Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6

INTRODUCTION

The informally named Harper group outcrops in the southern Ogilvie Mountains approximately 75-125 km northwest of Dawson, Yukon, in the Dawson map area (NTS 116B,C; Fig. 1). This report results from a detailed study of the Harper group sedimentary rocks, in progress by the senior author. The study is an outcome of the regional mapping program initiated in 1981 (Thompson and Roots, 1982), and is complementary to a study of the volcanic rocks and tectonic setting of the Harper group by Roots (1987).

REGIONAL FRAMEWORK

The Ogilvie Mountains are the northwesterly extension of the Cordilleran foreland fold and thrust belt. Sedimentary and volcanic rocks of the Ogilvie Mountains, ranging in age from mid-Proterozoic to Jurassic, were thrust northward during late Mesozoic — early Tertiary compression. Intrusive rocks consist of mid-Cretaceous syenitic plutons (Anderson, 1987). Within the Dawson map area, Proterozoic rocks occur as two geographically and lithologically distinct assemblages separated by a major east-trending thrust. South of the thrust, a thick succession of quartzofeldspathic sandstones, granulestones, and interbedded phyllites is overlain by a prominent light-grey-weathering limestone unit, in turn overlain by maroon and green argillites and siltstones (the latter contain the Early to Middle Cambrian trace fossil Oldhamia). Rare flutes on the soles of sandstone beds in this package indicate northerly sediment transport. This package is correlated with the "Grit Unit" of previous workers in the Dawson map sheet (Green, 1972) and in other parts of the Yukon (Gabrielse et al., 1973; Hofmann and Cecile, 1981). It corresponds to the proposed Hyland Group of Gordey (pers. comm., 1987) from the central Yukon. North of the thrust, Proterozoic rocks are generally confined to a broad, east-trending erosional inlier, named the "Coal Creek Dome" by Green (1972). Within this inlier, the oldest rocks consist of a thick (>4 km) succession of fine grained siliciclastic strata that are crosscut by heterolithic breccias, and an overlying unit of locally stromatolitic dolostone. These rocks are correlated with the Middle Proterozoic Wernecke Supergroup of the Wernecke Mountains to the east (Thompson and Roots, 1982; Delaney, 1981). These strata are unconformably overlain by >2km of platformal, locally stromatolitic dolostones, and less abundant basal mudstones and conglomerates. This sequence, here informally termed the Fifteenmile group, may correlate with the Middle Proterozoic Pinguicula Group and/or Mackenzie Mountain Supergroup to the east.

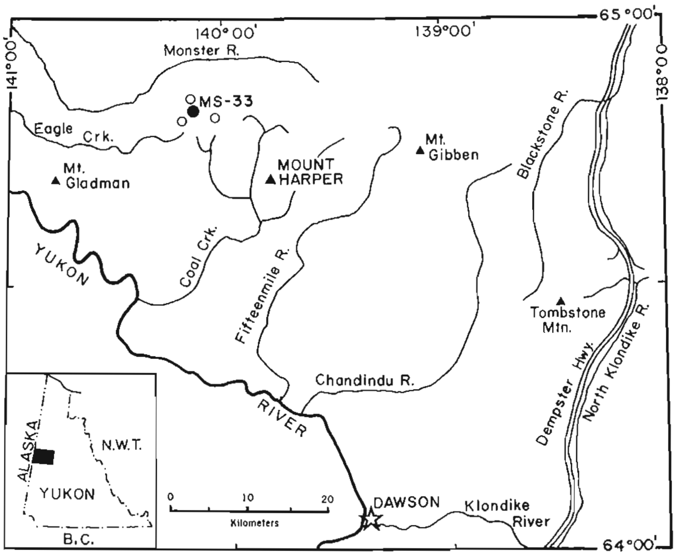


Figure 1. Dawson map sheet (NTS 116B,C) showing major geographic features, location of measured section MS-33 of Figures 3b and 4 (filled circle) and additional trace fossil localities (open circles).

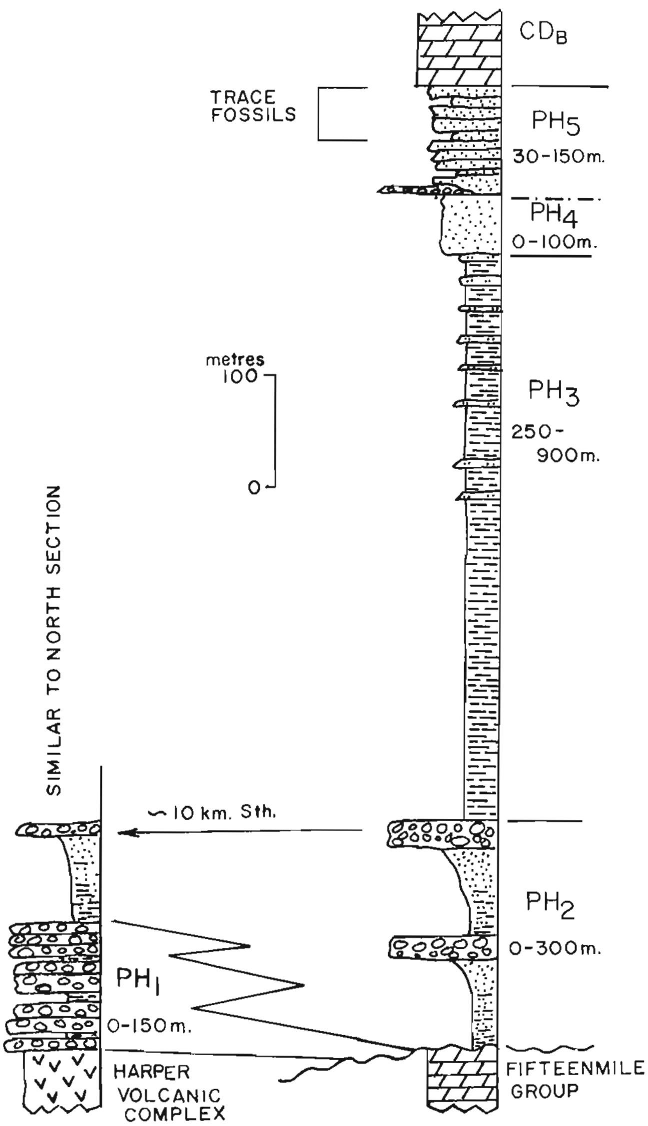


Figure 2. Generalized stratigraphic column for the upper Harper group showing map unit designations (PH_1 — PH_5, CD_B) and illustrating the restricted occurrence of unit PH_1 to areas overlying the Harper Volcanic Complex, mostly south of the main trace-fossil bearing strata. See text for description of the units.

The Harper group, which unconformably overlies the Fifteenmile Group, is preserved along the south and west margins of the inlier. It consists of a lower conglomerate-rich unit (0-900 m), the central Harper Volcanic Complex (0-1200 m), and an upper unit of conglomerate, sandstone, mudstone and minor limestone (0-1400 m). All of the sedimentary strata are unmetamorphosed and homoclinal, dipping 20-35° southwest. These units appear to have been deposited within a subsiding half-graben formed in response to major extension during the late Proterozoic (Thompson, 1986; Thompson et al., 1987; Roots, 1987).

Lower Harper group strata comprise coarse dolomitic conglomerate beds which interdigitate with, and overlie, dolomitic sandstone and mudstone to the north and northeast. The southern margin is defined by an exposed, syndepositional, high-angle normal fault. Northerly-directed paleocurrents reflect progradation of subaerial fans into a subaqueous (probably lacustrine) environment (Mustard and Donaldson, 1987). Clastic sedimentation was abruptly terminated by initial deposition of the conformably overlying Harper Volcanic Complex, a bimodal extrusive event related to deep crustal rifting (Roots and Thompson, 1986; Roots, 1986, 1987), dated (by U-Pb on zircons) at 751 + 21/-18 Ma (Roots, 1987). The upper Harper group is described below. Proterozoic strata of the erosional inlier are overlain by a distinctive unit of dolostone of Early Cambrian or younger age. Minor thrusts and normal faults with maximum displacements of a few hundred metres cut both the upper Harper Group and the Paleozoic dolostone in the northern and western parts of the map area.

STRATIGRAPHY OF THE UPPER HARPER GROUP

The upper Harper group overlies Middle Proterozoic dolostone of the Fifteenmile group with slight angular unconformity, except in the Mt. Harper area where it conformably overlies and interdigitates with the Harper Volcanic Complex. A generalized stratigraphic column is shown in Figure 2, and an oblique view of the major units is shown in Figure 3a. Basal intercalated volcanic and dolomitic conglomerates, as well as rare pyroclastic beds (unit PH_1, missing in the northern study area), give way upward to coarsening-up cycles of dolomitic mudstone-sandstone-conglomerate (unit PH_2). These cycles are overlain by, and are the lateral equivalent of, fissile black dolomitic mudstone and dark brown siltstone to fine grained dolomitic wacke (unit PH_3). This unit is overlain by lenticular and discontinuous bodies of fine- to medium-grained, orange-weathering dolomitic sandstone that display rare hummocky cross-stratification (unit PH_4). Thick (50-100 m) lenses of this sandstone are generally capped by 10-30 m of laminated black calcareous mudstone. The stratigraphically highest unit (PH_5) consists of up to 150 m of interbedded fine- to very-coarse-grained quartz wacke, fine grained dolomitic wacke and rare chert pebble conglomerate. Paleocurrent indicators are relatively common in the upper Harper group, and bed-tilt-corrected paleocurrents indicate southerly transport, except for those from siliciclastic sandstones and the chert pebble conglomerates (paleocurrents from these beds indicate northerly transport). Clasts in upper Harper group conglomerates are identical to lithologies of the underlying Fifteenmile Group, or

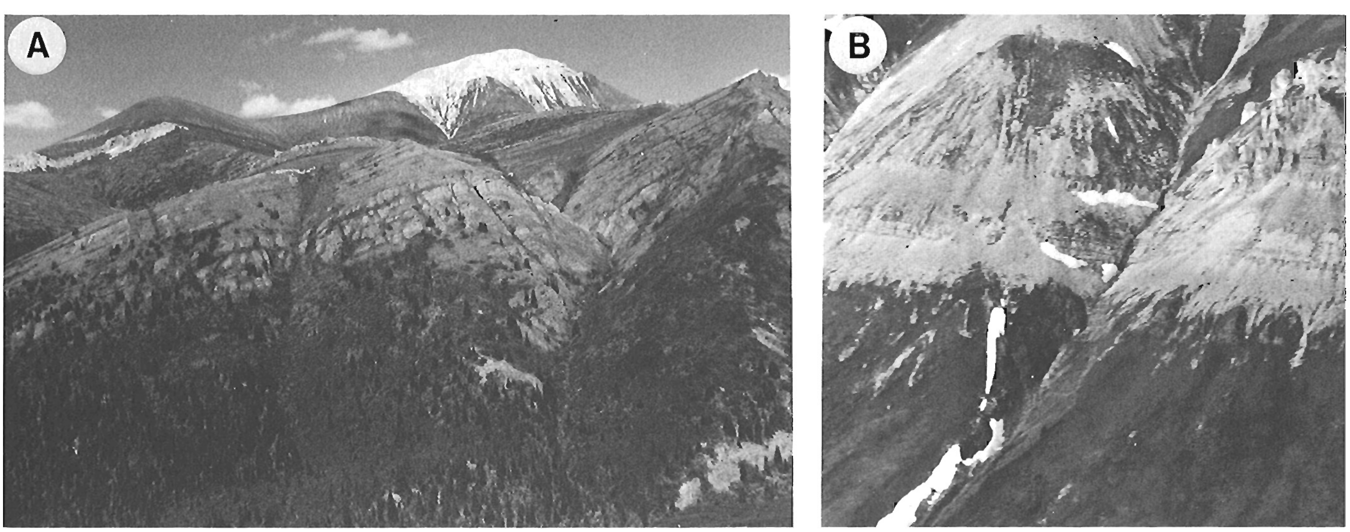


Figure 3. A. Slope containing almost the complete upper Harper group section (measured thickness of 1310 m), view foreshortened by telescopic lens. The basal contact with the Harper Volcanic Complex is not exposed in the photo, but occurs approximately 500 m to the east-northeast (right). Lower resistant strata are PH_1 — PH_2 conglomerates, overlain by PH_3, well-exposed in gullies, resistant PH_4, trace-fossil-bearing PH_5 (open circle southwest of MS-33, Fig. 1), and light-weathering CD_B dolostone at top.
B. East-facing exposure of measured section MS-33.

rarely the Harper Volcanic Complex (only in unit PH_1), with the exception of the light green chert clasts which make up >90 % of the chert pebble conglomerates. Provenance for these clasts is unknown. Mapping of these well exposed units at a scale of 1:25 000 demonstrates that contacts are conformable and generally gradational. No discontinuities were recognized. The Harper group is abruptly overlain by a distinctive, laterally extensive and thick (>300 m) light-grey-weathering, finely crystalline dolostone (Fig. 4a). Sparse Archaeocyathids from near the base of this unit have been identified as the late Lower Cambrian species tabulaconus. The contact between the Harper group and the dolostone unit is sharp, and bedding on both sides appears to be parallel, however, the abrupt change in lithology suggests that this contact represents a disconformity.

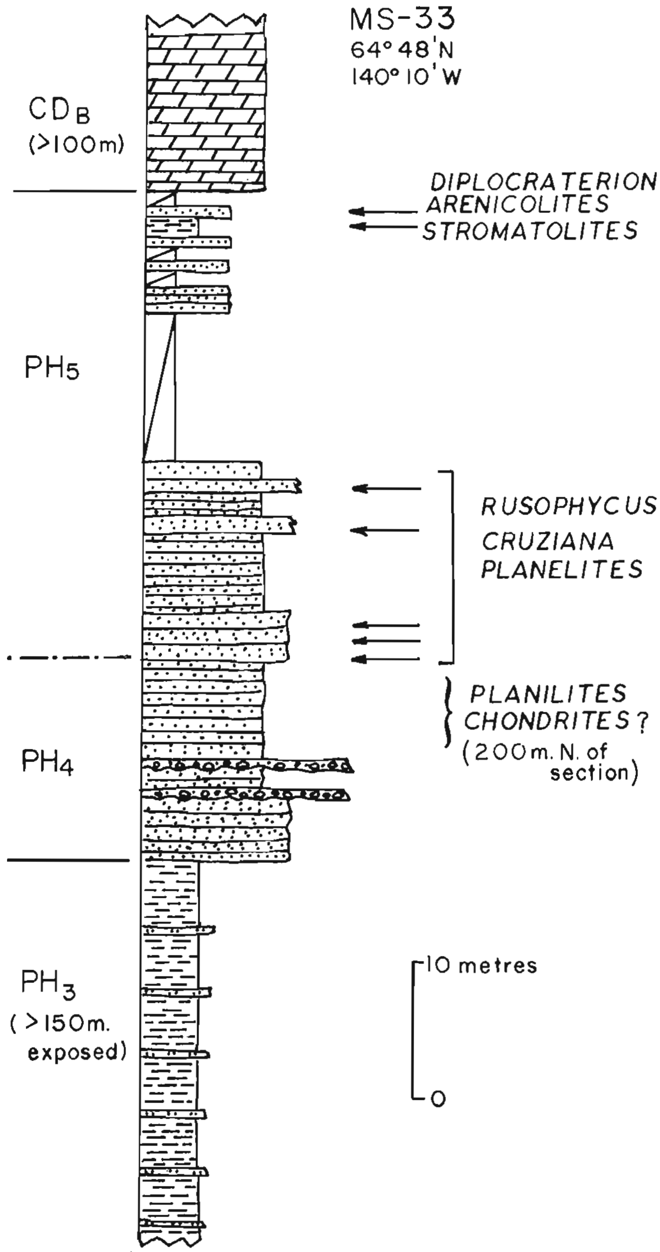


Figure 4. Section (MS-33) measured through trace-fossil-bearing map unit PH_5 indicating rock types and locations of trace fossils.

TRACE FOSSILS

Trace fossils were discovered at four localities (Fig. 1). All occurrences are within the uppermost mixed siliciclastic / carbonate-clastic map unit (PH_5), and all are less than 50 m from the upper contact of this unit. The trace fossils are best displayed on the lower surfaces of medium- to coarse-grained quartz wacke beds, most of which are normally graded and generally less than 5 cm thick; in a few places, composite bedsets up to 2 m thick display hummocky cross-stratification. Traces are less common on the soles of fine- to medium-grained, thin bedded dolomitic wackestones which are interbedded with the quartz wackes. Figures 3b and 4 illustrate a well exposed trace-fossil-bearing measured section. The traces have presently been identified at the ichnogenus level only. The most common are the primitive arthropod resting burrows Rusophycus (Fig. 5a,b,) and crawling trails Cruziana (Fig. 5c,d). These typically occur together on the same bed sole. The simple horizontal feeding burrow Planelites (Fig. 5e) is also common and occurs in approximately the same horizons, but not on the same bed soles as the arthropod traces. The branching horizontal feeding burrow Chondrites may occur as well, but examples are poorly preserved. Near the top of the illustrated section, abundant U-shaped burrows occur in a finely laminated, very fine grained dolomitic wackestone. These generally lack spreite, suggesting identification as Arenicolites (Fig. 5f), but some Diplocraterion containing spreite are also present. Centimetre-scale columnar stromatolites capped by cryptalgal layers occur in a 10 cm thick calcilutite bed near the top of this section. Although simple horizontal feeding traces appear to occur at the stratigraphically lowest levels, and the U-shaped burrows at the highest, generalizations about order of occurrence are unwarranted until additional fossil-bearing sections are measured.

DISCUSSION

Recent papers by Narbonne et al. (1987) and Crimes (1987) summarize the biostratigraphic basis for recognition of the Precambrian-Cambrian boundary. The condensed trace fossil interval in the Ogilvie Mountains in comparison to other occurrences makes recognition of specific trace fossil zones difficult. Both Arenicolites and Planelites can occur in uppermost Precambrian (Vendian) strata. However, the co-occurrence of Rusophycus, Cruziana, and Diplocraterion corresponds to Crimes's (1987) Zone III and the Rusophycus avalonensis Zone of Narbonne et al. (1987). Crimes regarded this zone as late Tommotian — early Atdabanian age, although Narbonne et al. argued that the base of this zone may be early or middle Tommotian.

The presence of this trace fossil zone beneath upper Lower Cambrian Archaeocyathid-bearing dolostones in the Ogilvie Mountains demonstrates an Early Cambrian age for uppermost strata of the Harper group, previously considered to be entirely of late Precambrian age. More precise placement of the boundary may be possible if carbonate samples currently being dissolved yield small shelly fossils similar to those in the Wernecke Mountains (Nowlan et al., 1985). Late Precambrian Ediacaran fossils occur in the Wernecke

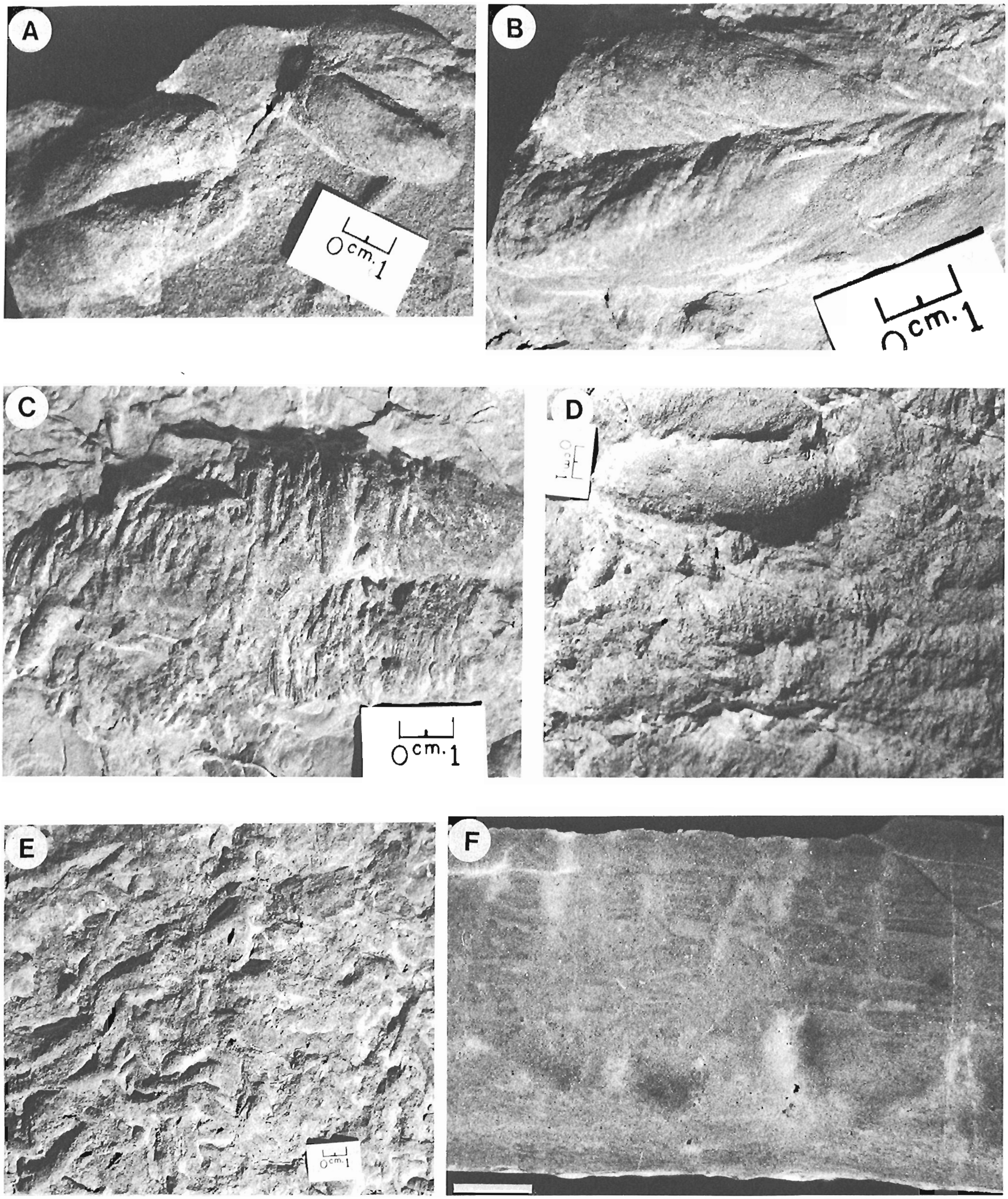


Figure 5. Trace fossils from the upper Harper group. Unless specified, all photos are convex hyporelief views of samples collected from outcrop. A. Two Rusophycus examples from top of section illustrated in Figure 3a. B. Partial Rusophycus with preserved scratch marks. Approximately 500 m north of MS-33 (Fig. 3b). C. Single Cruziana structure from MS-33. D. Abundant overlapping Cruziana and single Rusophycus from MS-33. E. Abundant overlapping Planelites from scree slab of unit PH_5, approximately 200 m. north of MS-33. F. Full relief, polished, longitudinal section containing Arenicolites; from MS-33. Scale bar = 5 mm.

Mountains in siltstones and mudstones similar to those of the thick unit (PH_3) preserved below the trace fossil bearing unit in the Ogilvie Mountains. No Ediacaran fossils were observed during mapping or section measurement, but in view of the present discovery, search of well-exposed sections of this unit now seems warranted.

Several stratigraphic sections measured in the Ogilvie Mountains contain a basal contact which interdigitates with the radiometrically dated Harper Volcanic Complex, overlain by a complete, essentially nondeformed sedimentary section capped by strata bearing the Early Cambrian trace fossils described in this paper. This combination of age brackets and lack of deformation for late Precambrian strata may be unique in the Canadian Cordillera. However, although no stratigraphic discontinuities were observed in the map area, the maximum measured thickness of the upper Harper group (1400 m) is extremely thin for a minimum deposition time of 160 Ma (estimated from the most likely value for the volcanic date of 751 Ma, and a Precambrian-Cambrian boundary date of 590 Ma suggested by Harland et al. (1982).

This discovery provides additional evidence that the Harper group was deposited within an isolated rift basin formed during late Precambrian extension as suggested by Thompson et al. (1987) and discussed in detail by Roots (1987). The presence of "grits" of southern derivations in the uppermost unit in the Harper group suggests correlation with the Hyland Group "grits" which outcrop south of a major thrust fault. Widespread occurrence of the Early to Middle Cambrian trace fossil Oldhamia in argillites above the Hyland Group "grits" (this study; Hofmann and Cecile, 1981) suggests that the thick siliciclastic package was deposited in a large basin which existed contemporaneously with, and which outlived, the Harper basin. We suggest that subsidence of the Harper Basin, probably due to combined post-rift thermal cooling and sediment loading, resulted in a linking of this small rift basin to the major "Hyland-Windermere" basin at the end of the Precambrian or Early Cambrian. This could account for the northerly directed influx of siliciclastics (including green chert conglomerate clasts of unknown provenance) into the precursor carbonate-clastic (southward-transported) "Harper" basin, and the sudden migration of organisms responsible for the trace fossils, resulting in the condensed trace fossil sequence preserved in the upper Harper group.

This discovery also amplifies regional correlations. Lithologically similar Precambrian-Cambrian trace-fossil-bearing sequences occur to the east in the Wernecke, Mackenzie and Selwyn mountains (Narbonne et al., 1985; Aitken, 1984; Fritz et al., 1983, 1984; Hofmann and Cecile, 1981), and to the south in the Cassiar (Fritz and Crimes, 1985), and Rocky and Cariboo mountains (Young, 1972). The upper Harper group lithostratigraphic sequence strongly resembles the sequences preserved in the Wernecke and Mackenzie mountains. We tentatively correlate the basal conglomeratic unit of the upper Harper group with the Rapitan Group to the east, although the glacial origin proposed for much of the Rapitan Group (Yeo, 1981) is rejected for the Harper group unit in favour of a coastal fan interpretation. If confirmed, this correlation indirectly provides the first firm date for initiation of "Windermere" sedimentation in the Mackenzie and Wernecke mountains. Correlation of Harper group strata with equivalent strata in the Wernecke and Mackenzie mountains, combined with the link now established with the Hyland Group "grits" to the south, and the detailed paleocurrent patterns which have been documented during this study, provide a basis for a more exacting interpretation of the evolution of the late Precambrian-Early Cambrian western margin of North America than previously possible.

ACKNOWLEDGMENTS

Funding additional to GSC support was supplied by NSERC Grant A5536 to JAD, a Carleton University Research Grant to JAD, and a grant from the DIAND Northern Scientific Training Programme to PSM. Field assistants Tiro Clarke and Winisk Oltman-Widmeyer, expediters Terri and Ross McKay, and helicopter pilot Adam Morrison significantly contributed to a productive and enjoyable field season. Steve Gordey kindly provided a draft version of his memoir, discussions with Charlie Roots, Charlie Jefferson and Gary Yeo of the GSC aided in our interpretations. A brief examination of some of the fossils by Guy Narbonne saved us from misidentification of one trace fossil.

REFERENCES

Aitken, J.D.
1984: Strata and trace fossils near the Precambrian-Cambrian boundary, Mackenzie, Selwyn and Wernecke mountains, Yukon and Northwest Territories: Discussion; *in* Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 401-407.

Anderson, R.G.
1987: Plutonic rocks in the Dawson map area, Yukon Territory; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 689-697.

Crimes, T.P.
1987: Trace fossils and correlation of late Precambrian and Early Cambrian strata; Geological Magazine, v. 124, p. 97-119.

Delaney, G.D.
1981: The mid-Proterozoic Wernecke Supergroup, Wernecke Mountains, Yukon Territory; *in* Proterozoic Basins of Canada, ed. F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 1-23.

Fritz, W.H., Narbonne, G.M., and Gordey, S.P.
1983: Strata and trace fossils near the Precambrian-Cambrian boundary, Mackenzie, Selwyn and Wernecke mountains, Yukon and Northwest Territories; *in* Current Research, Part B, Geological Survey of Canada, Paper 83-1B, p. 365-375.
1984: Strata and trace fossils near the Precambrian-Cambrian boundary, Mackenzie, Selwyn and Wernecke mountains, Yukon and Northwest Territories: Reply; *in* Current Research, Part B, Geological Survey of Canada, Paper 84-1B, p. 409-412.

Fritz, W.H. and Crimes, T.P.
1985: Lithology, trace fossils, and correlation of Precambrian-Cambrian boundary beds, Cassiar Mountains, north-central British Columbia; Geological Survey of Canada, Paper 83-13, 24 p.

Gabrielse, H., Blusson, S.L., and Roddick, J.A.
1973: Geology of Flat River, Glacier Lake, and Wrigley Lake map-areas, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Memoir 366, 268 p.

Green, L.H.
1972: Geology of Nash Creek, Larson Creek, and Dawson map-areas, Yukon Territory; Geological Survey of Canada, Memoir 364, 157 p.

Harland, W.B., Cox, A., Llewellyn, P.G., Picton, C.A.G., Smith, A.G., and Walters, R.
1982: A Geologic Time Scale; Cambridge University Press, Cambridge, England.

Hofmann, H.J. and Cecile, M.P.
1981: Occurrence of Oldhamia and other trace fossils in Lower Cambrian(?) argillites, Niddery Lake map area, Selwyn Mountains, Yukon Territory; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 281-290.

Mustard, P.S. and Donaldson, J.A.
1987: Coarse clastic sedimentation in a late Proterozoic half graben, Yukon Territory, Canada; Geological Society of America, Abstracts with Program, v. 19, p. 783.

Narbonne, G.M., Hofmann, H.J., and Aitken, J.D.
1985: Precambrian-Cambrian boundary sequence, Wernecke mountains, Yukon Territory; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 603-608.

Narbonne, G.M., Myrow, P.M., Landing, E., and Anderson, M.M.
1987: A candidate stratotype for the Precambrian-Cambrian boundary, Fortune Head, Burin Peninsula, southeastern Newfoundland; Canadian Journal of Earth Sciences, v. 24, p. 1277-1293.

Nowlan, G.S., Narbonne, G.M., and Fritz, W.H.
1985: Small shelly fossils and trace fossils near the Precambrian-Cambrian boundary in the Yukon Territory, Canada; Lethaia, v. 18, p. 233-256.

Roots, C.F.
1986: Petrogenetic evolution of the Late Proterozoic Mount Harper Complex, west-central Yukon; Geological Association of Canada, Program with Abstracts, v. 11, p. 121 (abstract).
1987: Regional tectonic setting and evolution of the Late Proterozoic Mount Harper Volcanic Complex, Ogilvie Mountains, Yukon; unpublished PhD thesis, Carleton University, Ottawa, Ontario, 180 p.

Roots, C.F. and Thompson, R.I.
1986: Igneous response to late Proterozoic rifting: geologic setting of the Mount Harper complex, Ogilvie Mountains, Yukon; Geological Association of Canada, Program with Abstracts, v. 11, p. 120-121 (abstract).

Thompson, R.I.
1986: Repeated extension on the proto-Pacific margin, west-central Yukon; Geological Survey of Canada, Paper 86-8, p. 11 (abstract).

Thompson, R.I., and Roots, C.F.
1982: Ogilvie Mountains project Yukon; part A: a new regional mapping program; *in* Current Research, Part A, Geological Survey of Canada, Paper 82-1A, p. 403-411.

Thompson, R.I., Mercier, E., and Roots, C.F.
1987: Extension and its influence on Canadian Cordilleran passive margin evolution; *in* Continental Extensional Tectonics, ed. M.P. Coward, J.F. Dewey, and P.L. Hancock; Geological Society of London, Special Publication, no. 28, p. 409-417.

Yeo, G.M.
1981: The late Proterozoic Rapitan glaciation in the northern Cordillera; *in* Proterozoic Basins of Canada, ed. F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 25-46.

Young, F.G.
1972: Early Cambrian and older trace fossils from the southern Cordillera of Canada; Canadian Journal of Earth Sciences, v. 9, p. 1-17.

FRONTIER GEOSCIENCE PROGRAM, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

PROGRAMME GÉOSCIENTIFIQUE DES RÉGIONS PIONNIERES, ÎLES DE LA REINE-CHARLOTTE, COLOMBIE-BRITANNIQUE

Introduction to the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia

Introduction au Programme géoscientifique des régions pionnières, îles de la Reine-Charlotte, Colombie-Britannique

R.I. Thompson
Cordilleran and Pacific Geoscience Division, Vancouver
Division géoscientifique de la Cordillère et du Pacifique, Vancouver

Thompson, R.I., Introduction to the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, pp. 207-208, 1988.

Thompson, R.I. : Introduction au Programme géoscientifique des régions pionnières, îles de la Reine-Charlotte, Colombie-Britannique; dans Recherches en cours, Partie E, Commission géologique du Canada, Étude 88-1E, p. 207-208, 1988.

Abstract

The Queen Charlotte Basin component of the Frontier Geoscience Program has four primary objectives: 1) understanding crustal processes that controlled basin development, 2) outlining the internal geology and evolutionary history of the basin, 3) establishing the character and distribution of source- and reservoir-type rocks, and 4) evaluating hazards that could affect petroleum exploration and production. Results will provide the geological and geophysical framework for resource evaluation, environmental impact assessment, resource development planning, stimulation of private sector interest, regulation, and policy development.

The project consists of eight scientific elements: biostratigraphy, sedimentology and paleogeography, structure and tectonics, seismic reflection and refraction, thermal history and heat flow, organic geochemistry, potential fields, and seabed hazards and seismicity. In all, 42 scientists are involved, most on a part time basis. Geological Survey of Canada participation comes from Ottawa, Calgary, Vancouver and Sidney B.C. offices; university participation by professors and graduate students is from University of British Columbia and University of Ottawa. Specialized services, such as acquisition of reflection seismic data, are provided by contractors and consultants. Industry co-operation is beneficial and appreciated.

Résumé

La partie du programme géoscientifique des régions pionnières réalisée dans le bassin de la Reine-Charlotte comporte quatre objectifs primaires: 1) comprendre les processus crustaux à la base du développement du bassin, 2) exposer dans ses lignes générales la géologie interne et l'évolution du bassin, 3) établir les caractéristiques et la répartition des roches de type mère et réservoir, et 4) évaluer les risques qui pourraient compromettre les travaux d'exploration et de production du pétrole. Les résultats fourniront le cadre géologique et géophysique nécessaire à l'évaluation des ressources, l'évaluation de l'impact environnemental, la planification de la mise en valeur des ressources, la stimulation de l'intérêt du secteur privé, la réglementation et la mise au point de politiques.

Le projet comprend huit éléments scientifiques: biostratigraphie, sédimentologie et paléogéographie, structure et tectonique, réflexion et réfraction sismique, évolution thermique et flux thermique, géochimie organique, champs de potentiel et risques pour le fond marin et sismicité. En tout, 42 scientifiques sont impliqués, la plupart à temps partiel. La participation de la Commission géologique du Canada vient des bureaux d'Ottawa, de Calgary, de Vancouver et de Sydney; la participation universitaire, assurée par des professeurs et des étudiants diplômés, est offerte par l'université de Colombie-Britannique et l'université d'Ottawa. Des entrepreneurs et des experts-conseil fournissent des services spécialisés comme l'acquisition de données de sismique réflexion. La coopération du secteur industriel est bénéfique et appréciée.

Contribution to Frontier Geoscience Program/Contribution au Programme géoscientifique des régions pionnières

The papers that follow describe the objectives of individual studies and, where possible, results from the 1987 field season, which was the initial season. Due to the preliminary nature of the work not all reports are accompanied by abstracts.

Les communications qui suivent décrivent les objectifs des études particulières et, lorsque l'éventualité se présente, les résultats de la saison sur le terrain 1987, soit la saison où tout a débuté.

Vu la nature préliminaire du travail, tous les rapports ne sont pas accompagnés de résumés.

Karmutsen Formation and the east boundary of Wrangellia, Queen Charlotte Basin, British Columbia†

G.J. Woodsworth
Cordilleran and Pacific Geoscience Division, Vancouver

Woodsworth, G.J., Karmutsen Formation and the east boundary of Wrangellia, Queen Charlotte Basin, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 209-212, 1988.

Abstract

Bonilla Island, on the east side of Hecate Strait, is composed of low grade, largely undeformed pillow lava and basalt. These rocks are lithologically and texturally indistinguishable from those of the Karmutsen Formation on Queen Charlotte Islands. Wrangellian strata may underlie most of Hecate Strait, and much of the strait may thus be favourable for oil exploration.

Résumé

L'île Bonilla, située du côté est du détroit d'Hecate, se compose de laves en coussins et basaltes faiblement métamorphisés et en majeure partie non déformés. Ces roches sont identiques, du point de vue de leur lithologie et de leur texture, à celles de la formation de Karmkutsen des îles de la Reine-Charlotte. Les strates du Wrangellien sont peut-être présentes dans la majeure partie du sous-sol du détroit d'Hecate, donc une grande partie du détroit en question est sans doute intéressante du point de vue de l'exploration pétrolière.

† Contribution to Frontier Geoscience Program

INTRODUCTION

Current models suggest that the most important oil source rocks on the Queen Charlotte Islands and in the Queen Charlotte Basin are Lower Jurassic and form part of Wrangellia (Cameron, 1987). However, the position of the northeastern edge of Wrangellia in this region is controversial, as most of the Queen Charlotte Basin lies beneath Hecate Strait, and as the original nature of strata in the Coast Plutonic Complex to the east is generally obscured by high grade metamorphism and deformation.

Based largely on gravity and magnetic anomalies, Yorath and Chase (1971) placed the boundary between Wrangellia and the Alexander Terrane along the Sandspit and southeast extension of the Rennell Sound fault zones (Fig. 1). If this conclusion is correct, then much of northern Hecate Strait and Dixon Entrance is underlain by Alexander Terrane and may be unfavourable for oil exploration.

An alternative model, implied by the data of Roddick (1970) and one K-Ar date, is that the pillow basalts on Bonilla Island in eastern Hecate Strait are correlative with the Upper Triassic Karmutsen Formation diagnostic of Wrangellia. If this is correct, then the Wrangellia-Alexander boundary is at least 80 km farther northeast than thought by Yorath and Chase (1981), and at least a further 15 000 km^2 of Queen Charlotte Basin may contain oil source rocks.

This project is designed to test these conflicting hypotheses by direct comparison of Karmutsen volcanics on Queen Charlotte Islands with basalts on Bonilla Island and thus to constrain the location of the northeast margin of Wrangellia in this economically important region. Although recent work

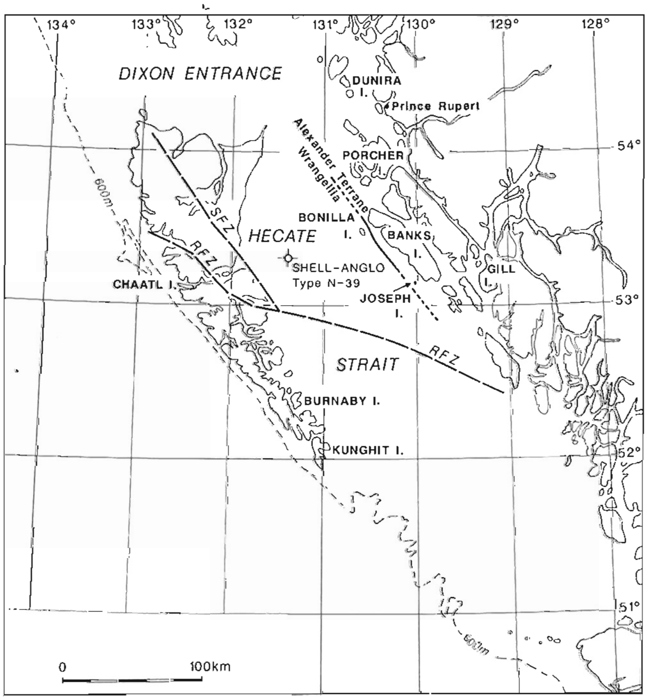


Figure 1. Location map. The Wrangellia-Alexander Terrane boundary according to Yorath and Chase (1981) lies along the Sandspit fault zone (SFZ) and, under Hecate Strait, the Rennell fault zone (RFZ). New data in this paper suggest the boundary lies close to the west edge of Banks Island.

(MacKevett et al., 1986) indicates that Alexander Terrane and Wrangellia were juxtaposed since Late Pennsylvanian time, the two terranes have different Mesozoic stratigraphies and economic importance, and the terms are retained in this report.

KARMUTSEN FORMATION ON QUEEN CHARLOTTE ISLANDS

The Upper Triassic Karmutsen Formation is the most distinctive component of Wragellia. Descriptions by Sutherland Brown (1968) of the extensive exposures of the unit on Queen Charlotte Islands are thorough and generally accurate and need not be repeated here. During summer 1987, well exposed sections from Burnaby Island south to Kunghit Island and on Chaatl Island were examined and sampled for chemical analysis.

On the Queen Charlotte Islands, the formation is composed almost entirely of basaltic volcanic rocks. Sutherland Brown (1968) suggested a thickness of more than 4200 m for the main reference section at Scaat Harbour, east of Burnaby Island. However, this section is interrupted by numerous brittle fault zones of unknown displacement and thus the thickness of the Karmutsen Formation in this area is unknown. These fault zones are marked by the local development of chlorite schist. On Vancouver Island the Karmutsen Formation conformably overlies Upper Ladinian shale which in turn unconformably overlies Upper Paleozoic Sicker Group (Muller et al., 1974). On the Queen Charlotte Islands, the base of the unit has not been found. However, rhyolites and minor interbedded sediments that may represent basement to the Karmutsen Formation were found east of Burnaby Island and on the south shore of Chaatl Island. The Karmutsen Formation is conformably overlain by Upper Triassic limestone of the basal member of the Kunga Formation.

Pillow lava is the dominant lithology in the Scaat Harbour area, particularly in the structurally (and stratigraphically?) lower parts of the section, and is common elsewhere in the unit (Fig. 2). Pillow breccia and hyaloclastite, subordinate to pillow lava at Scaat Harbour, are the dominant lithologies northwest of Kunghit Island. Massive, dark green flows and sills dominate the sections on eastern Kunghit Island and on Chaatl Island.

Figure 2. Pillow lava characteristic of Karmutsen Formation, southern Kunghit Island.

Most of the Karmutsen Formation appears to be in the prehnite-pumpellyite facies or the chlorite zone of the greenschist facies of regional metamorphism. Amphibolite facies assemblages are locally developed in contact aureoles near Jurassic(?) plutons at the south end of Kunghit Island. On Chaatl Island, the unit is regionally metamorphosed to greenschist facies and shows intense brittle deformation, locally with a strong mylonitic foliation that dips steeply north; stretching lineations plunge about 5° to the west. Regional amphibolite facies assemblages described by Sutherland Brown (1968) appear to be absent from the areas examined.

KARMUTSEN FORMATION ON BONILLA ISLAND

Basalt flows underlying all of Bonilla Island were briefly described by Roddick (1970). Based on the lack of appreciable metamorphism and deformation, he ascribed a Tertiary age to them but noted that in outcrop they resemble the Karmutsen Formation. A whole-rock K-Ar date of 202 ± 21 Ma (old constants) supported correlation with the Karmutsen Formation (Roddick, *in* Wanless et al., 1973). During summer of 1987 the rocks on Bonilla Island were re-examined and sampled to allow direct comparison with the Karmutsen Formation on Queen Charlotte Islands.

Bonilla Island and the many small rocks surrounding it are entirely underlain by dark-weathering basalt. About half the island is underlain by pillow lava and pillow breccia, with the remainder consisting of massive to amygdaloidal flows and diabasic textured sills or flows; the rocks commonly outcrop as spectacular sea cliffs. Aquagene tuff forms a minor part of the outcrop; limestone and other sedimentary interbeds were not seen, although pillow interstices are filled with recrystallized calcite, epidote, quartz and prehnite(?). These rock types, their relative abundances, and their general appearance in outcrop are indistinguishable from Karmutsen Formation on the Queen Charlotte Islands. Mineralogy and textural features also strongly resemble those on the Queen Charlottes, and hand specimens from the two areas cannot be told apart. Most of the rocks contain small plagioclase phenocrysts that locally reach 3 cm in length. Pyroxene phenocrysts are rare; olivine was not seen. A conspicuous feature of much of the basalt is a glomerophyric texture that is also a distinctive feature of the Karmutsen volcanics on Queen Charlotte and Vancouver islands (Fig. 3). On both Queen Charlotte and Bonilla islands, bedding is difficult to see and measure. On Bonilla Island the shapes of pillows indicate that the rocks are everywhere upright and suggest that the beds dip about 20° to the southwest. This dip implies a structural thickness of about 1600 m for the basalts in and around Bonilla Island.

Metamorphic grade of the Bonilla Island rocks is probably prehnite-pumpellyite facies or chlorite zone of the greenschist facies. Ductile deformation is absent and brittle deformation is restricted to fractures and narrow shears. No felsic or granitoid dykes, such as are common in the Coast Plutonic Complex were seen.

The striking similarities in outcrop appearance, general compositions, and textures between the basalts on Bonilla Island and the Karmutsen Formation on Queen Charlotte Islands strongly indicate that rocks on Bonilla Island should be included in the Karmutsen Formation. This correlation is supported by the 207 Ma (recalculated with new constants) K-Ar date which, although imprecise, is consistent with a Late Triassic age for the Bonilla Island basalts.

Yorath and Chase (1981) preferred to correlate the Bonilla Island volcanics with Upper Triassic rocks in the Alexander Terrane, rather than with the Karmutsen Formation. However, their correlation is improbable for two reasons. Firstly, the general appearance of the Bonilla basalts more closely resembles the Karmutsen Formation than Triassic basalts from the Alexander terrane. Secondly and more compellingly, Upper Triassic volcanics of the Alexander Terrane are a bimodal suite. Dacitic to rhyolitic rocks are present in most Upper Triassic units in the Alexander Terrane of southeastern Alaska (e.g. Gehrels et al., 1987), and predominantly basaltic units such as the Hound Island Volcanics range in composition from basalt to dacite (Muffler, 1967). In contrast, the Bonilla volcanics and the Karmutsen Formation are entirely basalt, with no variation in composition evident even through relatively thick sections.

Much of the argument made by Yorath and Chase (1981) for the existence of Alexander Terrane beneath Hecate Strait rests on the presence of intrusive rocks in the Shell Anglo Tyee N-39 well. They noted that these gave whole-rock K-Ar dates ranging from Permian to Early Jurassic and concluded that these correlated with Paleozoic plutons of the Alexander Terrane exposed in southeast Alaska. Permian plutons are, however, unknown in southeastern Alaska, and Paleozoic plutons are present in Wrangellia. But more importantly, whole-rock K-Ar dates with large errors (± 32 to 34 Ma) from drill cuttings described as "a mixed assemblage of microgabbro and 'granite wash'" can be interpreted in many fashions and are not valid evidence for the existence of Alexander Terrane or, for that matter, Wrangellia. The data from Bonilla Island do support the hypothesis of Cameron (1987), based on the distribution of oil stains and bitumen, that Hecate Strait is largely underlain by Wrangellian strata.

In conclusion, the Bonilla Island basalts should be treated as part of the Karmutsen Formation unless strong new evidence is presented to the contrary. Thus it appears proba-

Figure 3. Porphyritic to glomerophyric texture in basalt from Bonilla Island; this texture is common throughout the Karmutsen Formation.

ble that rocks belonging to Wrangellia occur along the east edge of Queen Charlotte Basin. The chemical analyses needed to confirm this conclusion are in progress.

DISCUSSION

Woodsworth and Orchard (1985) showed that the rocks on Dunira and nearby islands in eastern Dixon Entrance are underlain by strata of Alexander Terrane. They postulated that the Coast Plutonic Complex on the islands east of Hecate Strait is also underlain by Alexander Terrane and that the entire region is favourable for precious metal deposits and volcanogenic massive sulphide deposits. If so, then the boundary between Alexander Terrane and Wrangellia may coincide with the west edge of the Coast Plutonic Complex in this area and lie along the west sides of Banks and Porcher islands.

Septa of greenschist to amphibolite facies strata on Banks, Gill, and Porcher islands, described by Roddick (1970) and Hutchison (1982), were examined during 1987. These rocks are dominantly thin bedded, fine grained siliceous and calcareous rocks of uncertain protolith. Pelites are rare, and amphibolite and greenstone such as might be produced by metamorphism of basaltic volcanics are absent. The rocks are unfossiliferous and have undergone strong ductile deformation. The strata are lithologically unlike the Bonilla Island volcanics or other Mesozoic units on the Queen Charlotte Islands. They bear some resemblance to Late Paleozoic to Jurassic rocks described by Woodsworth and Orchard (1985) and to Late Paleozoic parts of the Alexander Terrane in southeastern Alaska. Although the evidence is not compelling, it seems plausible that the islands forming the western part of the Coast Plutonic Complex are underlain by Alexander Terrane strata.

Karmutsen Formation occurs on tiny rocks east of Bonilla Island, within 5 km of the large pluton underlying much of western Banks Island. Small Joseph Island off the south end of Banks Island consists of hornblende-biotite quartz diorite similar to that on Trutch Island. The data suggest that the eastern edge of Wrangellia in Queen Charlotte Basin trends northwest, roughly parallel to the west shore of Banks Island. The contrast in metamorphic and structural styles between Bonilla Island and Banks Island, together with the complete absence of plutonic rocks on Bonilla Island suggests that the contact between the two terranes may be a fault, at least in this area.

ACKNOWLEDGMENTS

Kathleen Dixon gave cheerful and enthusiastic assistance in the field. Excellent logistic support for the Queen Charlottes part of the program was provided by Doug Hartley and Paddy Herman of the *M.V. "Beatrice."* Ella Ferland of Sandspit gave thoughtful and caring expediting service. Fieldwork on Banks, Gil, and Joseph islands was done jointly with Peter van der Heyden of the University of British Columbia.

REFERENCES

Cameron, B.E.B.
1987: Significance of Lower Jurassic hydrocarbon source rocks in the Cumshewa Inlet area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 925-928.

Gehrels, G.E., Saleeby, J.B., and Berg, H.C.
1987: Geology of Annette, Gravina, and Duke islands, southeastern Alaska; Canadian Journal of Earth Sciences, v. 24, p. 866-881.

Hutchison, W.W.
1982: Geology of the Prince Rupert-Skeena map area, British Columbia; Geological Survey of Canada, Memoir 394, 116 p.

MacKevett, E.M., Jr., Gardner, M.C., Bergman, S.C., Cushing, G., and McClelland, W.D.
1986: Geological evidence for Late Pennsylvanian juxtaposition of Wrangellia and the Alexander Terrane, Alaska; Geological Society of America, Abstracts with Programs, v. 18, p. 128.

Muffler, L.J.P.
1967: Stratigraphy of the Keku Islets and neighboring parts of Kuiu and Kupreanof Islands, southeastern Alaska; United States Geological Survey, Bulletin 1241-C, 52 p.

Muller, J.E., Northcote, K.E., and Carlisle, D.
1974: Geology and mineral deposits of Alert—Cape Scott map-area, Vancouver Island, British Columbia; Geological Survey of Canada, Paper 74-8, 77 p.

Roddick, J.A.
1970: Douglas Channel-Hecate Strait map-area, British Columbia; Geological Survey of Canada, Paper 70-41, 56 p.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Wanless, R.K., Stevens, R.D., Lachance, G.R., and Delabio, R.N.
1973: Age determinations and geological studies: K-Ar isotopic ages, Report 11; Geological Survey of Canada, Paper 73-2, 139 p.

Woodsworth, G.J. and Orchard, M.J.
1985: Upper Paleozoic to lower Mesozoic strata and their conodonts, western Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 1329-1344.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas — a model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Jurassic and Cretaceous-Tertiary plutonic rocks on the Queen Charlotte Islands, British Columbia†

R.G. Anderson
Cordilleran and Pacific Geoscience Division, Vancouver

Anderson, R.G., Jurassic and Cretaceous-Tertiary plutonic rocks on the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 213-216, 1988.

Abstract

Three informal plutonic suites on Moresby Island have distinctive plutonic styles.

The San Christoval plutonic suite comprises biotite- hornblende diorite, gabbro, quartz monzodiorite and quartz diorite. Oblate fine grained mafic inclusions mark 0.5-2 km wide contact zones with the Upper Triassic Karmutsen Formation and interphase contacts but are not deformed by superimposed tectonism.

Burnaby Island plutonic suite consists of a heterogeneous, sequentially intruded mafic (hornblendite and gabbro), intermediate (quartz monzodiorite) and felsic (biotite granite and quartz monzonite) phases. Widespread and intense alteration (locally to calc-silicate skarn) and brittle fracture are characteristic and may explain the suite's anomalously high aeromagnetic signature.

Carpenter Bay plutonic suite includes fine- to medium-grained biotite-hornblende quartz monzodiorite and quartz monzonite phases which may be higher level equivalents of the Burnaby Island suite. Interphase contacts are concordant with crosscutting, north-trending composite, mafic to felsic dykes which characterize the suite and may be cogenetic with the Middle Jurassic Yakoun volcanics.

Résumé

Trois séries plutoniques informelles dans l'île Moresby ont des styles plutoniques distinctifs.

La série plutonique de San Christoval comprend de la diorite à biotite et hornblende, du gabbro, de la monzodiorite quartzique et de la diorite quartzique. Des inclusions mafiques à grain fin et aplaties marquent des zones de contact de 0,5 à 2 km de large avec la formation de Karmusten du Trias supérieur et des contacts d'interphase, mais ne sont pas déformées par un tectonisme surimposé.

La série plutonique de Burnaby Island comprend une phase hétérogène de roches mafiques marquées par des intrusions successives (hornblendite et gabbro), une phase intermédiaire (monzodiorite quartzique) et une phase de roches felsiques (granite à biotite et monzonite quartzique). Une altération intense et très répandue (localement jusqu'au niveau de la skarn calco-silicaté) et une fracturation cassante sont caractéristiques et peuvent expliquer la signature aéromagnétique exceptionnellement élevée de la série.

La série plutonique de Carpenter Bay comprend des phases de monzodiorite quartzique à biotite et hornblende et à grain dont la taille varie de fine à moyenne, et de monzonite quartzique qui peuvent être des équivalents de niveaux plus élevés de la série de Burnaby Island. Les contacts d'interphase sont en concordance avec les dykes transversaux composites, de direction nord et dont la nature varie de mafique à felsique, qui caractérisent la série et peuvent partager une origine commune avec les roches volcaniques de Yakoun du Jurassique moyen.

---

† Contribution to Frontier Geoscience Program

INTRODUCTION

Granitoid plutonism is an important element of the physiography, tectonic evolution and thermal history of Moresby and southern Graham islands. For example, the much-described rocky spine of northwestern Moresby Island, the Queen Charlotte Ranges, is underlain by the San Christoval batholith. The age and extent of plutonism has an obvious importance in evaluation of possible over-maturation of otherwise promising petroliferous source rock.

Mapping at 1:50 00 scale and sampling were undertaken along the east coast of Moresby Island to improve understanding of the nature, tectonic setting and age of plutonic suites and provide insight into the uplift and thermal history of the terrane. The suites were subdivided by Sutherland Brown (1968) into Jurassic syn-tectonic and Cretaceous-Tertiary post-tectonic varieties (Fig. 1).

Three (Late?) Jurassic plutonic suites are informally defined by their individual plutonic styles: San Christoval, Burnaby Island, and Carpenter Bay suites. Distribution and nature of phases, aeromagnetic signature (Geological Survey of Canada, 1987a, b, c, d, e, f, and g), mineral composition and fabric, cogenetic dykes and intrusive relations define respective plutonic styles. In the absence of a detailed geochronometric framework, Cretaceous-Tertiary plutons are only reliably known from intrusive relations with distinctive Cretaceous and Tertiary strata. Re-interpretation of structural fabric in the San Christoval suite and unpublished geochronometry (e.g., Young, 1981, p. 50-51) suggest limited utility for an earlier, tectonic classification of Queen Charlotte Island plutonism.

GEOLOGY OF THE COUNTRY ROCKS

Upper Triassic to Tertiary country rock for the Mesozoic to Tertiary intrusions provide only broad constraints on the suites' stratigraphic age. Upper Triassic (Carnian) Karmutsen Formation basalt (massive, volcaniclastic and plagioclase-glomerophyric varieties; Woodsworth, 1988) and Upper Triassic and Lower Jurassic Kunga Group limestone and argillite (Sandilands Formation, in part) host the Carpenter Bay and Burnaby Island plutonic suites. The Kunga Group is intruded, deformed, engulfed, and contact metamorphosed along plutonic margins. Massive Karmutsen Formation basalt and mafic volcaniclastics are apparently less affected except along parts of the intrusive contact with the San Christoval plutonic suite. In Haswell Bay, decimetre scale, mylonitized lit-par-lit injection zones are developed and felsite apophyses are common within 100-200 of the contact.

Plagioclase porphyry intrusive facies and heterolithic plagioclase-phyric volcanic conglomerate of the Middle Jurassic Yakoun Group are crosscut by the Burnaby Island plutonic suite along the north coast of Burnaby Island and along Cumshewa Inlet.

Sutherland Brown (1968) described the intrusive contacts between members of the Burnaby Island plutonic suite and Cretaceous and younger strata. Except in two cases, the nature of the contacts or geological relationships involving the plutonic suites are poorly exposed or have not been re-investigated. Many of the granitoid fragments in the Lower Cretaceous Longarm Formation and in the Upper Cretaceous Honna Formation are lithologically similar to the San Christoval plutonic suite and are coeval (148 ± 5 and 152 ± 5 Ma; Yorath and Chase, 1981, p. 1728) with K-Ar isotopic ages from the suite (142-143 Ma; Young, 1981, p. 51). At Dawson Inlet, Central Kano pluton quartz monzodiorite clearly decreases in grain size and increases in mafic content within 100-200 m of the contact with subvertical Tertiary Masset Group flow-layered rhyolite and welded tuff. The sharp contact is uninformative with respect to intrusive relations but the changes in the Kano pluton toward the contact and orientation of the Masset Group strata support an intrusive relationship.

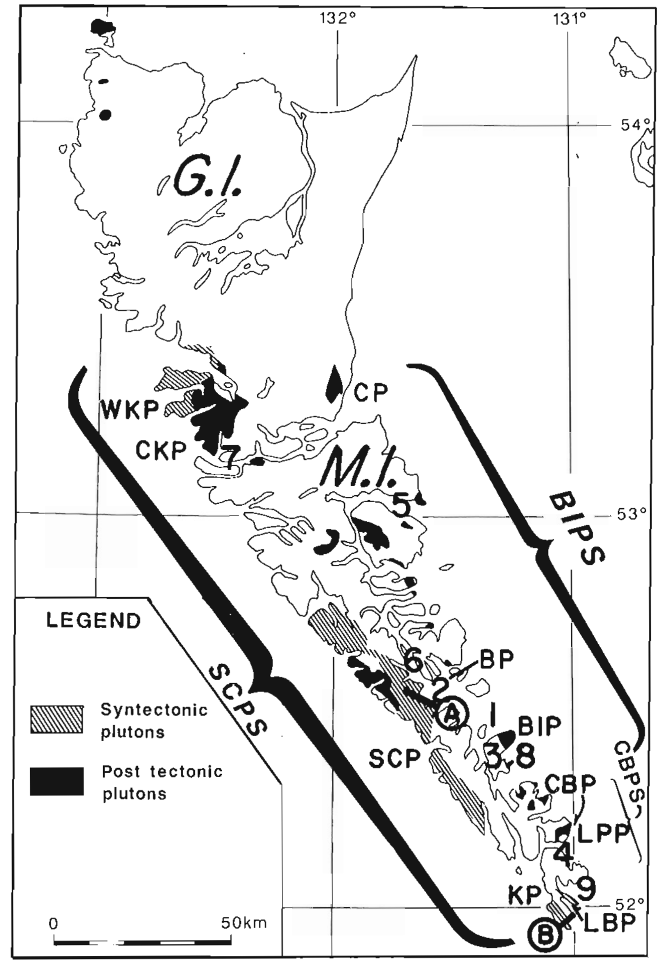


Figure 1. Distribution of Sutherland Brown's (1968) syntectonic and post-tectonic plutons and the plutonic suites on Graham Island (G.I.) and Moresby Island (M.I.) described in text. Numbers indicate physiographic features mentioned in text: 1. Arichika Island; 2. Bischof Islands and Beresford Inlet; 3. Burnaby Island; 4. Charles Island; 5. Cumshewa Inlet; 6. Darwin Sound; 7. Dawson Inlet; 8. Howay Island; 9. Luxana Bay. Plutons are: BIP = Burnaby Island pluton; BP = Bischof pluton; CBP = Carpenter Bay pluton; CKP = Central Kano pluton; CP = Chinukundl pluton; KP = Kunghit pluton; LPP = Langford Point pluton; LBP = Luxana Bay pluton; SCP = San Christoval pluton; WKP = West Kano pluton. Jurassic plutonic suites are: BIPS = Burnaby Island plutonic suite; CBPS = Carpenter Bay plutonic suite; and SCPS = San Christoval plutonic suite. Transects A and B through the San Christoval plutonic suite are the Haswell Bay-De La Beche Inlet transect and Woodruff Bay transect.

GEOLOGY OF THE JURASSIC PLUTONIC SUITES

San Christoval plutonic suite

San Christoval plutonic suite is an informal designation for some of the "syntectonic" plutons of Sutherland Brown (1968) which outcrop along the west coast of Moresby Island and southwestern part of Graham Island: Kunghit, Luxana, San Christoval and West Kano plutons. Bischof pluton has scattered gneissic portions but its aeromagnetic signature, composition, mineralogy, alteration and fracture are more typical of the Burnaby Island plutonic suite. The San Christoval plutonic suite is characterized by its homogeneity and a marked foliation of minerals, oblate mafic inclusions and(or) melanosome-leucosome alternations (Sutherland Brown, 1968). This feature led to the twofold tectonic classification of the Queen Charlotte Island granitoids into "syntectonic" and "posttectonic" plutons (Sutherland Brown, 1968). Transects across the Kunghit pluton (along Woodruff Bay), Luxana pluton (along Luxana Bay) and main San Christoval pluton (along Haswell Bay-De La Beche Inlet) indicate at least two origins for the foliated granitoids. The San Christoval plutonic suite is characterized by aeromagnetic lows and a subdued signature (56300-56600 gammas) compared to the Burnaby Lake suite (Geological Survey of Canada, 1987a, b, d).

Along the Woodruff Bay and Haswell Bay-De La Beche Inlet transects, the San Christoval plutonic suite is a massive to foliated, medium grained, equigranular to seriate biotite-hornblende quartz monzodiorite to granodiorite. In De La Beche Inlet, an older mafic, hornblende diorite to gabbro phase is intruded by the quartz monzodiorite. Prismatic hornblende is coarser grained than other minerals and together with the paucity of sphene (titanite) are distinctive. Fine grained mafic inclusions are also typical, 15-40 cm (averaging 5-10 cm) in largest dimension, and make up 2-10 % of the rock. Locally, they are round and massive. Within 500 m to 2 km of contacts with Karmutsen Formation greenstone and volcaniclastics or with the older diorite phase, oblate inclusions within a massive quartz monzodiorite host are foliated (rarely lineated) concordantly with the contacts.

Green aphanitic and plagioclase porphyritic andesite dykes are rare and thin in the San Christoval suite.

There is little evidence for widespread, post-intrusive, ductile deformation of the San Christoval suite except for the intensely mylonitized rocks along Luxana Bay. A 100 m to 1 km wide, steeply northeasterly-dipping lit-par-lit zone of alternating and deformed amphibolite and light grey, aphanitic granitoid occur locally along the plutonic-Karmutsen Formation contact in Haswell Bay and invariably along the southwest side of the Luxana Bay. Scattered intrusive relations are preserved, but at Luxana Bay, the rocks are commonly mylonitized (Sutherland Brown, 1968) and a shallow, northwest-plunging mineral lineation is developed. A green, undeformed aphanitic andesite dyke crosscuts the mylonitized unit at Luxana Bay and resembles dykes characteristic of the Carpenter Bay plutonic suite.

Two K-Ar isotopic ages on hornblende (143 ± 7 Ma and 142 ± 4 Ma; Young, 1981, p. 51) agree with the loose stratigraphic constraints on the San Christoval suite's age but are interpreted as cooling ages (Young, 1981). The range of composition, prismatic hornblende and paucity of sphene which characterize the San Christoval plutonic suite compare closely with the Early Jurassic (180-190 Ma) Island Intrusions (Carson, 1973; Isachsen, 1984; Isachsen et al., 1985; R.G. Anderson, unpublished data). U-Pb geochronometry on zircon from the suite may provide more precise estimates of the intrusive age.

Burnaby Island plutonic suite

The Late? Jurassic Burnaby Island plutonic suite includes Sutherland Brown's (1968) "post-tectonic" plutons (Sandspit, Louise and northern part of the Southern groups) which extend from Chinukundl River on southeastern Graham Island to Collision Bay in east central Moresby Island. The suite is heterogeneous, massive, intensely altered (locally to calc-silicate endoskarn), brittly fractured and, possibly as a result, characterized by aeromagnetic highs (56400-57100 gammas; Geological Survey of Canada, 1987b, c, d). Heterogeneous phases on Bischof Islands and bordering Beresford Inlet (Sutherland Brown's (1968) units Js and Jsm) are included in the suite.

From most to least extensive are hornblende- and(or) biotite-bearing quartz monzodiorite, quartz monzonite or granite, gabbro and hornblendite and muscovite granite. The phases were emplaced sequentially, mafic to felsic. Rocks are massive, medium grained and equigranular to seriate (especially felsic phases). Hornblende is subhedral, unlike the prismatic hornblende typical of the San Christoval plutonic suite. Fine grained mafic inclusions are important although scattered (2-5 % of the rock). No regional fabric is developed in the inclusions or plutonic host.

The suite is characterized by common fracture zones which are the locus for widespread, brown sericite alteration zones whose intensity commonly obliterates the protolith. The zones are preferentially eroded to form wave-cut benches. Quartz and calcite veins heal the fractures. In a few places, garnet-epidote endoskarn is developed in the quartz monzodiorite near the fracture sets. Three trends for the steep fractures predominate (in order of formation): a common easterly to east-southeasterly and north-northeasterly orthogonal set; and a late, less common, south-southeasterly trending set. On Howay Island, the fracture-alteration zones are crosscut by distinctive green, aphanitic and flow-layered dykes. Similar flow-layered dykes intrude the Lower Cretaceous Longarm Formation on Arichika Island and may be feeders to the Masset Group. Late fractures are developed along the flow-layered dyke margins.

Green aphanitic to plagioclase-, biotite- and hornblende-phyric andesite to dacite dykes and less common, clinopyroxene-rich, flow-layered dykes are scattered throughout the Burnaby Island plutonic suite but are unimportant compared to the abundance of dykes typical of the Carpenter Bay plutonic suite.

Two K-Ar isotopic ages for hornblende from the Chinukundl and Burnaby Island members of the suite indicate Late Jurassic cooling ages (156 ± 5 Ma and 142 ± 19 Ma, respectively; Wanless et al., 1968; Young, 1981, p. 51) coeval with cooling ages for the San Christoval plutonic suite. The two northwest-trending suites are closest along Darwin Sound but no intrusive relations are exposed.

Carpenter Bay plutonic suite

The southern half of Sutherland Brown's (1968) "post-tectonic" southern group of plutons makes up the Late Jurassic? Carpenter Bay plutonic suite (Carpenter Bay and Langford Point plutons). The suite is compositionally similar to part of the Burnaby Island suite and may be a high level equivalent. However, the Carpenter Bay suite differs in its abundance of dykes (Souther, 1988), subdued aeromagnetic expression (56200-56400 gammas; Geological Survey of Canada, 1987a), paucity of fracture zones or alteration, and a dearth of mafic (gabbro, diorite or hornblendite) phases.

Composite plutons of sequentially-intruded, fine grained monzodiorite (rare), hornblende-biotite quartz monzodiorite (common) and biotite quartz monzonite (uncommon) characterize the suite. The granitoids are massive, fine- to medium-grained, equigranular, and almost inclusion-free (at most, 1-2 % small, fine grained, mafic inclusions). An exception is Charles Island where a quartz monzodiorite-hosted agmatite is developed at the intrusive contact with the Karmutsen Formation basalt.

Dykes are common to abundant and nearly invariably north-northeasterly to north-northwesterly trending, concordant to the trend of interphase contacts in the host pluton. The swarms comprise 1-2 m wide, individual dykes and composite dykes which compose 10-20 % to 100 % of the outcrop. Green, aphanitic and biotite-, pyrite-, hornblende- and(or) plagioclase-phyric andesite varieties are most common. Distinctive though rare, arsenopyrite-plagioclase dacite and alkali feldspar-phyric trachyte dykes intrude green andesite dykes. There is a complete spectrum between massive, individual andesite dykes to layered individual dykes to composite dykes where there is clearly several generations of dyke emplacement. Layering in individual andesite dykes is common and occurs within 20-50 cm of the margin. Internal contacts in the composite dykes are cuspate or scalloped indicative of synintrusion deformation.

The K-Ar (on hornblende and biotite) and U-Pb (on zircon) geochronometry for Carpenter Bay plutonic suite is in progress. The dyke swarms characterize, are concordant with and are likely cogenetic with the suite. If the dykes are feeders to the Middle Jurassic Yakoun volcanics (Souther, 1988), the plutonic suite is coeval.

SUMMARY AND CONCLUSIONS

The San Christoval, Burnaby Island and Carpenter Bay plutonic suites are distinguished by their homogeneity, the nature and distribution of phases, compositional spectrum, mineralogy, structural fabric development, aeromagnetic signature, associated dykes and intrusive relations. Intrusive relations with the Lower Jurassic Sandilands Formation of the Kunga Group suggest a maximum Early Jurassic age for some of the suites. Reconnaissance K-Ar geochronometry (Young, 1981) suggests the suites, though distinct, have overlapping K-Ar cooling ages and may be no younger than Late Jurassic. A suggested cogenetic connection between the dyke swarms which characterize the Carpenter Bay plutonic suite and the Middle Jurassic Yakoun Group volcanics may date that suite.

Structural fabric in the San Christoval plutonic suite appears to be closely associated with external and interphase internal intrusive contacts and is interpreted as synintrusive rather than as syntectonic as suggested by Sutherland Brown (1968). Little post-intrusion deformation appears to be superimposed on the suite.

The abundant fracture and alteration zones (in part, calc-silicate endoskarn) which characterize the Burnaby Island plutonic suite are consistent with its association with nearby Cu-Fe skarns developed in the Kunga Group and anomalously high aeromagnetic signature.

ACKNOWLEDGMENTS

Kevin May and David Rhys provided cheerful assistance in the field. Kevin's expert, seemingly effortless, seamanship proved critical to the success of some of the work. Dave compiled a simplified version of the aeromagnetic maps. Doug Hartley (skipper) and Paddy Herman (mate and cook), of the *M. V. "Beatrice,"* maintained a calm, warm and dry haven from the storm. Expediter Ella Ferland conscientiously kept us in touch with the world and the grocery store. The efforts of Bob Thompson, who shouldered the responsibility of establishing and maintaining the FGP base camp at Sandspit with his usual good humour and efficiency, are greatly appreciated.

REFERENCES

Carson, D.J.T.
1973: The plutonic rocks of Vancouver Island; Geological Survey of Canada, Paper 72-44, 70 p.

Geological Survey of Canada
1987a: Aeromomagnetic Map 7721G, British Columbia (102 O)
1987b: Aeromomagnetic Map 7737G, Moresby Island (103 B)
1987c: Aeromomagnetic Map 7738G, British Columbia (103 C)
1987d: Aeromomagnetic Map 7752G, Hecate Strait (103 G-H)
1987e: Aeromomagnetic Map 7753G, Graham Island (103 E-F)
1987f: Aeromomagnetic Map 7762G, Prince Rupert (103 J)
1987g: Aeromomagnetic Map 7763G, Dixon Entrance (103 K-L)

Isachsen, C.
1984: Geology, geochemistry, and geochronology of the Westcoast Crystalline Complex, Vancouver Island, British Columbia; unpublished MSc thesis, University of British Columbia, 144 p.

Isachsen, C., Armstrong, R.L. and Parrish, R.R.
1985: U-Pb, Rb-Sr and K-Ar geochronometry of Vancouver Island igneous rocks; Geological Association of Canada, Pacific Section, Programme and Abstracts, April 19, 1985, p. 21-22 (abstract).

Souther, J.G.
1988: Implications for hydrocarbon exploration of dyke emplacement in the Queen Charlotte Islands; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Wanless, R.K., Stevens, R.D., Lachance, G.R., and Edmonds, C.M.
1968: Age determinations and geological studies, K-Ar isotopic ages, Report 8; Geological Survey of Canada, Paper 67-2, Part A, 141 p.

Woodsworth, G.J.
1988: Karmutsen Formation and the east boundary of Wrangellia, Queen Charlotte Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas — a model; Canadian Journal of Earth Sciences, v. 18, p 1717-1739.

Young, I.F.
1981: Structure of the western margin of the Queen Charlotte Basin, British Columbia; unpublished MSc thesis, University of British Columbia, 380 p.

Late Triassic through Cretaceous geological evolution, Queen Charlotte Islands, British Columbia[†]

R.I. Thompson
Cordilleran and Pacific Geoscience Division, Vancouver

Thompson, R.I., Late Triassic through Cretaceous geological evolution, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 217-219, 1988.

Abstract

The tectonostratigraphic setting of the Queen Charlotte Islands changed after deposition of the petroliferous Upper Triassic to Lower Jurassic Kunga and Maude groups. In the mid-Jurassic those groups were folded, faulted and intruded by dykes that fed porphyritic flows and breccias of the Yakoun Group. Since then uplift, erosion and deposition associated with the formation and filling of successor basins has occurred. During the infilling of these basins, porphyries of the Yakoun Group have been important sources of clastic material. The successor basin cycle was accompanied by 3 episodes of compression which have generated folds and contraction faults. These episodes were during, and possibly just preceding, eruption of Yakoun Group rocks (mid-Jurassic); after deposition of the Honna conglomerate (late Cretaceous or early Tertiary), and after the start of deposition of the Skonun Formation. Lacking thus far, is evidence that these events were associated with significant strike slip displacement.

Résumé

Le cadre tectono-stratigraphique des îles de la Reine-Charlotte a changé après la mise en place des groupes pétrolifères de Kunga et de Maude dont l'âge varie du Trias supérieur au Jurassique inférieur. Au milieu du Jurassique, ces groupes ont été plissés, faillés et pénétrés par des dykes qui ont alimenté des coulées porphyriques et des brèches du groupe de Yakoun. Par la suite, un soulèvement, de l'érosion et une sédimentation associés à la formation et au remplissage des bassins successeurs se sont produits. Pendant le remplissage de ces bassins, des porphyres du groupe de Yakoun ont été des sources importantes de matériaux clastiques. Le cycle du bassin successeur a été accompagné de trois épisodes de compression qui ont engendré des plissements et des failles de contraction. Ces épisodes ont eu lieu durant, et peut-être juste avant, l'éruption de roches du groupe de Yakoun (milieu du Jurassique); après la mise en place du conglomérat de Honna (fin du Crétacé ou début du Tertiaire), et après le début de la mise en place de la formation de Skonun. On n'avait jusque-là aucune preuve que ces événements étaient associés à un important déplacement par décrochement.

[†] Contribution to Frontier Geoscience Program

GEOLOGICAL FRAMEWORK

The geological framework of the Queen Charlotte Islands has been outlined by Sutherland Brown (1968) and others (Cameron and Tipper 1985; Yorath and Chase 1981). Upper Triassic through Tertiary rocks of the Queen Charlotte Islands consist of two primary parts: 1) Locally petroliferous, Upper Triassic through early Jurassic carbonate, sandstone and shale (Kunga and Maude groups) deposited on a broad, stable shelf underlain by Karmutsen volcanics; and 2) a mid-Jurassic through Tertiary succession of sandstone, conglomerate, shale, volcanic and volcaniclastic successor basin deposits (Cameron and Hamilton, 1988). The change in tectonostratigraphic setting occurred during the mid-Jurassic when Kunga and Maude groups were folded, faulted and intruded by dykes that fed porphyritic flows and breccias of the Yakoun Group. Since then the region was disrupted by several cycles of uplift, erosion and deposition associated with the formation and filling of successor basins.

SCOPE AND PURPOSE

The author's frontier geoscience program (FGP) consists of land based, 1:50 000 mapping focusing on regions where Kunga through Honna stratigraphy is exposed. In 1987, the area from Skidegate Lake (Fig. 1) was covered. Individual sedimentary facies within the Yakoun, Moresby, Haida and Honna successions are being mapped separately, where possible.

The work provides a base from which a reconstruction of the structural and stratigraphic history of the region can be attempted. It is anticipated that models of basin evolution derived on land will help constrain the interpretation of offshore geophysical data. Important structural features mapped during 1987 can be projected eastward beneath Hecate Strait.

SUMMARY OF RESULTS: 1987 FIELD SEASON

1. The Rennell Sound fault system (Sutherland Brown, 1968) is more properly characterized as a fold belt (Fig. 1) in which the Kunga and Maude strata are intensively deformed into chevron folds. It is not clear whether overlying Yakoun, Moresby and Longarm strata underwent the same degree of folding (Lewis and Ross, 1988). Fold limbs and cores are cut by contraction faults. Brittle fractures disrupt bedding; in places they form "crushed" zones a few tens of metres wide with a consistent strike of about 120°. Map relationships on either side of Skidegate Narrows suggest little or no strike slip displacement within the fold system (Lewis and Ross, 1988).

2. The Kunga and Maude groups were deformed prior to, or during, the intrusion of Yakoun feeder dykes. Yakoun Group volcanism may account for high paleotemperatures of Kunga strata on Moresby Island (Souther, 1988).

3. On southern Moresby Island, Kunga strata are cut by Yakoun feeder dykes, but Yakoun volcanics are absent. This leads to the speculation that a much larger landmass may once have existed, and perhaps extended, beneath the present site of Hecate Strait and that this landmass was a source for Cretaceous sandstones and conglomerate.

4. Lower Cretaceous strata were more widespread prior to mid-Cretaceous block faulting. A new locality of Longarm(?) Formation was found on Maude Island (Fig. 1). Character and provenance of these sandstones is similar to the Moresby Group and Haida Formation.

5. An important block faulting event preceded (and possibly initiated(?)) Haida Formation deposition. The unconformity at the base of the Haida cuts down through the Longarm Formation, and the Moresby, Yakoun and Kunga groups into Karmutsen Group volcanics.

6. Haida facies are absent on the eastern side of Moresby Island where Honna conglomerate overlies Yakoun volcanics. It is possible that the conglomerate and sandstone at the base of the Honna is a time-stratigraphic equivalent to the Haida.

7. Evidence that the Yakoun was an important detrital source for younger clastic sediments can be seen at local and regional scales. There is a striking similarity in the character and composition of clasts and sandstones of the Yakoun, Moresby, Longarm and Haida formations. All were derived, in large measure, from the products of erosion of Yakoun Group porphyries or by the recycling of such products.

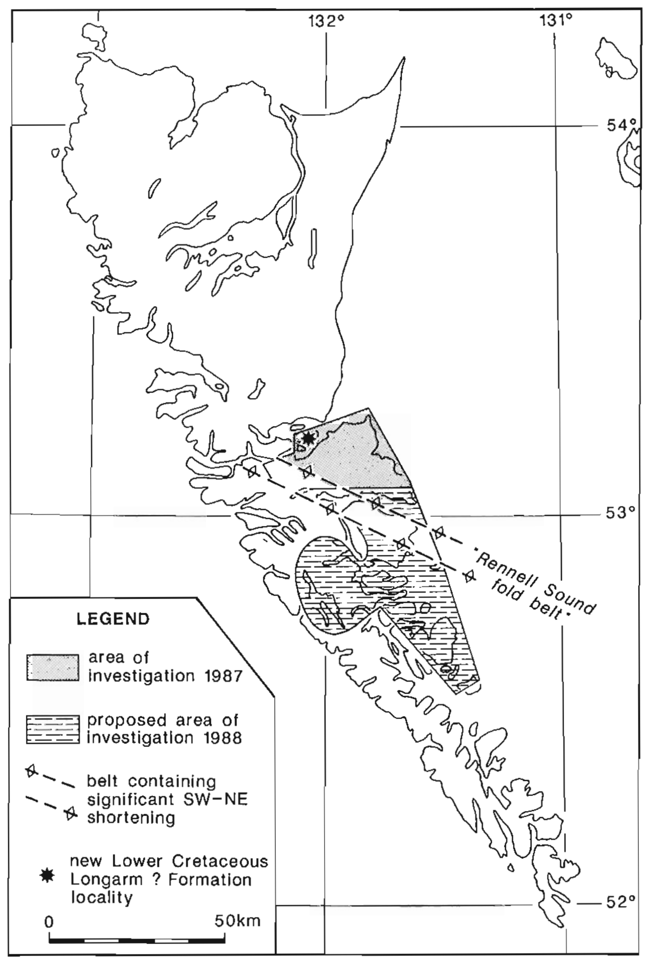


Figure 1. Map showing trend and approximate width of steep limbed folds of Upper Triassic through Upper Cretaceous sedimentary strata. Location of study areas (1987, 1988) are shaded.

8. A compressive episode generated folds and contraction faults in late Cretaceous or early Tertiary time after Honna conglomerate deposition.

9. A compressive episode also occurred in the late Tertiary after initiation of Skonun deposition.

10. Compelling evidence for large-scale strike slip displacement on the Sandspit Fault is lacking.

IMPLICATIONS REGARDING HYDROCARBON ASSESSMENT, HECATE STRAIT

1. The ''Rennell Sound'' fold belt projects east-southeast (approx. 120°) across Louise Island (H.W. Tipper, pers. comm., 1987) and beneath Hecate Strait. South of the fold belt (beneath Hecate Strait) basement highs of Karmutsen volcanics and/or Kunga carbonate overlain directly by Tertiary Skonun Formation may be expected. A thick, broadly folded succession of Haida sandstone and/or Honna conglomerate should be found northeast of the southeastward projection of the fold belt beneath the strait.

2. The ''Rennell Sound'' fold belt is probably not a terrane boundary. Triassic and younger stratigraphy can be mapped across it. Magnetic and gravity anomalies, interpreted by Yorath and Chase (1981) as evidence for existence of an Alexander-Wrangellia boundary beneath Hecate Strait (Woodsworth, 1988), could alternatively represent evidence for the southeastward projection of the ''Rennell Sound'' fold belt.

3. The potential of the Kunga and Maude groups as source rocks may depend on the distribution of Yakoun volcanic rocks. Heat associated with the mid-Jurassic volcanic event may have rendered organic matter overmature. This would have left little likelihood for migration of hydrocarbons into Cretaceous or Tertiary reservoirs from the Triassic and lower Jurassic source beds (Souther, 1988).

REFERENCES

Cameron, B.E.B. and Hamilton, T.S.
1988: Contributions to the stratigraphy and tectonics of the Queen Charlotte Basin, British Columbia, *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Cameron, B.E.B. and Tipper, H.W.
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365.

Lewis, P.D. and Ross, J.V.
1988: Preliminary investigations of structural styles in Mesozoic strata of the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Souther, J.G.
1988: Implications for hydrocarbon exploration of dyke emplacement in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Woodsworth, G.J.
1988: Karmutsen Formation and the east boundary of Wrangellia, Queen Charlotte Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas — a model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Contributions to the stratigraphy and tectonics of the Queen Charlotte Basin, British Columbia†

B.E.B. Cameron and T.S. Hamilton
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Cameron, B.E.B. and Hamilton, T.S., Contributions to the stratigraphy and tectonics of the Queen Charlotte Basin, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 221-227, 1988.

Abstract

The known stratigraphy of the Queen Charlotte Basin is reviewed and discussed with respect to significant new observations. These new data are assessed in the context of petroleum geology, local structural development and the tectonic history of the area.

Résumé

La stratigraphie connue du bassin de la Reine-Charlotte est examinée et discutée en fonction de nouvelles observations importantes. Ces nouvelles données font l'objet d'une évaluation dans le contexte de la géologie pétrolière, du développement structural local et de l'évolution tectonique de la région.

† Contribution to Frontier Geoscience Program

INTRODUCTION

The major objectives of the Frontier Geoscience Program on the Pacific coast of Canada include a relatively disciplined approach to geological problems which will ultimately lead to an appreciation of the hydrocarbon resource potential of the region. Of necessity, studies must be multidisciplinary and include structure, stratigraphy, sedimentology and biostratigraphy. The following notes dealing with stratigraphic and tectonic observations are intended to supplement and expand our present knowledge of these aspects of the Queen Charlotte Basin as contributions to our continuing research in these fields.

KEYNOTES

Geographic localities referred to in the stratigraphic discussion are indicated on Figure 1. The succession of rock units as presently understood is represented in Figure 2 (modified after Hamilton and Cameron, in press). Each of the units discussed below can be referred to this column by the numbered sequence 1 to 18 appearing on the margins of Figure 2.

1. The Karmutsen Formation is the oldest known rock unit of the succession and is thus considered as local basement. The very dense and strongly magnetic nature of these basic volcanics make them amenable to geophysical mapping throughout most of the Queen Charlotte Basin. The main exposures are on south Moresby Island with rare outliers on western Graham Island. The profound thickness of crustal rocks inferred from the gravity field on south Moresby Island may either imply older (?Paleozoic) underlying stratigraphy

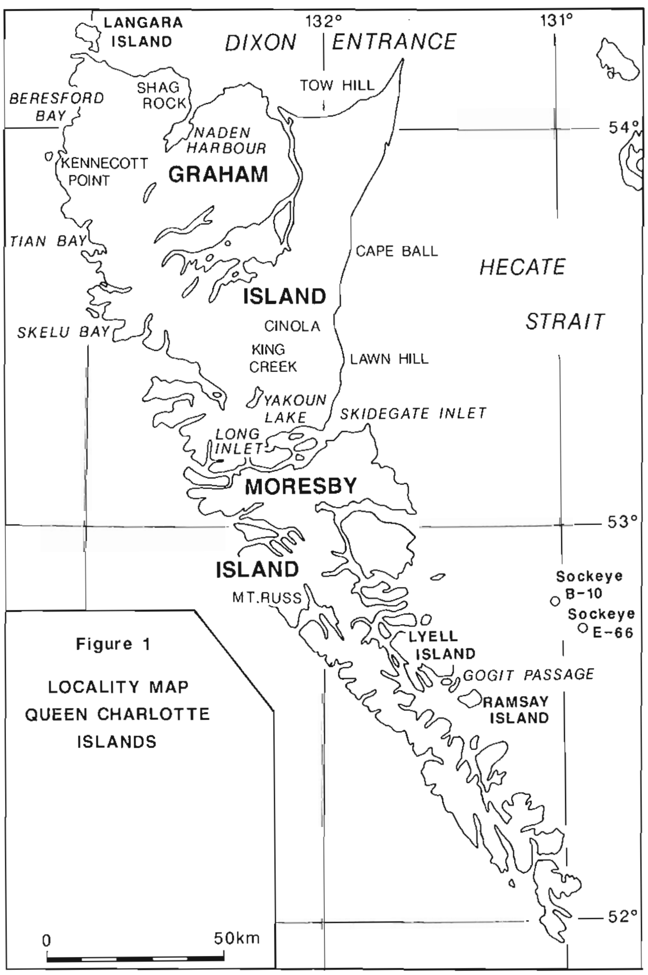


Figure 1. Location map showing geographic place names in the Queen Charlotte Basin.

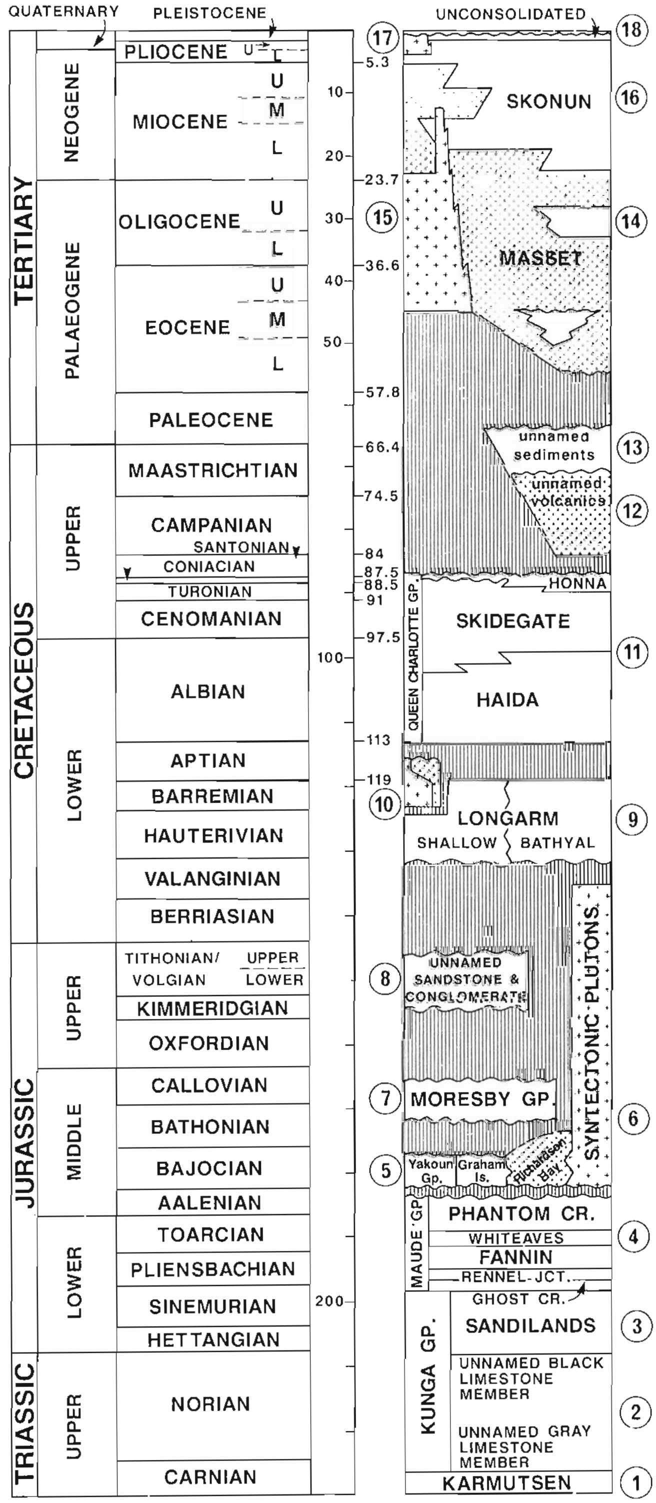


Figure 2. Geological column for Queen Charlotte Basin depicting the revised stratigraphic succession and facies relationships (modified after Hamilton and Cameron, in press).

or structural thickening either by imbrication of the known section or by underthrusted younger seafloor from the west.

2. Two very differing limestone units occupy the lower part of the Kunga Group and are late Triassic. The grey limestone member is characteristically a massive, coarsely crystalline carbonate and is highly variable in thickness where examined in the field. Some algal-stromatolitic structures have been observed. The overlying black limestone member represents a deeper water facies of the Norian and is the oldest recognized hydrocarbon source succession (Fig. 3).

3. The Sandilands Formation is the youngest unit of the Kunga Group and is believed to represent an excellent hydrocarbon source succession. It was previously believed to be entirely Sinemurian in age but new evidence suggests that the Hettangian is also represented (H.W. Tipper, pers. comm., 1987).

4. The Maude Group represents formations ranging in palaeodepth (Fig. 3) from deep water bituminous dark shale (Ghost Creek Formation) to very shallow water sandstone (Fannin and Phantom Creek formations). The Ghost Creek Formation is one of the prospective source rock intervals for the region.

5. The Yakoun Group consists of calc-alkaline volcanics and volcaniclastics of Bajocian age and may represent an arc stitching episode of the Wrangellia and Alexander terranes. Thus it is the first heating and deformational event after the deposition of the significant early Jurassic hydrocarbon source beds. The diachronous unconformity at the top of the Richardson Bay Formation is suggested from a radiometric age obtained from a sidewall core from volcanics in the base of the Shell Anglo Sockeye E-66 well. An absolute age of 165 $\pm$ 8 Ma age was obtained, suggesting a Late Bajocian to Oxfordian age (Young, 1981). Because there is no indication from subaerial exposures of Jurassic volcanics younger than Bajocian, it is assumed that the radiometric age is a little too young. Feldspar-hornblende porphyry sills, some cutting older strata, are presumed to be hypabyssal equivalents of the Richardson Bay volcanics and represent an intermediate link to the syntectonic plutons.

6. The syntectonic plutons, as presently understood, range in age from Middle Jurassic to earliest Cretaceous. Thus they are the plutonic equivalents and successors to the Yakoun arc volcanics, and may be correlative with the Gravina-Nutzotin Arc (Berg et al., 1972).

7. The Moresby Group represents a relatively brief transgressive cycle of Middle Jurassic age (Fig. 3). Its distribution within the Queen Charlotte Basin appears to be limited (Cameron and Tipper, 1985), possibly due to the uplift accompanying the implacement of the syntectonic plutons.

8. Like the Moresby Group, the very shallow water sediments of the Late Jurassic are known from very few localities mainly on western and northwestern Graham Island. A similar relationship with the syntectonic plutons may explain this limited distribution.

9. The basal unit of the Cretaceous as presently known is the Longarm Formation (Sutherland Brown, 1968). Lithologically it is highly variable ranging from well indurated sandstone and siltstone in the type area, to shallow water sandstone and conglomerate and to deeper water green weathering shale and fine sandstone. All of these rocks have been referred to the Longarm Formation but the only common aspect among them is their general Barremian to Valanginian age. As more information is gathered concerning this unit, a redefinition of the formation will probably become necessary. Coarse channel conglomerate with crosscutting channels, complex grading relationships, blocks of resedimented conglomerate and almost 100 % volcanic provenance for the clasts outcrop on northern Lyell Island where they overlie recognizable Yakoun Group. These beds, previously assigned to the Longarm, have no fossil control on their age assignment but from their provenance it would seem that they are quite locally derived from eroded volcanics of the Richardson Bay Formation and may be better assigned to the Middle Jurassic.

10. A radiometric age of 118 $\pm$ 7 Ma has been reported from a basalt porphyry in the Shell Anglo Sockeye E-66 well (Young, 1981). Thus an Aptian to Barremian age is suggested for the basalt, basalt porphyry and pyroclastics which lie below the Paleocene sediments in this well. This could represent unrecognized and unnamed volcanic and plutonic material in the section or altered Yakoun material with an anomalously young age. Some support for this being a real unit comes from the existence of the volcanic conglomerate facies of the Longarm on northern Lyell Island.

11. The succession of formations within the middle and Upper Cretaceous, Queen Charlotte Group (Fig. 4) has been misunderstood by various authors over a great many years. Previously, the succession was believed to be Haida, Honna and Skidegate formations in ascending order (Sutherland Brown, 1968; Sutherland Brown et al., 1983). Studies begun in 1982 revealed the presence of planktonic foraminifers within the Skidegate which were equivalent in age to those recovered from the Upper Shale Member (Sutherland Brown, 1968) of the Haida Formation. Equivalency, at least in part, of the Skidegate and Haida formations was indicated. This time equivalency has since been confirmed by ammonoid faunas (Haggart, 1986). Rather than introduce new stratigraphic names to resolve this problem, it is herein suggested that the name Haida Formation be restricted to the basal sandstone and conglomerate unit only. Thus, the Haida Formation is essentially of Albian age. The name Skidegate Formation is expanded to include those fine sandstones, mudstones and shales of the type Skidegate in the western Skidegate Inlet area and the predominantly shale facies of the upper Shale Member of the Haida Formation. The age of the Skidegate Formation as herein redefined is essentially Cenomanian to Turonian. The age of the overlying Honna conglomerate and sandstone as suggested by ammonoids is known up to this date as Coniacian (Haggart, 1986). In the light of these revised superpositional relationships, the distribution of the Skidegate Formation is not restricted to western Skidegate Inlet but is broadly distributed throughout the Queen Charlotte Islands. Sutherland Brown et al. (1983) suggested that the Skidegate represented a lacustrine or shallow marine environment in its type area. Further examination of these rocks indicates that the sequence represents a deep marine flyschoid deposit. None of the sedimentary structures, such as desiccation mud cracks or red bed facies, mentioned by the above authors in confirming

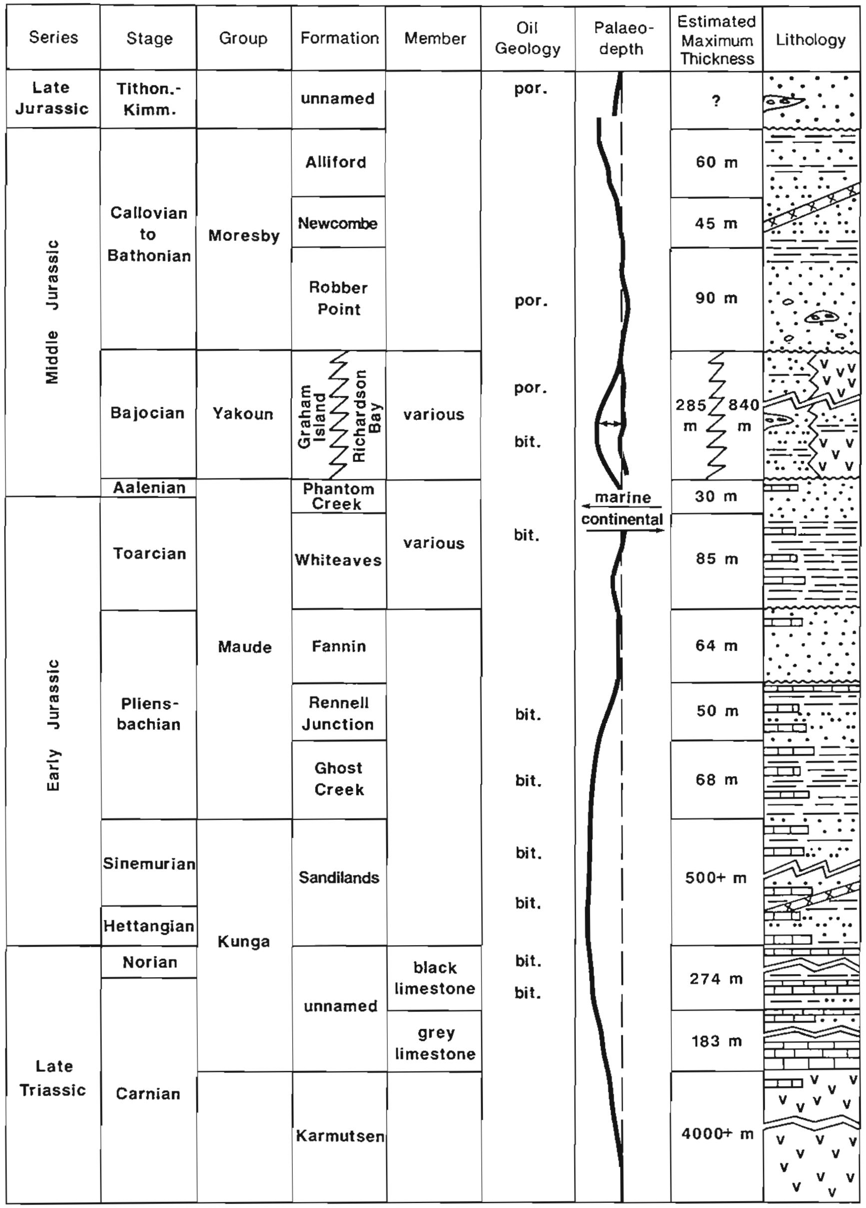


Figure 3

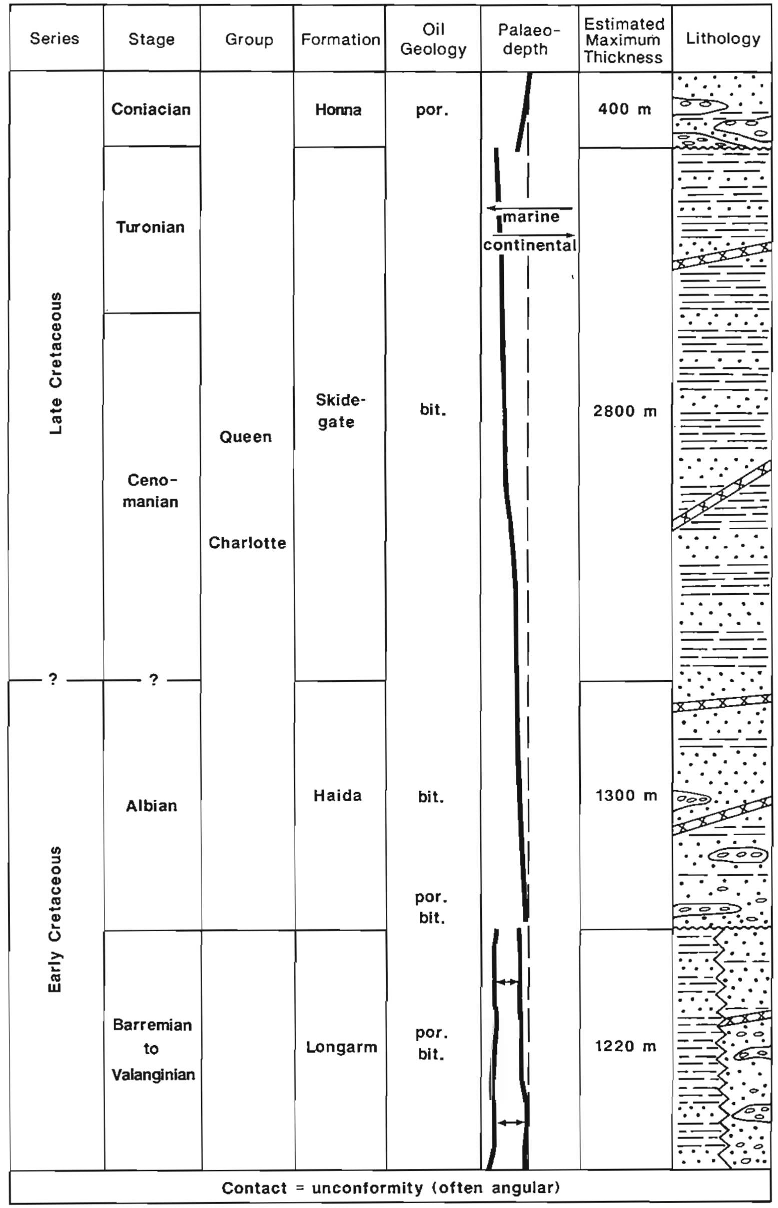


Figure 4

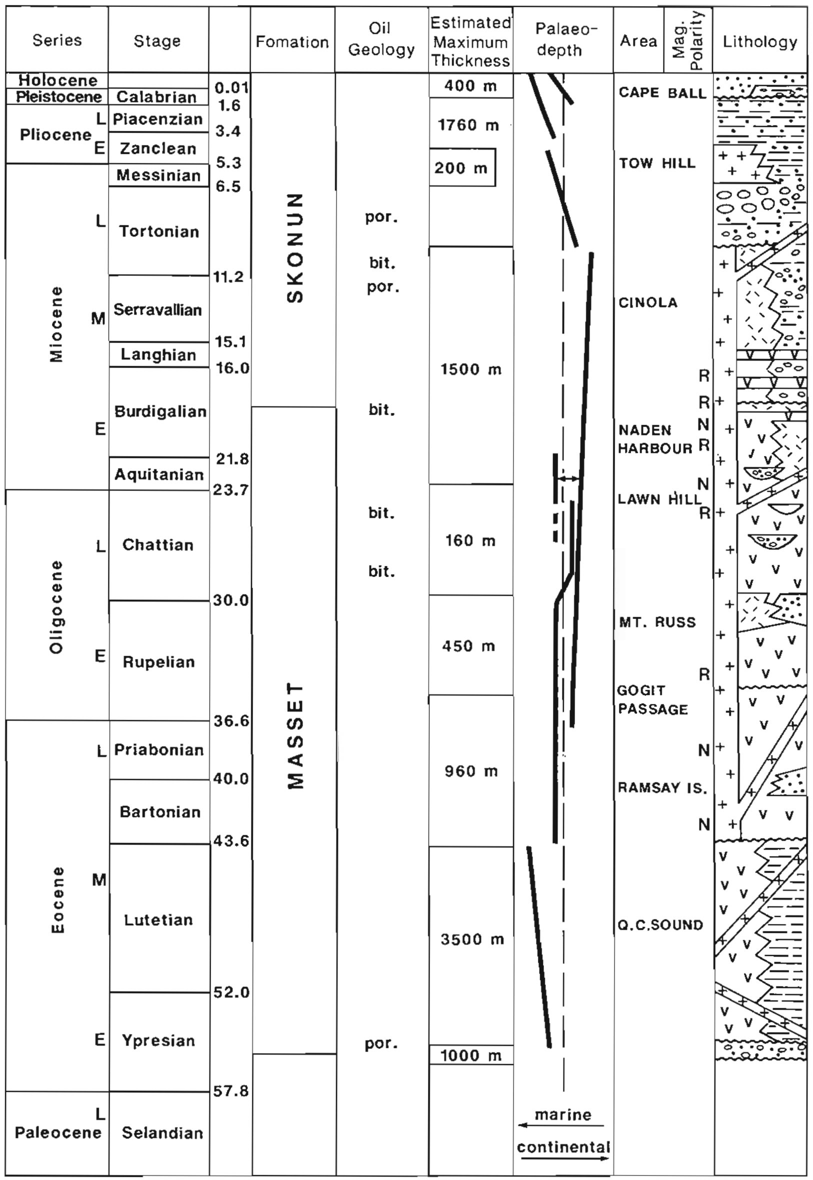


Figure 5

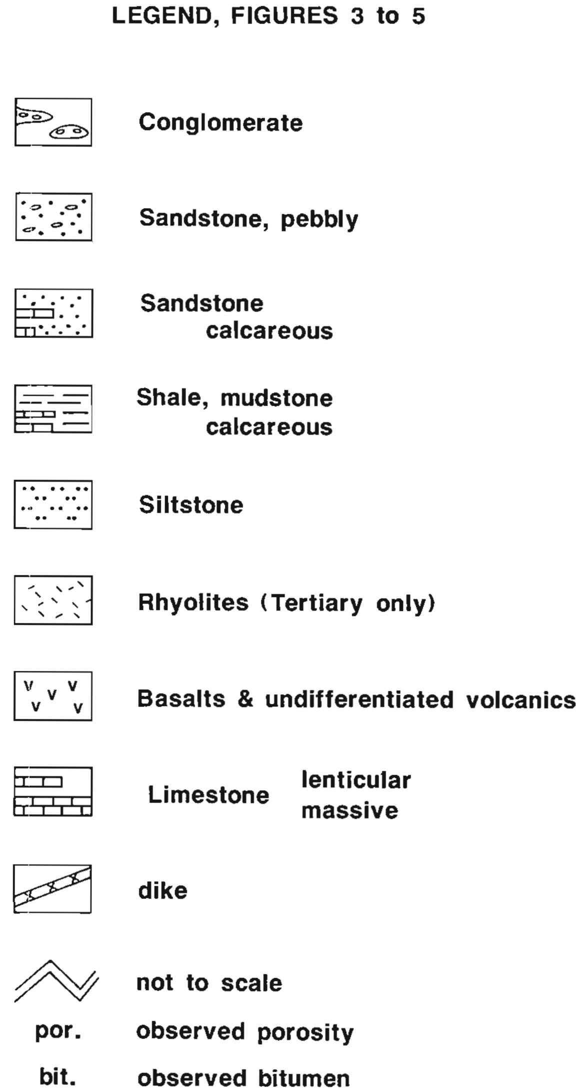


Figure 3. Composite Triassic and Jurassic stratigraphy of the Queen Charlotte Islands (modified after Cameron and Tipper, 1985).

Figure 4. Composite Cretaceous stratigraphy of the Queen Charlotte Islands.

Figure 5. Composite Cenozoic stratigraphy of the Queen Charlotte Islands.

a shallow environment have been observed during the present investigation. The Honna overlies the Skidegate in some areas paraconformably while in others an angular relationship is apparent. The Honna is a marine deposit at least in the basal part, but no reliable indicators of the approximate water depth of deposition have been observed.

12. Radiometric ages of 72 ± 6 Ma from a basalt porphyry and 84 ± 10 Ma from a basalt were obtained from sidewall core and cuttings respectively in the Shell Anglo Sockeye B-10 offshore well (Young, 1981). These volcanics of approximately Campanian age occur below a sedimentary unit of latest Cretaceous or earliest Tertiary age. Neither of these units have been formally named. Rocks of this age may occur within the basin beneath Hecate Strait but require further drilling to confirm their presence.

13. Evidence is also indicated from the Shell Anglo Sockeye B-10 well of an Upper Cretaceous (or basal Tertiary) nonmarine sedimentary unit. These strata are known from this locality only and their distribution and significance will only become more apparent with further drilling.

14. Sedimentary facies occur within the volcanic succession of the Masset Formation on Graham Island. These intra-volcanic sediments comprise less than a few tens of metres of section as exposed at various localities from King Creek to the north coast of Graham Island or encountered in well intersections at Tian Bay and Naden Harbour. Although some of the sedimentary bodies contain marine fossils and are tabular with up to a kilometre of lateral extent, most bodies are lenticular and discontinuous with abundant terrigenous and woody plant debris. This terrigenous plant debris could represent a possible Tertiary source of kerogen. Distribution of these sedimentary facies and thickness is related directly to their relative position with respect to depocentres and volcanic sources. Lithologies include volcanic conglomerate, volcanic arenite and tuffaceous siltstone. Most of these clastics are poorly sorted, muddy or matrix supported, with little primary porosity and are well lithified or cemented by carbonate, authigenic clays and zeolites. Secondary porosity is typically in the 2 to 10 % range in fractures, intrafragmental or as dissolution pits within altered volcanic feldspars. Except where secondary porosity becomes unusually well developed, these intravolcanic and volcanic proximal sediments make poor reservoir rocks and like the Tertiary volcanics will make better permeability barriers and cap rocks.

15. Tertiary volcanism with its related hypabyssal dykes and plutons is of long duration. New radiometric dates range from 41.1 to 11.0 Ma, confirming the age span reported by Young (1981). The main implications are significant heat input into the Queen Charlotte Basin over a long period of time and the development of a thick Tertiary section in a region of active volcanism. High level volcano-tectonic controls on Tertiary sedimentation and structural development are to be expected.

16. Facies relationships between Masset volcanics proximal to the vents (with little concommitant sediment accumulation) and distal sedimentation indicate that the Masset and Skonun formations are in part time correlative. There is no group name that includes both of these formations. The usual practice is to call any volcanic rock Masset, while the sediments are referred to as Skonun with no further refinement. Significantly different rock types have been described from a great many areas of the Queen Charlotte Islands (Fig. 5). Ultimately, these rocks will have to be redefined and at least include a division of sediments into later nonmarine and earlier marine facies or members.

17. The Tow Hill basaltic sills, like some of the 10 Ma rhyodacite vents of central Graham Island, are chemically equivalent to the Masset volcanics and show that Masset volcanism and late Tertiary heating persisted into Skonun time.

18. Unconsolidated Quaternary deposits include interglacial, glacial and postglacial units with both submarine and subaerial (continental) facies (Clague et al., 1982). Locally the section can exceed 400 m in thickness as is the case in the Cape Ball area and in the offshore wells. For marine drilling operations the Quaternary geology poses two main concerns. In shallow water areas and along the western margin of Hecate Strait there is pronounced sediment transport and bedform migration related to strong tidal currents and large storms (Barrie, in press). Acoustic reflection records indicate the extensive occurrence of both biogenic and thermogenic gas which could pose a threat to drilling (Hamilton and Cameron, in press; Barrie, in press).

TECTONIC OVERVIEW

The sequence of geological events in the Queen Charlotte Basin (sedimentary depositional cycles, erosional unconformities, deformations and magmatism) is strongly influenced by oceanic and oceanic-continental margin tectonic events. This is a consequence of the intra-oceanic and continental margin setting of this fragment of Wrangellian crust throughout its entire geological history. Paleontological and paleomagnetic evidence suggests that the original setting (Karmutsen to Kunga Group) was intra-oceanic in southerly latitudes (M. Gabrielse and C.J. Yorath, pers. comm., 1987). The unconformity at the top of the Maude Group corresponds to rifting between Gondwana and Laurasia with the opening of the central Atlantic Ocean. This first major basinwide unconformity in the section is the local Queen Charlotte Basin expression of that major plate re-organization and change in plate directions. The interval of syntectonic plutonism is the local equivalent of the Nevadan Orogeny and marks an interval of plate convergence and uplift on a regional scale.

The interval of Longarm sedimentation marks a local depositional cycle between two significant global plate reorganizations. Its base (Valanginian) is equivalent to the onset of major oceanic rifting in the Indian and south Atlantic oceans. This is the time of assemblage and docking of Cordilleran Superterrane I (Stikinia and Quesnellia, Irving et al., 1985). The top of the Longarm (Aptian) marks the onset of rifting in the Labrador Sea. The latter event certainly involved a significant change in the relative motion of the North American and Farallon plates. During Longarm sedimentation the ancestral Queen Charlotte Basin/Wrangellian block was riding the Farallon plate northwards. This is a time of slow relative Farallon-North America plate motion.

The deposition of the Queen Charlotte Group corresponds to oblique subduction of the Farallon plate beneath North America along with some sinistral shear. The Queen Charlotte Basin was in a fore-arc position. The onset of deposition is the local expression of plate motion changes corresponding to the opening of the Canada Basin and the beginning of major dextral strike slip faulting in the northern Canadian Cordillera (H. Gabrielse and C.J. Yorath, pers. comm., 1987). The abrupt end of the Queen Charlotte Group sedimentary cycle with the Coniacian Honna conglomerate marks the final assembly of Superterrane II (Wrangellia, Alexander and Taku). Paleomagnetic evidence (Irving et al., 1985) suggests that "Baja, BC" (the Insular Belt and Coast Range) was still in a southerly position at this time, approximately opposite southern California. This may imply basinal equivalencies between the Cretaceous successions in southern and central California and the Queen Charlotte Islands area. The deposition of the Honna conglomerate corresponds to the birth of the Kula Plate and the onset of Kula-Farallon spreading (Woods and Davies, 1982). From this time onwards the Queen Charlotte Basin fragment of Wrangellia was riding the Kula plate northwards. Strong dextral shear and local emergence are indicated. The unconformity at the base of the Tertiary succession marks the emplacement of "Baja, B.C.", Farallon-Pacific spreading and re-organization north of the Mendocino Fracture Zone and the opening to the Norwegian Sea. The decrease in Masset volcanism (circa 19-20 Ma) corresponds to the northwards passage of the failed Kula-Pacific rise. Deposition of the Skonun Formation occurred during a time of stable plate configuration with a greatly simplified structure of the East Pacific Rise (6000 km linear anomaly 6) and continued until the final consumption/subduction of the Kula Plate (Atwater, 1970; Naugler and Wageman, 1973).

REFERENCES

Atwater, T.
1970: Implications of plate tectonics for the Cenozoic tectonic evolution of western North America; Geological Society of America, Bulletin, v. 81, p. 3513-3536.

Barrie, J.V.
— Surficial geology of Hecate Strait, British Columbia Continental Shelf; Geological Survey of Canada, Open File (in press).

Berg, H.C., Jones, D.L., and Richter, D.H.
1972: The Gravina-Nutzotin Belt — tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska; United States Geological Survey, Professional Paper 800D, p. D1-D24.

Cameron, B.E.B. and Tipper, H.W.
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365, 49 p.

Clague, J.J., Mathewes, R.W., and Warner, B.G.
1982: Quaternary geology of eastern Graham Island, Queen Charlotte Islands, British Columbia; Canadian Journal of Earth Sciences, v. 19, p. 1786-1795.

Haggart, J.W.
1986: Stratigraphic investigations of the Cretaceous Queen Charlotte Group, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Paper 86-20, 24 p.

Hamilton, T.S. and Cameron, B.E.B.
— Hydrocarbon occurrences on the western margin of the Queen Charlotte Basin; Bulletin of Canadian Petroleum Geology (in press).

Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A.
1985: Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 584-598.

Naugler, F.P. and Wageman, J.M.
1973: Gulf of Alaska magnetic anomalies, fracture zones and plate interaction; Geological Society of America, Bulletin, v. 84, p. 1575-1584.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Sutherland Brown, A., Yorath, C.J., and Tipper, H.W.
1983: Geology and tectonic history of the Queen Charlotte Islands; Geological Association of Canada, Field Trip Guidebook, Trip 8, 21 p.

Woods, M.T. and Davies, G.F.
1982: Late Cretaceous genesis of the Kula Plate; Earth and Planetary Science Letters, v. 58, p. 161-166.

Young, I.F.
1981: Structure of the western margin of the Queen Charlotte Basin; unpublished M.Sc. thesis, University of British Columbia, 380 p.

Studies on the Triassic Kunga Group, Queen Charlotte Islands, British Columbia†

M.J. Orchard
Cordilleran and Pacific Geoscience Division, Vancouver

Orchard, M.J., Studies on the Triassic Kunga Group, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 229, 1988.

During June 1987, the charter vessel **Beatrice** was used as a logistics base for investigation of Early Mesozoic Kunga Group of eastern Moresby Island. Most of the Triassic outcrops delineated by Sutherland Brown (1968) were visited. M.J. Orchard sampled for conodonts, A. Desrochers (University of Ottawa) studied the sedimentology, and E.T. Tozer was responsible for macropaleontology. These investigators were also visited by E. Carter, who carried out sampling for radiolarians. Further studies were carried out by G.J. Woodsworth on the underlying Karmutsen Formation by R.G. Anderson and J. Souther on, respectively, plutons and dykes that intrude the Kunga Group; and by M. Bustin and D. Vellutini (University of British Columbia), who collected samples for geochemical analysis.

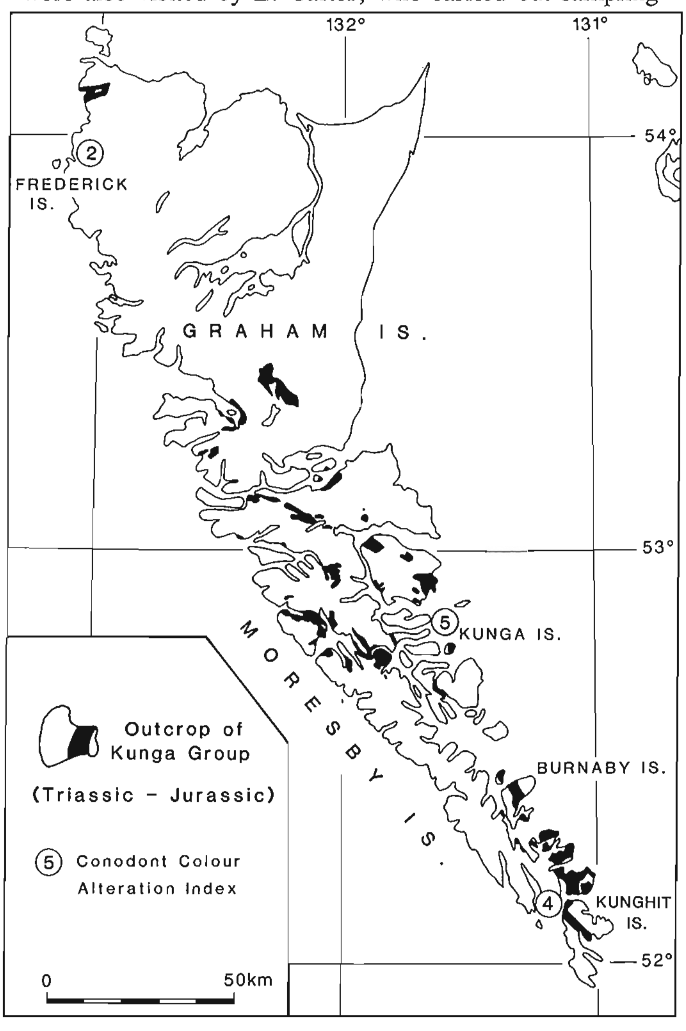


Figure 1. Outline map of the Queen Charlotte Islands showing principal outcrops of the Kunga Group,and some preliminary Conodont Colour Alteration Index (CAI) values.

Sections of Triassic Kunga Group, recognized in general by their macrofossil content and to a lesser extent by their lithology, were measured and sampled systematically. Detailed correlation of Triassic strata is being attempted using conodonts, radiolarians, ammonoids and bivalves: the result will constitute a framework for sedimentary analysis and environmental interpretations. Biogeographic aspects of the faunas are being studied to determine provenance. Study of conodont colour alteration is being undertaken to assess post-depositional temperatures of the host rocks.

In total, about 320 samples were collected for conodont processing. Macrofossil determinations by E.T. Tozer (written comm., 1987), indicate that strata of Late Carnian, Early? Norian, Middle Norian, and Late Norian are present. Preliminary results from conodont processing, currently underway, confirm the presence of each of the substages of the Norian, and a thick Carnian section. Several Norian conodont zones recognized in the Pardonnet Formation of northeastern British Columbia (Orchard, 1983) are identified in the Kunga Group.

Conodont colour alteration (CAI) provide a guide to post-depositional temperatures experienced by the Kunga Group (Fig. 1). Oil is generated within the range CAI 1-2, and a CAI of 4.5 represents the cutoff for gas. Regional trends and local effects have yet to be evaluated, but most of the CAI values in the Triassic of Moresby Island lie either near the cutoff limit (e.g. CAI = 4 on Kunghit and Burnaby islands), or in the supramature field (e.g. CAI = 5 on Kunga Island). Preliminary values for northern Graham Island (CAI = 1.5-2 on Frederick Island) are lower and lie well within the hydrocarbon window.

REFERENCES

Orchard, M.J.
1983: **Epigondolella** populations and their phylogeny and zonation in the Norian (Upper Triassic); Fossils and Strata, No. 15, p. 177-192. (Proceedings of the 3rd European Conodont symposium, Lund, Sweden, 1982).

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54.

† Contribution to Frontier Geoscience Program

A note on the status of Lower Jurassic ammonite biostratigraphy and paleontology of Queen Charlotte Islands, British Columbia[†]

H.W. Tipper, P.L. Smith[1], and G. Jakobs[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Tipper, H.W., Smith, P.L., and Jakobs, G., A note on the status of Lower Jurassic ammonite biostratigraphy and paleontology of Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 231, 1988.

Previously the lithostratigraphy of Lower Jurassic stratigraphic units of Queen Charlotte Islands was described (Cameron and Tipper, 1985; Sutherland Brown, 1968) with preliminary identifications of related ammonite faunas. Detailed studies of the faunas and systematic collecting are in progress and understanding of the ammonite succession now permits initial world-wide correlations, particularly with the classic faunas of Europe. The ammonite succession provides a standard by which associated microfossils — radiolaria, foraminifera, ostracods, and other forms — may be precisely zoned. This should provide a useful method of correlation of borehole samples in future drilling programs in the region.

Ammonites from Toarcian strata were collected with great care and thoroughness. There appears to be an almost uninterrupted ammonite succession representing the entire Toarcian stage but minor hiatuses may be present. Well-preserved and abundant fossils are found in three formations of the Maude Group, the Fannin, Whiteaves, and Phantom Creek formations. A detailed study of the fauna, now underway, will be the subject of a doctoral dissertation (Jakobs) at the University of British Columbia.

A continuing study of Pliensbachian faunas is well-advanced. Additional collections were made from the Cumshewa Inlet and Louise Island areas. A paper dealing with Pliensbachian ammonite zonation, based largely on Queen Charlotte Island material, was completed (Smith et. al., in press).

Ammonites from the Sandilands Formation of the Kunga Group were exhaustively collected. The formation spans the Sinemurian and may extend downward into the Hettangian stage. The faunas are relatively abundant but not particularly diverse. The section may be uninterrupted, no evidence of stratigraphic ommissions were noted, but many metres of section are devoid of fossils. The formation is typified by finely laminated shale, siltstone, sandstone and minor limestone in beds rarely greater than 2 cm thick. In the Cumshewa Inlet — Skidegate Inlet region the sediments are interlayered with white or grey weathering acid tuff, probably of air-fall origin, that forms beds up to 3 cm thick. Northwestward the tuff beds thin to extremely thin laminae and are absent in the northwestern part of Graham Island. Similarly, the tuff is reported to thin out to the south of Cumshewa Inlet. The volcanism associated with the Sandilands Formation was apparently of short duration; underlying Hettangian beds are not tuffaceous.

Unquestionably the most complete and best preserved Lower Jurassic ammonite fauna in Canada is found in Queen Charlotte Islands. Studies to date establish that ammonite faunas from all of Early Jurassic time are represented with the possible exception of earliest Hettangian. Abundant microfossils associated with the ammonites present the opportunity to relate the microfauna assemblages to ammonite zones and hence with the classic faunal successions of Europe and elsewhere in the world. Further work is planned.

REFERENCES

Cameron, B.E.B. and Tipper, H.W.
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365.

Smith, P.L., Tipper, H.W., Taylor, D.G., and Guex, J.
— An ammmonite zonation for the Lower Jurassic of the western Canadian Cordillera and the United States: the Pliensbachian; Canadian Journal of Earth Sciences (in press).

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54.

[†] Contribution to Frontier Geoscience Program
[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

New developments and current research on Middle Jurassic ammonite biostratigraphy, Queen Charlotte Islands, British Columbia[†]

T.P. Poulton and H.W. Tipper
Cordilleran and Pacific Geoscience Division, Vancouver

Poulton, T.P. and Tipper, H.W., New developments and current research on Middle Jurassic ammonite biostratigraphy, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 233, 1988.

Aalenian ammonites from two localities on Graham Island were mentioned by Cameron and Tipper (1981) and are illustrated and described in a taxonomic and biostratigraphic report on all Aalenian ammonites and strata in the western Canadian Cordillera (Poulton and Tipper, in press.). The ammonites, *Bredyia* aff, *manflasensis* Westermann reported by Cameron and Tipper (1985) as *Hammatoceras* cf. *H. semilunatum* (Quenstedt) and *Tmetoceras* are apparently Lower Aalenian based on their similarity, if not identity, with a South American species. *B.* aff. *manflasensis*, which seems to be an indicator for the Lower Aalenian, has not been found elsewhere in North America. The fauna is closest to that of South America and similar to that of northwest Europe but is entirely distinct from that of the North American and Asian Arctic. The significance of the strong differences with other parts of western Canada is not clear because of the paucity of the fauna.

The Lower Aalenian strata are thin and appear to represent local erosional remnants below a sub-Bajocian unconformity. They were apparently deposited in continuity with underlying Upper Toarcian strata, the two comprising the Phantom Creek Formation of the Maude Group (Cameron and Tipper, 1985).

The early Early Bajocian ammonite fauna, including *Docidoceras, Sonninia, Witchellia, Guhsania,* and *Bradfordia*? reported for the first time by Cameron and Tipper (1981) is currently the subject of description and illustration in a collaborative study with R.L. Hall. The fauna comes from the Graham Island Formation of the Yakoun Group and is included in beds that disconformably overlie Lower Aalenian strata of the Phantom Creek Formation. Together with those of the Lower Aalenian, these fauna partly fill the lengthy hiatus between the Bajocian and Toarcian beds that was postulated in the older literature. The faunal data presented here indicates that the hiatus spans Late Aalenian and, perhaps, earliest Early Bajocian time only.

REFERENCES

Cameron, B.E.B. and Tipper, H.W.

1981: Jurassic biostratigraphy, stratigraphy, and related hydrocarbon occurrences of Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 209-212.

1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365.

Poulton, T.P. and Tipper, H.W.

— Aalenian ammonites and strata of western Canada; Geological Survey of Canada, Bulletin (in press).

[†] Contribution to Frontier Geoscience Program

Radiolarian studies in the Queen Charlotte Islands, British Columbia†

Elizabeth S. Carter[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Carter, E.S., Radiolarian studies in the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 235-238, 1988.

Abstract

The past, present and future of Mesozoic radiolarian studies in the Queen Charlotte Islands is discussed. A brief review of initial studies by Pessagno and associates, Whalen, and Carter is followed by a summary of Carter's unpublished work on late Carnian-early Norian and late early Norian faunas from Sandilands Island.

Possible source beds for hydrocarbons have been recognized previously in the Upper Triassic and Lower Jurassic of the Queen Charlotte Islands. Current radiolarian investigations by Carter focus on this stratigraphic interval and include studies of Carnian and Norian faunas from the lower and middle members of the Kunga Formation, and Hettangian-Sinemurian faunas from the Sandilands Formation. Detailed study of these faunas is of importance to any future economic program especially as radiolarians are commonly the only abundant, age diagnostic fossil fauna consistently present in Carnian to Sinemurian age strata.

Résumé

On discute ici du passé, du présent et du futur des études sur les radiolaires du Mésozoïque dans les îles de la Reine-Charlotte. Un bref examen des premières études accomplies par Pessagno et associés, Whalen, et Carter précède un résumé du travail non publié de Carter sur les faunes ayant existé entre la fin du Carnien et le début du Norien et les faunes tardives du début du Norien provenant de l'île Sandilands.

Dans le Trias supérieur et le Jurassique inférieur des îles de la Reine-Charlotte, on avait déjà reconnu des roches mères qui pourraient renfermer des hydrocarbures. Les recherches actuelles sur les radiolaires faites par Carter visent cet intervalle stratigraphique et comprennent des études des faunes du Carnien et du Norien reconnues entre les membres les plus inférieurs et les membres intermédiaires de la formation de Kunga, et les faunes de l'Hettangien et du Sinémurien de la formation de Sandilands. L'étude détaillée de ces faunes est importante pour tout futur programme économique, particulièrement en raison du fait que les radiolaires sont habituellement la seule faune fossile abondante et aux âges caractéristiques qui se manifeste de manière régulière dans les strates datant du Carnien au Sinémurien.

† Contribution to Frontier Geoscience Program
[1] 58335 Timber Road, Vernonia OR 9706A, U.S.A.

INTRODUCTION

Radiolarian research in Western Canada is still in its infancy. In the Queen Charlotte Islands, radiolarians were first recognized as pelagic microfossils by Sutherland Brown (1968). Since then, excellent faunas from relatively uninterrupted sequences of Mesozoic strata have been the subject of several works and continue to provide material for study. Assemblages are stratigraphically controlled by well dated ammonoid and/or conodont faunas. Continuing documentation of the radiolarian faunal succession will establish a zonation intercalibrated with ammonoids, conodonts and foraminifers that holds great promise for correlation within and between terranes of the Canadian Cordillera and in any future drilling program initiated on the west coast of Canada.

Possible source beds of hydrocarbons have been recognized in early and middle Jurassic sections of the Kunga, Maude and Moresby groups (Cameron and Tipper, 1981, 1985; Cameron, 1987). Possible source beds are prevalent in the Sandilands Formation of Hettangian?, Sinemurian age and may be represented in the more sandy beds of latest Triassic age underlying the Sandilands and in the underlying black limestone member of the Kunga Formation (Sutherland Brown, 1968). Preliminary results from recent collections made by Carter indicate radiolarians of late Triassic to earliest Jurassic age are extremely diverse presumably because of rapid evolution. This fact coupled with the scarcity of ammonites and absence of foraminifers in the Carnian to Hettangian time interval make the detailed zonation of radiolarians of particular importance.

The purpose of this report is to summarize Mesozoic radiolarian studies in the Queen Charlotte Islands: what has been done, what is presently being done and what remains to be done.

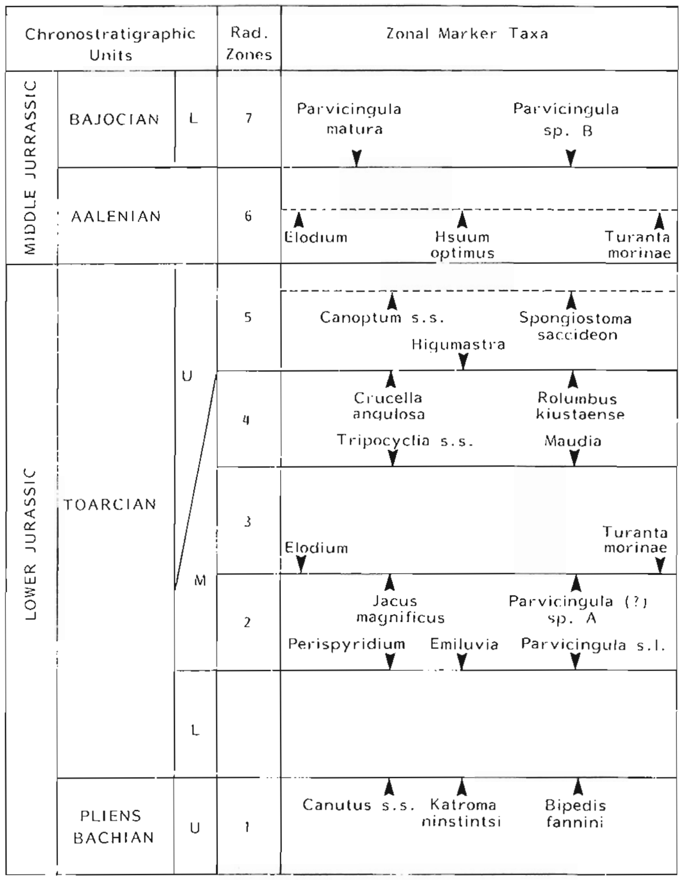


Figure 1. Zonal marker taxa for radiolarian units proposed for Upper Pliensbachian to Lower Bajocian strata in the Queen Charlotte Islands, after Carter (in press). ▼ = downward pointing triangle represents the last occurrence of a taxon; ▲ = upward pointing triange represents the first occurrence of a taxon.

TRIASSIC

Initial studies of Triassic radiolarians were confined to late Norian faunas from the uppermost part of the black limestone member at the type section of the Kunga Formation on Kunga Island (Pessagno and Blome, 1980; Blome, 1984). These works were largely taxonomic. Some preliminary range zone data is found in Pessagno and Blome (1980). Blome (1984) described additional taxa and incorporated the Queen Charlotte data in a radiolarian zonation for the Upper Triassic.

The first work on Triassic radiolarians older than late Norian was by E.S. Carter, who studies faunas from the black limestone member of the Kunga Formation on Sandilands Island (unpub. rep., 1986; EMR Canada Contract No. 23445-6-0067/01-6SB). Assemblages were dated by conodonts (M.J. Orchard, GSC), and two distinct faunas recognized; the older is late Carnian to early Norian; the younger, late early Norian. The older assemblage closely resembles Tethyan faunas from the Mediterranean area described by De Wever (1979) and includes species such as *Capnuchosphaera theloides, Poulpus phasmatodes* and forms comparable to *Capnodoce anapetes* and *Poulpus piabyx. Spongostylus tortilis* and *Capnodoce* are present but the latter is rare. *Justium novum* is the only characteristic species present belonging to the lowest *Justium novum* Subzone of Blome (1984). The absence of so many of Blome's subzonal taxa suggest this assemblage may be somewhat older than Blome's oldest faunas from the Rail Cabin Mudstone in Oregon, dated Upper Carnian?/Lower to upper Middle Norian. The late early Norian assemblage is characterized by the dominance of *Capnodoce, Syringocapsa, Acanthocircus* and several new forms. It contains many species representative of Blome's *Latium paucum* Subzone. Blome (1984) placed the upper boundary of the *Latium paucum* Subzone in the upper Middle Norian; the lower subzone boundary is tentatively placed just above the base of the Middle Norian (Blome, 1984, text-Fig. 7). Radiolarians from Sandilands Island suggest the *Latium paucum* Subzone should also include the upper Lower Norian.

In 1986-87 field seasons, E.S. Carter and M.J. Orchard (GSC) sampled from many of Sutherland Brown's localities. Preliminary results from 1986 indicate the presence of Lower and Middle Norian radiolarians in addition to a unique and very diverse, largely undescribed Carnian fauna. Carnian radiolarians other than those from the lower and uppermost parts are poorly known worldwide. Field observations suggest a thick Carnian section with relatively uninterrupted sedimentation. Further laboratory results should provide ample material for extensive biostratigraphic and taxonomic studies of Carnian, and possibly older, radiolarians. Collections are still being processed but preliminary observations of several excellently preserved assemblages from an interval well above *Monotis* suggest zonation of the very latest Triassic may be possible in the Queen Charlotte Islands. Furthermore, if collections from the grey limestone member yield radiolarians, biostratigraphic information gained should aid greatly in determining the age of the cessation of Karmutsen volcanism and the initiation of limestone sedimentation in Wrangellia.

JURASSIC

Radiolarian studies began in the late 1970s and results have been confined primarily to the description of new taxa with some preliminary range zone data (Pessagno and Blome, 1980; Pessagno and Whalen, 1982; Pessagno et al., 1986; Whalen, 1985). A major zonal scheme which incorporates some Queen Charlotte data has been proposed by Pessagno et al. (1987). Carter (1985) constructed an informal radiolarian zonation for Jurassic strata of late Pliensbachian to early Bajocian age from the Fannin, Whiteaves, Phantom Creek and Graham Island formations. Seven distinct assemblages are recognized (see Fig. 1). For further details of this zonation and of the new taxa described see Carter et al. (in press).

Of major interest at present is the Hettangian and Lower Sinemurian interval where accurate dating by macrofossils historically has been poor. The "unfossiliferous interval" referred to in various works by Pessagno et al. (1980, 1982, 1986, 1987) and Whalen (1985) very likely represents at least part of the Hettangian stage. Results from Carter's 1985-86 collections illustrate the great diversity of radiolarians from these beds which are above *Monotis*, and below the first Sinemurian arietitid ammonites. The major objective of the present study is to determine if true Hettangian rocks exist in the Queen Charlotte Islands and if so, to further study the biostratigraphy of the Radiolaria. This will require collecting radiolarians in association with Hettangian ammonites. A further objective is to define the boundary between the Lower and Upper Sinemurian on the basis of radiolarians. Pessagno et al. (1987) have erected two radiolarian zones for the Sinemurian (Zones 04 and 03) but the boundary between the two has yet to be correlated with ammonite zones. Carter's 1987 radiolarian collections, taken from measured sections containing ammonites sampled over a wide geographic area should help resolve these problems. Other projects include the continuing study of late Pliensbachian through early Bajocian faunas to test or, in necessary, modify Carter's zonation. Additional collections are needed from the lower Middle Toarcian and Aalenian to more precisely define these time intervals.

Excellent material is available for future radiolarian investigations in the Queen Charlotte Islands. Dating provided by the rich and closely associated ammonite fauna makes the area especially suitable for study of Lower and Middle Jurassic Radiolaria. Lower Jurassic forms, in particular, are extremely diverse and generally short-ranging, making them ideal for use in detailed biostratigraphic analysis. Taxonomically, there is much work to be done; the Pliensbachian with its greatly varied, and mostly undescribed, Tethyan fauna is a case in point.

The Lower Toarcian is of particular interest for future study. Lower Toarcian Radiolaria worldwide, are virtually unknown; the interval is either missing or if present, lacks radiolarians. Lower Toarcian strata containing *Dactylioceras* is present at several localities in the Charlottes but thus far, it too has failed to yield radiolarians. As new localities become available and more intensive and varied sampling continues, it is possible radiolarians from this critical interval may be found in the Queen Charlotte Islands. Other areas of interest include the upper Lower Bajocian of the Richardson Bay Formation and the Upper Bathonian to Lower Callovian of the Robber Point, Newcombe and Alliford formations. Lower Callovian shales contain abundant radiolarians but limestones thus far have failed to yield a well preserved fauna.

CRETACEOUS

Cretaceous radiolarians are very abundant in shales of the Haida and Skidegate formations but less so in limestone nodules where preservation is generally much better. This appears to be a preservation problem and a more varied system of sampling and/or processing techniques may increase the yield. Cretaceous radiolarians are diverse and the limited material presently available promises a refined zonation in the future. Several excellent faunas of Albian-Cenomanian and possibly Coniacian age are known from Skidegate Inlet and northwest Graham Island. Collections from Cretaceous formations made in (1987) the Skidegate Inlet area are currently being processed and results will be reported at a later date. Future radiolarian work should include systematic sampling of the thick Cretaceous sequence on northwest Graham Island; sampling there to date has been minimal.

CONCLUSIONS

The state of radiolarian biostratigraphy in the Queen Charlotte Islands is discussed above. This is a new study that is intended to solve problems where other fossil assemblages fail. In order for this method to succeed, it is necessary first to build a detailed zonation scheme where other faunas are present to provide accurate stratigraphic control. This criterion is met in the Queen Charlottes where rich ammonite, conodont and foraminiferal faunas prevail. Radiolarian biostratigraphy is providing new and continuing data that should be of substantial value to any future economic program in the Queen Charlotte Islands.

REFERENCES

Blome, C.D.
1984: Upper Triassic Radiolaria and radiolarian zonation from Western North America; Bulletins of American Paleontology, v. 85, no. 318, 88 p.

Cameron, B.E.B.
1987: Significance of Lower Jurassic hydrocarbon source rocks in the Cumshewa Inlet area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 925-928.

Cameron, B.E.B. and Tipper, H.W.
1981: Jurassic biostratigraphy, stratigraphy and related hydrocarbon occurrences of Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 81-1A, p. 209-212.
1985: Jurassic stratigraphy of the Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin 365, 49 p.

Carter, E.S.
1985: Early and Middle Jurassic radiolarian biostratigraphy, Queen Charlotte Islands, British Columbia; unpublished Ms thesis, University of British Columbia, Vancouver, 291 p.
— Radiolarian biostratigraphy (Early and Middle Jurassic), Queen Charlotte Islands, British Columbia; 2nd International Symposium on Jurassic Stratigraphy, Lisbon, September 12-27, 1987, Symposium Volume, (in press).

Carter, E.S., Cameron, B.E.B., and Smith, P.L.
— Early and Middle Jurassic radiolarian biostratigraphy and systematic paleontology, Queen Charlotte Islands, British Columbia; Geological Survey of Canada Bulletin (in press).

De Wever, P., Sanfilippo, A., Riedel, W.R., and Gruber, B.
1979: Triassic radiolarians from Greece, Sicily and Turkey; Micropaleontology, v. 25, no. 1, p. 75-110.

Pessagno, E.A. Jr. and Blome, C.D.
1980: Upper Triassic and Jurassic Pantanellinae from California, Oregon and British Columbia; Micropaleontology, v. 26, no. 3, p. 225-273.

Pessagno, E.A. Jr. and Whalen, P.A.
1982: Lower and Middle Jurassic Radiolaria (multicyrtid Nassellariina) from California, east-central Oregon and the Queen Charlotte Islands, B.C.; Micropaleontology, v. 28, no. 2, p. 111-169.

Pessagno, E.A. Jr., Blome, C.D., Carter, E.S., MacLeod, N., Whalen, P.A., and Yeh, K.-Y.
1987: Part II. Preliminary radiolarian zonation for the Jurassic of North America; *in* Studies of North American Jurassic Radiolaria; Cushman Foundation for Foraminiferal Research, Special Publication No. 23, 18 p.

Pessagno, E.A. Jr., Whalen, P.A., and Yeh, K.-Y.
1986: Jurassic Nassellariina (Radiolaria) from North American geologic terranes; Bulletins of American Paleontology, v. 91, no. 326, 75 p.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Whalen, P.A.
1985: Lower Jurassic radiolarian biostratigraphy of the Kunga Formation, Queen Charlotte Islands, British Columbia, and the San Hipolito Formation, Baja California Sur; Ph.D. dissertation, University of Texas at Dallas, Programs in Geosciences, 439 p.

Tertiary biostratigraphy, Queen Charlotte Basin, British Columbia†

James M. White
Institute of Sedimentary and Petroleum Geology, Calgary

White, J.M., Tertiary biostratigraphy, Queen Charlotte Basin, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 239, 1988.

Tertiary biostratigraphy is required to establish age control, to provide paleoenvironmental interpretations, and to correlate strata between wells and outcrops. These data will be provided by study of palynomorphs and foraminifera.

A taxonomic basis for Queen Charlotte Basin Neogene palynology has been provided by Martin and Rouse (1966). Hopkins (1975, 1981) has provided preliminary palynostratigraphy for the Shell Anglo Osprey D-36, Harlequin D-86, Auklet G-41, and Murrelet L-15 wells. Rouse, *in* Champigny et al. (1981) has proposed biostratigraphic markers for the Middle Miocene. Biostratigraphic interpretations of Shell Anglo's West Coast offshore wells are found in an internal Shell report (Anon.), whose author notes that Neogene biostratigraphy is derived more from climatically induced vegetation change than from evolutionary floral change.

The current palynological research will evaluate biostratigraphic potential using core samples from Richfield et al. Two Hill No. 1 well. A microsphere spike added to the palynological samples, and the computer program POLSTA will allow quantitative analysis of the data. Interpretations of the Tow Hill well will serve as the basis for evaluating and correlating previous palynological results. Analyses of other wells or outcrops await the results of this evaluation.

Biostratigraphic and paleoenvironmental information will be provided by foraminiferal analysis of the marine sections of Murrelet L-15, Harlequin D-86, and Osprey D-36 wells. This will allow a cross-check with palynological biostratigraphic interpretations. R.T. Patterson has been contracted to do the foraminiferal analysis.

REFERENCES

Anonymous
n.d. West coast paleontology and palynology; unpublished report, Shell Canada.

Champigny, N., Henderson, C.M., and Rouse, B.E.
1981: New evidence for the age of the Skonun Formation, Queen Charlotte Islands, British Columbia; Canadian Journal of Earth Sciences, v. 18, p. 1900-1903.

Hopkins, W.S. Jr.
1975: Palynological study of Shell Anglo Harlequin D-86 well (NTS 102/0), offshore British Columbia; Geological Survey of Canada, Open File 268.
1981: Palynology of four offshore British Columbia wells; Geological Survey of Canada, Open File 808.

Martin, H.A. and Rouse, G.E.
1966: Palynology of late Tertiary sediments from Queen Charlotte Islands, British Columbia; Canadian Journal of Botany, v. 44, p. 171-208.

† Contribution to Frontier Geoscience Program

Implications for hydrocarbon exploration of dyke emplacement in the Queen Charlotte Islands, British Columbia†

J.G. Souther
Cordilleran and Pacific Geoscience Division, Vancouver

Souther, J.G., Implications for hydrocarbon exploration of dyke emplacement in the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 241-245, 1988.

Abstract

Pervasive dyke and sill emplacement during Middle Jurassic, Yakoun volcanism may have resulted in thermal over-maturation of large areas of hydrocarbon source rocks in the Triassic- Jurassic Kunga Formation prior to deposition of potential reservoir rocks during the Cretaceous and Tertiary. In contrast, dyke emplacement associated with Tertiary Masset volcanism appears to be localized within a few major swarms separated by broad areas containing relatively few dykes.

Résumé

La mise en place de très nombreux dykes et sills, au cours du Jurassique moyen, et le volcanisme de Yakoun ont peut-être provoqué une surmaturation thermique de vastes étendues de roches mères contenant des hydrocarbures dans la formation de Kunga du Trias et du Jurassique, avant le dépôt de roches-réservoirs potentielles durant le Crétacé et le Tertiaire. Par contre, il semble que la mise en place des dykes associés au volcanisme tertiaire de Masset soit limitée à quelques grands essaims de dykes séparés par de vastes zones contenant relativement peu de dykes.

† Contribution to Frontier Geoscience Program

INTRODUCTION

About six weeks, June 15 to July 25, were spent collecting field data on dykes in the Queen Charlotte Islands. The work concentrated on shorelines, where exposures are sufficiently continuous to provide a statistically valid sample of dyke density. Field data were collected on all dykes exposed along about 300 km of shoreline which were examined either from a boat or by walking on wave-cut benches. Thickness, orientation, lithology and contact relationships were recorded on 656 dykes and 340 samples were collected for petrological, chemical and geochronological work.

The dyke study was funded by and co-ordinated with the broader Frontier Geoscience Program initiated in 1987 to assess the petroleum potential of Queen Charlotte Basin. Data on the dykes will be used to model the thermal effects of igneous intrusion on both potential hydrocarbon source and reservoir rocks. The following report, based on a preliminary assessment of the field and laboratory data, will be followed by additional fieldwork and more rigorous analysis of the results.

GEOLOGICAL SETTING

The Triassic-Jurassic Kunga Formation and the Lower Jurassic Maude Formation comprise an assemblage of shale, sandstone, argillite and limestone which is locally petroliferous and is believed to include hydrocarbon source rocks (Sutherland Brown, 1968; Yorath and Hyndman, 1983; Orchard, 1988). The sediments are overlain by the predominantly volcanic, Upper Jurassic Yakoun Formation which appears to be the protolith from which massive Cretaceous sandstones were derived (Thompson, 1988). These sandstones, which are locally porous enough to have reservoir potential, are overlain by the Masset Formation, a complex assemblage of Tertiary volcanic and minor volcaniclastic rocks (Hickson, 1988).

In addition to igneous activity related to Yakoun and Masset volcanism several large granitic plutons on the Queen Charlotte Islands are classified as "post-tectonic" by Sutherland Brown (1968). Some of these cut and metamorphose Cretaceous and Early Tertiary rocks (Anderson, 1988) and are clearly related to an igneous episode that postdates the Yakoun. Others, such as the Carpenter Bay Pluton (Fig. 3) are not in direct contact with rocks younger than the Kunga. The lithological similarity between fine grained phases of the Carpenter Bay Pluton and widespread Yakoun dykes throughout south Moresby suggests that the Carpenter Bay and possibly other "post-tectonic" plutons may be subvolcanic equivalents of the Yakoun.

REGIONAL DISTRIBUTION

The density of dykes varies dramatically from place to place within the Queen Charlotte Islands. Most of those studied during the 1987 field season are concentrated in four well defined swarms (Fig. 1) separated by extensive areas which contain little or no dyke material. Each swarm contains a dominant set of dykes with fairly consistent trends and lithologies but, as is evident from the rose diagrams (Fig. 1), there is considerable local scatter, particularly in the Selwyn Inlet and Tasu Sound swarms.

AGE AND ASSOCIATION

Except for those rare localities where crosscutting relations are exposed it is difficult to discriminate between dykes of different ages and associations.

In general greenish-grey "andesite" dykes, which are lithologically similar to and probably comagmatic with the Yakoun volcanics, are confined to the Kunga and Yakoun formations. Their orientation is locally consistent but both dyke density and orientation vary from one locality to another. They are most abundant near Kunga-Yakoun contacts, suggesting that pervasive, high level dyke and sill emplacement accompanied Yakoun volcanism. The dykes, which range from 1 to 8 m thick, are commonly associated with comagmatic sills from 1 to more than 15 m thick. Columnar jointing is either absent or poorly developed (Fig. 2). Intrusive contacts with Kunga sediments are extremely sharp and display little or no thermal alteration of the intruded rock and only moderate quenching of thin selvages on the dykes and sills. However, both dykes and sills have suffered varying degrees of post-emplacement deformation. Because the dykes are relatively more competent than the enclosing sediments deformation is commonly manifest in shearing and brittle fracturing along contacts but many Yakoun dykes and sills have also been folded or offset by minor faults. Structural relationships suggest that emplacement of Yakoun dykes and sills was coeval with deformation of the Kunga.

Dykes associated with "post-tectonic" plutons resemble those associated with the Yakoun volcanics, but they form unidirectional swarms of great length which merge with late stage, fine grained phases of the parent pluton. The association is well displayed at the southern end of the Carpenter Bay swarm where as much as 80 % of the exposed rock consists of coalescing dykes enclosing residual lenses and pockets of intensely deformed Kunga sediments.

Basalt, andesite?, and rhyolite dykes believed to be Masset feeders are present in each of the four major swarms. Basalt is by far the most abundant and widespread phase. It forms 1 to 10 m thick dykes with well developed columnar jointing and straight, sharp, undeformed contacts. Masset andesite dykes locally cut those of basalt and rhyolite. They are difficult to distinguish in the field from andesite dykes associated with the Yakoun but the two are easily recognized in thin section (see below). Rhyolite dykes of Masset age are uncommon and were found only within, and close to, areas underlain by Masset volcanics. Rhyolite dykes near the western edge of the Rennell Sound swarm are commonly more than 10 m thick and have pronounced subvitreous selvages. Similar, rusty weathering rhyolite within the other swarms is also confined to a few very large bodies, some several hundreds of metres across. The distribution of Masset dykes indicates that the basaltic feeder system was far more widespread and far more disseminated than feeders to the more siliceous phases. Masset rhyolite appears to have been channelled to the surface through relatively few large conduits, whereas the basalt ascended through a myriad of relatively thin dykes concentrated in well defined swarms. Masset dykes of all types are most abundant near areas of Masset outcrop, suggesting that the original extent of the Masset volcanic pile may not have been much greater that the present distribution.

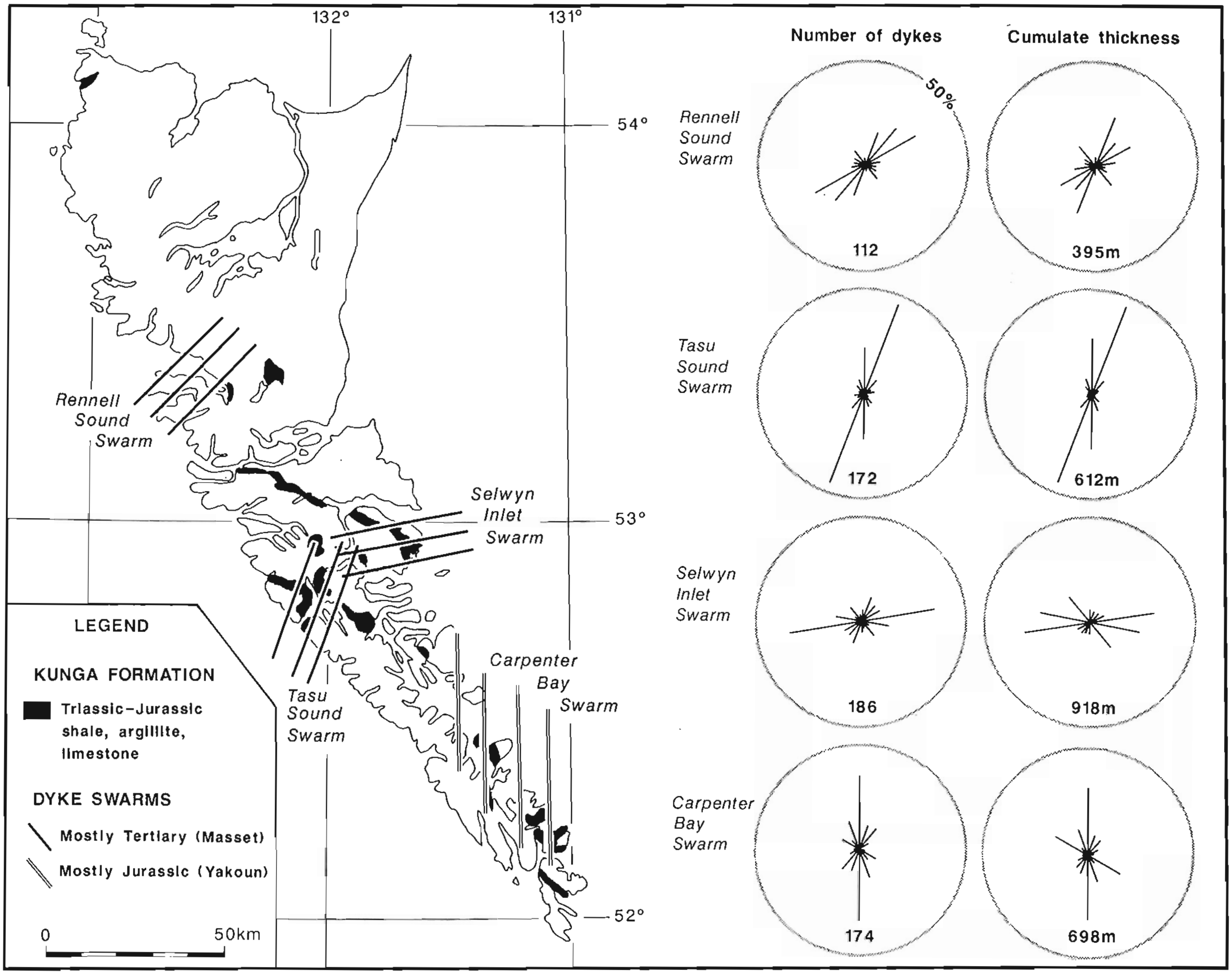


Figure 1. Sketch map showing the distribution of possible hydrocarbon source rocks and principal dyke swarms, investigated during the 1987 field season. Rose diagrams show the percentage of the total number of dykes, and the percentage of the total thickness of dykes oriented within each 20° sector of the compass. The total number of dykes recorded and their cumulative thickness in each swarm are also given.

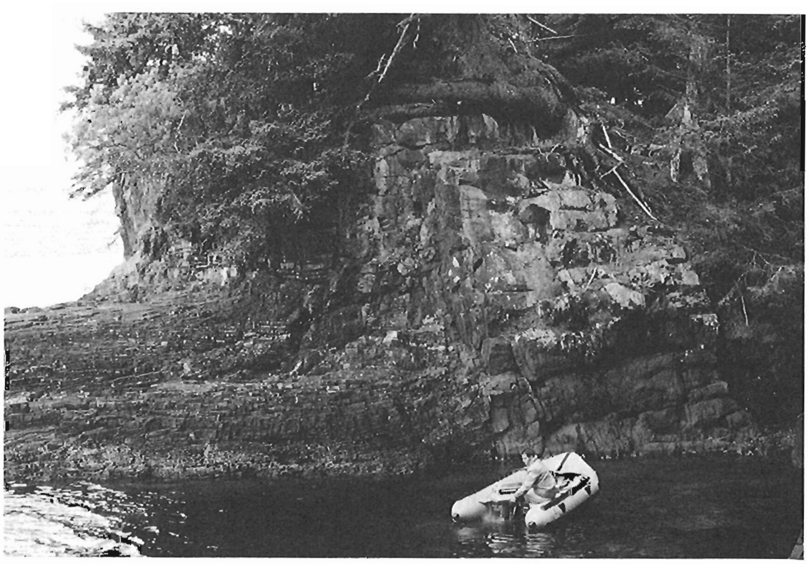


Figure 2. Nearly flat-lying beds of Triassic, Kunga calcareous shale cut by a 6 m thick Yakoun columnar andesite dyke on Moresby Island.

LITHOLOGY

With few exceptions the 656 dykes recorded during the 1987 field season are composed of fine- to medium-grained aphyric rock. A few dykes near the northwestern end of the Rennell Sound swarm contain small (2 to 3 mm) feldspar phenocrysts and a few dykes near the southern end of the Carpenter Bay swarm are hornblende-phyric. Elsewhere the dyke rocks are not only devoid of phenocrysts but the groundmass feldspars are commonly not aligned. Even the fine grained basalts and andesites are characterized by randomly oriented mineral grains, often having an interlocking diabasic texture. The magma clearly lacked any significant solid phases at the time of intrusion; instead, crystallization appears to have taken place in situ, after the cessation of flow.

Examination of thin sections shows that dykes of probable Yakoun affiliation are characterized by a dirth of primary mafic minerals. The predominant lithology is medium grained, aphyric andesite comprising randomly oriented, stubby crystals of sodic plagioclase and interstitial areas of pale green feathery chlorite and secondary carbonate. Rarely small remnants of pyroxene are preserved within the chloritized areas.

Thin sections from dykes associated with the Carpenter Bay Pluton show those rocks to be slightly less altered but otherwise similar to sections of Yakoun andesite dykes elsewhere in the Carpenter Bay swarm.

Rocks from dykes associated with the Masset are considerably less altered than those of probable Yakoun age. The basalts are typically ophitic or subophitic, comprising randomly oriented plagioclase laths surrounded by interstitial clinopyroxene and varying amounts of fine granular secondary minerals derived from devitrification of glass. No olivine was observed in any of the thin sections examined. Masset andesite dykes are texturally similar to the basalts, but they contain traces of interstitial quartz and the mafic minerals, which include hornblende as well as pyroxene, are mostly altered to chlorite. The rhyolites examined in thin section comprise a fine myrmekitic intergrowth of quartz and feldspar containing sparse grains of chlorite and opaque oxides.

STRUCTURAL IMPLICATIONS

Differences in dyke orientation among the four principal swarms are probably due in part to differences in age. The Carpenter Bay swarm for example is dominated by dykes related to Cretaceous-Tertiary plutons. The northerly trend of this swarm reflects a much deeper regime than that of the other swarms.

Both the Carpenter Bay and Selwyn Inlet swarms include a relatively high proportion of Yakoun dykes which, because many have been deformed, leads to greater scatter in the rose diagrams (Fig. 1).

The predominant trends in the Rennell Sound, Selwyn Inlet and Tasu Sound swarms are dominantly those of Masset dykes. This implies either profound local differences in regional stress fields during Masset time or significant post-Masset rotation of large blocks of terrane within the Queen Charlotte Islands. There does not appear to be any compelling evidence to rule out either possibility. The direction of the Rennell Sound and Tasu Sound swarms is consistent with extension related to movement on Queen Charlotte Fault. Indeed right lateral offsets of Massett dykes on northwesterly-trending minor faults were observed at many places within the Rennell Sound and Tasu Sound swarms. The anomalous, easterly trend of the Selwyn Bay swarm is more difficult to rationalize and invites speculation that it may be a northern extension of the Tasu Sound swarm which has been rotated about 60° clockwise.

Each of the four swarms studied is between 10 and 15 km wide. The amount of crustal dilation due to dyke emplacement within the swarms varies from about 0.5 % across the Rennell Sound swarm to about 2 % across the Tasu Sound and Selwyn Inlet swarms. Dilation across the northern part of the Carpenter Bay swarm is a similar order of magnitude but at its southern end, where coalescing dykes merge with a comagmatic pluton, dilation across a 4 km wide zone exceeds 80 %.

THERMAL ENVIRONMENT

A preliminary assessment of the 1987 data suggests a fundamental difference in the style of dyke emplacement associated with Yakoun and Masset volcanism.

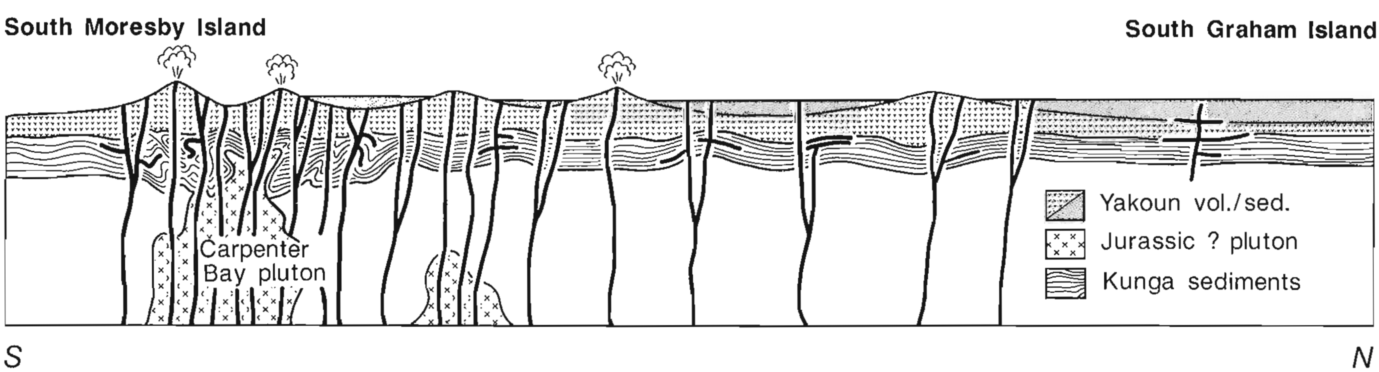


Figure 3. Schematic cross-section from southern Graham Island to Cape St. James, showing an interpretation of the relationship between Kunga sediments and Yakoun igneous rocks.

Yakoun feeders form widespread, pervasive, dykes and sills that cut almost all exposed areas of Triassic-Jurassic, Kunga sediments. Their emplacement appears to have been coeval with deformation of the Kunga and their density appears to increase southward from Rennell Sound to Carpenter Bay (Fig. 3). The lithological similarity and close spatial association between the Carpenter Bay dykes and the Carpenter Bay Pluton suggests a genetic relationship. Indeed both the dykes and the pluton may be subvolcanic equivalents of the Yakoun. If this is so then Yakoun volcanism must have been associated with the emplacement of both large and small high level plutons accompanied by deformation and a regional increase in the geothermal gradient. These events must certainly have had a profound effect on hydrocarbon source rocks in the Kunga, possibly leading to thermal over maturation before potential reservoir sands were deposited during the Cretaceous and Tertiary.

In contrast to the pervasive intrusion that accompanied Yakoun volcanism, the Masset feeders appear to be confined to relatively narrow linear zones in which dyke density decreases abruptly away from existing areas of Masset volcanics. More than 80 % of the Masset dykes in the Rennell Sound, Tasu Sound and Selwyn Inlet swarms are basic (basalt or basaltic andesite) and are not associated with any significant hydrothermal alteration of the intruded rock. Masset rhyolite intrusions are even more restricted to areas near or adjacent to the volcanic piles. They comprise relatively few, thick dykes or irregular intrusive bodies surrounded by haloes of silicified, hydrothermally altered country rock. Their distribution suggests that feeders to the acidic members of the Masset pile were centrally located and are still mostly covered by coeval volcanics. The thermal effect of Masset intrusion on potential hydrocarbon source or reservoir rocks may have been confined to relatively narrow dyke swarms and to those areas, now underlain by acid volcanic rocks, where emplacement of large rhyolitic intrusions may have initiated local hydrothermal systems.

REFERENCES

Anderson, R.G.
1988: Jurassic and Cretaceous-Tertiary plutonic rocks on the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Hamilton, T.S. and Cameron, B.E.B.
— Hydrocarbon occurrences on the western margin of the Queen Charlotte Basin; Bulletin of Canadian Petroleum Geology (in press).

Hickson, C.J.
1988: Structure and stratigraphy of the Masse Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Orchard, M.J.
1988: Studies on the Triassic Kunga Group, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Thompson, R.I.
1988: Late Triassic through Cretaceous geological evolution, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Geothermal studies in Queen Charlotte Basin, British Columbia†

T.J. Lewis, W.H. Bentkowski, M. Bone, R. MacDonald, and J.A. Wright[1]
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Lewis, T.J., Bentkowski, W.H., Bone, M., MacDonald, R., and Wright, J.A., Geothermal studies in Queen Charlotte Basin, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 247-249, 1988.

Abstract

Measured heat flux and calculated crustal temperatures are needed to compare with expected values from different tectonic models and with temperatures for hydrocarbon maturation in Queen Charlotte basin. Geothermal measurements were made at additional land sites bordering Hecate Strait, and marine measurements in Queen Charlotte Sound and Hecate Strait were continued. These data combined with previous measurements surrounding the Queen Charlotte basin give a good distribution of heat flux. Marine data over a period of a few years are required to overcome large changes in bottom water temperatures.

Résumé

Le flux thermique mesuré et les températures crustales calculées sont nécessaires afin de les comparer aux valeurs de différents modèles tectoniques et aux températures liées à la maturation des hydrocarbures dans le bassin de la Reine-Charlotte. Des mesures géothermiques ont été prises à d'autres endroits à terre, en marge du détroit d'Hécate, et on a poursuivi la prise des mesures marines dans le détroit de la Reine-Charlotte et le détroit d'Hécate. Ces données, combinées aux mesures antérieures prises sur le pourtour du bassin de la Reine-Charlotte, donnent une bonne distribution du flux thermique. Les données prises en mer pendant une période de quelques années sont nécessaires en raison des variations considérables enregistrées dans les températures de l'eau du fond de la mer.

† Contribution to Frontier Geoscience Program

[1] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5

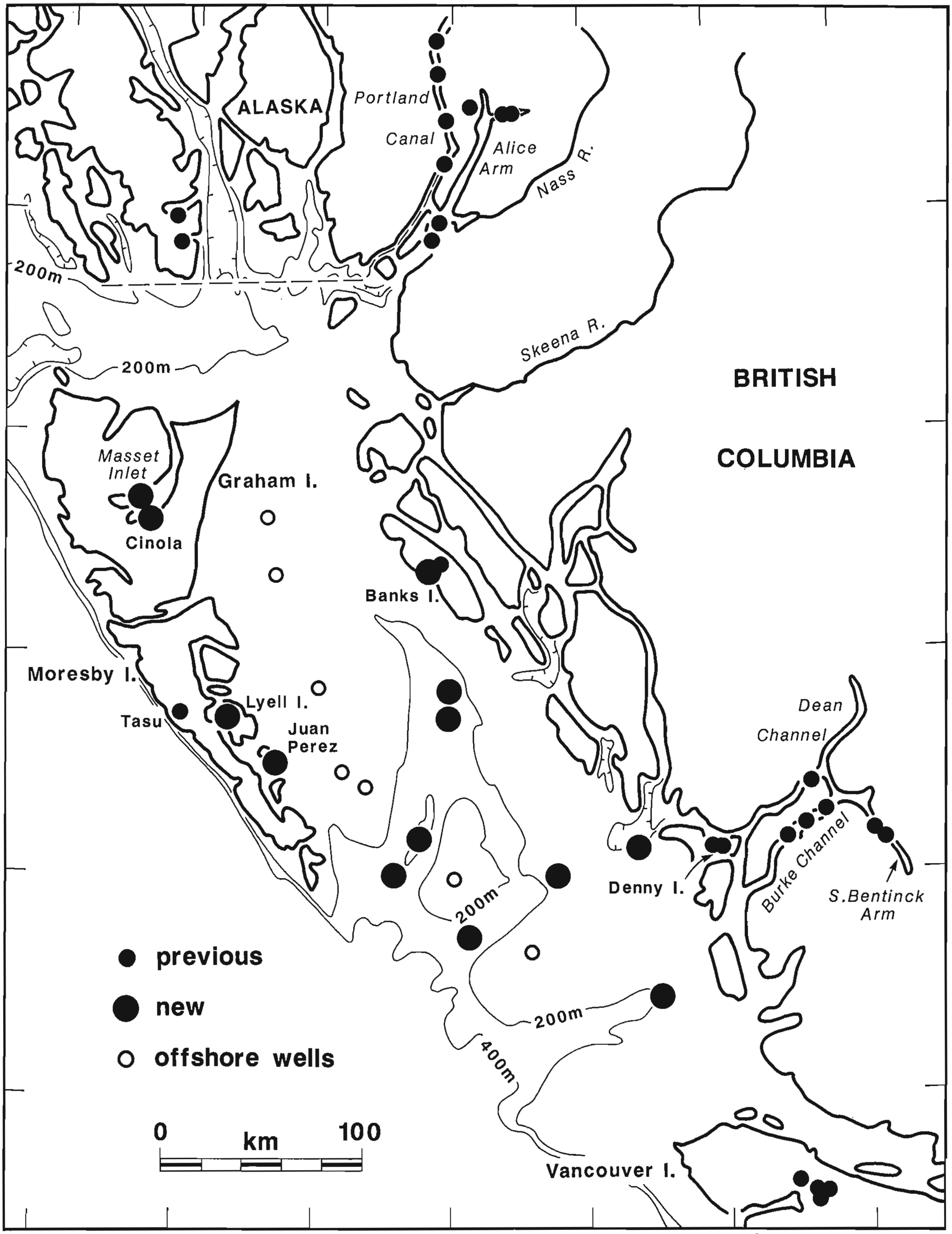


Figure 1. Heat-flow site locations in and around Queen Charlotte Sound.

INTRODUCTION

The first objective of this program is to obtain geothermal data from the Queen Charlotte Basin so that the equilibrium heat flux can be determined across the basin and present crustal temperatures can be modelled. The heat flux and crustal temperatures can be compared with predicted values from various models of basin evolution and with temperatures for the hydrocarbon maturation window. Yorath and Hyndman (1983) calculated the paleo-heat flux and subsidence using data from offshore wells (see Fig. 1) and suggested a model of basin formation involving rifting followed by oblique subduction. Heat flux data from the basin's perimeter are relevant to any modelling. Hyndman et al. (1982) measured high heat fluxes on the young seafloor west of Moresby Island at depths greater than 800 m. On-land measurements have been made at Tasu on Moresby Island (Hyndman et al., 1982), in southeast Alaska (Sass et al., 1985), and on northern Vancouver Island (Lewis et al., 1985; Bentkowski and Lewis, 1984). Analysis is continuing on previous measurements on Banks Island, on Denny Island, at Anyox, and in the fjords on the B.C. mainland (see Fig. 1).

At present more geothermal data are being gathered on land using measurements in boreholes drilled by the mineral exploration industry and on the continental shelf using modified oceanographic techniques. Obtaining the heat flux using oceanographic techniques in shallow water is difficult because unlike deep ocean water, the bottom water temperature (BWT) changes with time. Data loggers moored near the bottom at a few sites for a period of a year at a time are recording the BWTs, and on successive annual cruises deep (11 m) temperature gradients are being measured within the top sediments at several sites. The bottom water history can be modelled and compared to measured values, in order to obtain the equilibrium heat flux. Less important longer term BWT fluctuations are not well known, but some data exist (Thomson et al., 1981; Crawford et al., 1987). Data indicate a BWT change of approximately 0.6°C annually, comparable to the total temperature difference measured along the length of a long heat-flow probe.

PROGRESS REPORT

Boreholes were successfully logged at the Cinola property (City Resources) on Graham Island and on the April Claims (Placer Development) on Lyell Island. Local water flows modify the temperatures in the top 200 m of the Cinola deposit. Analysis of the data and measurement of the thermal conductivity of core samples is underway.

In 1986 the first of three cruises to Queen Charlotte Sound gathered geothermal data, and deployed three dataloggers. In September, 1987 two of the three dataloggers were recovered and bottom water temperatures were measured accurately using portable borehole logging equipment at 10 stations, including four sites where dataloggers were redeployed. The redesigned 11 m heat flow probe penetrated deeper than in 1986 at all repeated stations, including 5 where the previous strength members were badly damaged. The probe penetrated sediments at 28 of 29 stations, achieving full penetration at 13 stations. The average penetration was 9.5 m. A 7 m probe was deployed at 13 stations. Preliminary analysis of data from Queen Charlotte Sound, Hecate Strait and Masset Inlet shows heat flux generally varying in the top 4-5 m by large amounts, indicating the need for careful analysis of large BWT transients.

To obtain deep penetration into shelf sediments, areas were chosen using published data on surficial sediments (Luternauer and Murray, 1983; Luternauer and Conway, 1986; Barrie, in press) and sites were chosen using 3.5kHz sounding within these areas. Profiles were run in Masset Inlet (30 km), the east (100 km) and west (45 km) sides of Hecate Strait, off Milbanke Sound (45 km), and Moresby Trough (40 km), as well as near all stations.

REFERENCES

Barrie, J.V.
— Surficial geology of Hecate Strait, British Columbia Continental Shelf; Geological Survey of Canada, Open File (in press).

Bentkowski, W.H. and Lewis, T.J.
1984: Preliminary results from drilling in the Alert Bay Volcanic Belt, 1982; Earth Physics Branch, Open File Report 84-2, 16 p.

Crawford, W.R., Huggett, W.S., and Lee, K.S.
1987: Water property observations from Queen Charlotte Sound, May and September, 1982; Fisheries and Oceans, Canadian Data Report of Hydrography and Ocean Sciences No. 50, 224 p.

Hyndman, R.D., Lewis, T.J., Wright, J.A., Burgess, M., Chapman, D.S., and Yamano, M.
1982: Queen Charlotte Fault Zone: heat flow measurements; Canadian Journal of Earth Sciences, v. 19, p. 1657-1669.

Lewis, T.J., Jessop, A.M., and Judge, A.S.
1985: Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics; Canadian Journal of Earth Sciences, v. 22, p. 1262-1273.

Luternauer, J.L. and Conway, K.W.
1986: Geohazards, lithology and shallow seismostratigraphy of the Moresby Trough/Middle Bank area, Queen Charlotte Sound, British Columbia; Geological Survey of Canada, Open File 1420 (2 sheets).

Luternauer, J.L. and Murray, J.W.
1983: Late Quaternary morphologic development and sedimentation, central British Columbia continental shelf; Geological Survey of Canada, Paper 83-21.

Sass, J.H., Lawver, L.A., and Munroe, R.J.
1985: A heat-flow reconnaissance of southeastern Alaska; Canadian Journal of Earth Sciences, v. 22, p. 416-421.

Thomson, R.E., Huggett, W.S., and Kuwahara, L.S.C.
1981: Queen Charlotte Sound and Hecate Strait, Part 1-Water property observations May, July and September, 1977; Canadian Hydrographic Service, Data Record of Current Observations, v. 17, 195 p.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Progress report on organic geochemistry, Queen Charlotte Islands, British Columbia[†]

L.R. Snowdon, M.G. Fowler, and T.S. Hamilton[1]
Institute of Sedimentary and Petroleum Geology, Calgary

Snowdon, L.R., Fowler, M.G., and Hamilton, T.S.,Progress report on organic geochemistry, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 251-253, 1988.

Abstract

Prelimary analyses of oil seep and extract samples from the Queen Charlotte Islands indicate the presence of a few Tertiary bitumens derived from terrestrial organic matter. Correlation of seep samples with samples from the Kunga and Maude group source rocks could not be made.

Résumé

Des analyses préliminaires d'échantillons d'indices et d'extraits d'huile provenant des îles Reine-Charlotte indiquent la présence de bitumes dérivés de matières organiques terrestres. Une corrélation peut être établie entre ces échantillons d'indices d'huile et ceux des roches mères des groupes Kunga et Maude.

[†] Contribution to Frontier Geoscience Program
[1] Cordilleran and Pacific Geoscience Division.

INTRODUCTION

In order to obtain the best possible estimate of the petroleum resources present in the vicinity of the Queen Charlotte Islands, a study of the source potential of various rock units has been undertaken as well as the characterization of several oil seep and bitumen shows. Previous work by Macauley (1983) has been supplemented by rerunning Rock-Eval/TOC analyses on a number of outcrop and core samples from the Kunga and Maude groups as well as analyzing additional samples from boreholes on the island (Tlell No. 1, Tow Hill No. 1, Naden B-27). In addition, several samples from the Intercoast wells (I-1-78, I-2-78, and I-1-79) have been solvent extracted. Bitumen and oil seep samples (Hamilton and Cameron, work in progress) collected over the past several years (including 1987) have also been analyzed.

ROCK-EVAL/TOC ANALYSES

The Rock-Eval/TOC analyses for the Macauley (1983) sample set were rerun because of a calibration error in the instrument at the time the initial runs were made. Originally reported S2 and TOC values were too high; the new S2 values are lower by a factor of about 0.40, and the new TOC values lower by a factor of about 0.80. As a result, the calculated Hydrogen Index values (S2*100/TOC) are reduced by about 50 per cent. The Tmax values and inferred maturity remain more or less the same, as does the overall sense of the relative quality of the samples. The absolute yields and HI are reduced and inferred organic type altered.

The Rock-Eval/TOC results for the exploration borehole samples noted above yielded rather low values in general, indicating poor source potential in the sections represented.

EXTRACT, CHROMATOGRAPHY ANALYSES

The solvent extracts and bitumen samples were fractionated using open column chromatography (Snowdon et al., 1986) into saturates, aromatics, NSO's (nitrogen, sulfur, and oxygen containing) and asphaltenes. The saturate fractions were analyzed using capillary column gas chromatography (Fig. 1). Because many of the seep samples and a few of the extract samples from the Intercoast cores were biodegraded, little information was available about the nature of the original organic matter or its current state of evolution. Gas chromatography-mass spectrometry was used to analyze the polycyclic saturate compounds (steranes and terpanes), which are less susceptible to degradation and thus retain additional information.

Several of the samples were so extensively degraded that even the steranes and terpanes were more or less completely altered. An additional technique, hydrous pyrolysis of the asphaltene fraction (Fowler et al., 1987), was employed in an attempt to regenerate a nondegraded hydrocarbon (saturate plus aromatic) fraction. Hydrous pyrolyzates were recovered from the bomb apparatus and treated as normal extracts for GC and GC-MS analysis. Figure 2 shows an example of the saturate fraction recovered from the hydrous pyrolysis of a biodegraded samples (see Figure 1a).

INTERPRETATIONS

Bitumen and extract analyses have not yet been completed and, therefore, the interpretations are preliminary and tentative. No compelling correlation of the biological marker chemistry of the Kunga and Maude extracts with the bitumen samples can yet be made, but these units cannot as yet be precluded as the source for some of the bitumens. A few

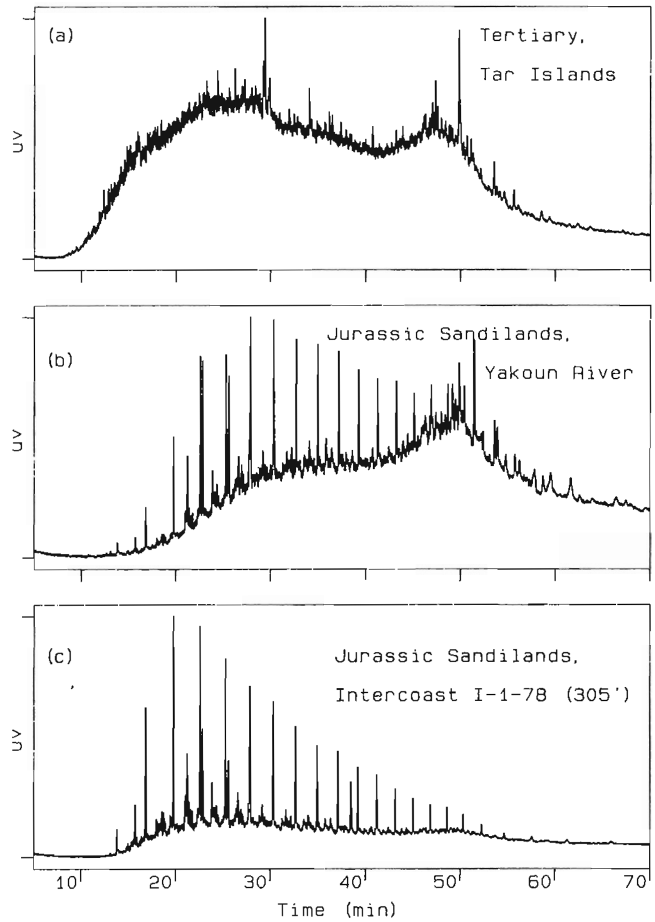


Figure 1. Saturate fraction gas chromatograms of a. biodegraded bitumen from Tertiary rocks of the Tar Islands; b. bitumen from the Jurassic Sandilands Formation (Kunga) in the vicinity of the Yakoun River, Graham Island; and c. the solvent extract from the Intercoast I-1-78 well on Graham Island.

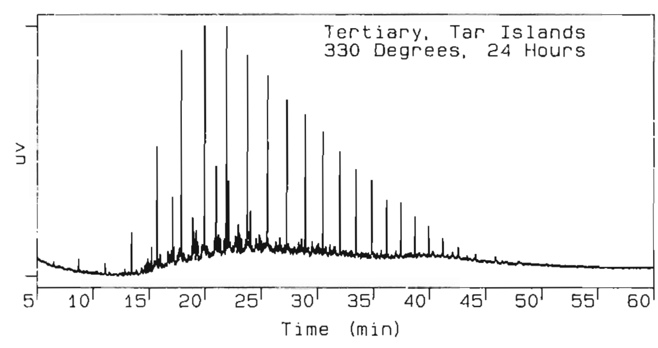


Figure 2. Saturate fraction gas chromatogram of hydrous pyrolyzate of sample shown in Figure 1a.

of the bitumen samples, notably from Cretaceous and Tertiary rocks, contain oleanane, a biological marker compound only known in tricyclic diterpanes from Tertiary rocks, which indicates that they have been derived from terrestrial organic matter. The abundant but very immature coaly material in the Tertiary section, particularly intervals of the Skonun Formation, would be a good candidate for the source of theses bitumens if subjected to sufficient heat.

Most of the bitumen samples have been recovered either directly from or in close association with late Tertiary volcanic rocks. This may indicate that the bitumen has been generated mainly in response to igneous heating, either as a result of generally higher heat flows over relatively extensive regions or in a virtual contact metamorphism sense. Detailed consideration of the analytical results may eventually result in the conclusive determination of which of these options is applicable.

FUTURE WORK

Analyses of extracts and bitumens will be completed, and geochemical interpretations made. These results will then be placed back into the context of the geological evolution of the basin in order to arrive at the best possible petroleum generation model. This model will be used to extrapolate from known areas to areas yet to be explored, notably in the offshore.

REFERENCES

Fowler, M.G., Snowdon, L.R., Brooks, P.W., and Hamilton, T.S.
1987: Hydrous pyrolysis and biomarker characterization of bitumens in Queen Charlotte Islands basalt; Abstract, XIII International Meeting on Organic Geochemistry, Venice.

Macauley, G.M.
1983: Source rock - oil shale potential of the Jurassic Kunga Formation, Queen Charlotte Islands; Geological Survey of Canada, Open File Report no. 921.

Snowdon, L.R., Brooks, P.W., and Goodarzi, F.
1986: Chemical and petrological properties of some liptinite-rich coals from British Columbia; Fuel, v. 65, p. 459-472.

Preliminary results on organic maturation of the Tertiary Skonun Formation, Queen Charlotte Islands, British Columbia†

D. Vellutini and R.M. Bustin[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Vellutini, D. and Bustin, R.M., Preliminary results on organic maturation of the Tertiary Skonun Formation, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 255-258, 1988.

Abstract

The level of organic maturation of the Neogene Skonun Formation on Graham Island has been determined from six exploration wells and surface samples. The mean random vitrinite reflectance values ($\%Ro_{rand}$), determined from exploratory wells, range from 0.18 $\%Ro_{rand}$ to 1.38 $\%Ro_{rand}$; and range up to 1.19 $\%Ro_{rand}$ for the outcrop samples. Maturation gradients determined from the wells range from 0.18 log($\%Ro_{rand}$)/km to 0.30 log($\%Ro_{rand}$)/km. The depth to the top of the oil window, as calculated from measured maturation gradients, increases from northern (1583 m at the Tow Hill well) to southern Graham Island (2892 m at the Tlell well), whereas the calculated thickness of eroded strata increases northerly from the Tlell well (355 m) to the Tow Hill well (984 m).

The vitrinite reflectance data indicates that the Skonun Formation is generally immature, with respect to oil generation, except in the Port Louis well and in the basal 300 m of the Tow Hill well. Locally, anomalously high levels of organic maturation occur adjacent to intrusive rocks in the upper part of the Tow Hill well and at Skonun Point.

Résumé

Le niveau de maturation organique de la formation néogène de Skonun sur l'île Graham a été déterminé à partir de six puits d'exploration et d'échantillons de surface. Les valeurs de réflectance (% Ro_{rand}) moyennes et aléatoires de la vitrinite, déterminées à partir des puits d'exploration, varient de 0,18 % Ro_{rand} à 1,38 % Ro_{rand}, et atteignent jusqu'à 1,19 % Ro_{rand} dans les échantillons prélevés dans des affleurements. Des gradients de maturation déterminés à partir des puits varient de 0,18 % log (% Ro_{rand})/km à 0,30 log (% Ro_{rand})/km. La profondeur jusqu'au sommet de la fenêtre tectonique pétrolifère, telle que calculée à partir des gradients de maturation mesurés, augmente du nord (1583 m au puits de Tow Hill) vers le sud de l'île Graham (2892 m au puits Tlell), tandis que l'épaisseur calculée des strates érodées augmente vers le nord, du puits Tlell (335 m) au puits Tow Hill (984 m).

Les données sur la réflectance de la vitrinite indiquent que la formation de Skonun est généralement immature, par rapport à la production de pétrole, à l'exception du puits Port Louis et dans les 300 m à la base du puits Tow Hill. Des niveaux exceptionnellement élevés de maturation organique se trouvent par endroits dans les roches intrusives contigües dans la partie supérieure du puits de Tow Hill et à Skonun Point.

---

† Contribution to Frontier Geoscience Program
[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

INTRODUCTION

The Skonun Formation (Sutherland Brown, 1968) comprises a succession of Neogene clastic sediment, possibly up to 4500 m thick, that outcrop on, or underlie a thin veneer of Quaternary sediments on eastern Graham Island and extend offshore to Hecate Strait and Queen Charlotte Sound (Sutherland Brown, 1968; Shouldice, 1973; Yorath and Hyndman, 1983). The Skonun Formation has been considered a potential hydrocarbon reservoir and has been test drilled on Graham Island, in Hecate Strait, and Queen Charlotte Sound. Although no significant hydrocarbon discoveries have been made to date, documented oil seeps on Graham Island (Cameron, 1987), together with the thick sequence of strata that include potential reservoir and source rocks, suggest that significant hydrocarbon accumulations may exist in the Skonun Formation.

As part of a study designed to assess the organic maturation and source rock potential of Mesozoic and Tertiary strata in the Queen Charlotte Islands, well core, well cuttings, and outcrop samples were collected from the Skonun Formation and their level of organic maturation determined by vitrinite reflectance techniques (Fig. 1, Table 1). This paper documents the results and preliminary interpretations of the data which have been acquired to date.

METHODS

One hundred and thirty-two samples of lignite and carbonaceous sediment were collected from the following wells: Richfield et al. Cape Ball a-41-1, Richfield Mic Mac Homestead Gold Creek #1, Richfield Mic Mac Homestead Nadu River, Richfield Mic Mac Homestead Tlell #1, Richfield Mic Mac Homestead Tow Hill #1, and Union Port Louis c-28-1. Outcrop samples were collected from the Skonun Formation on Graham Island: six lignite samples from Skonun Point, one lignite sample from Miller Creek, and one carbonaceous siltstone sample from Log Creek.

Samples containing low concentrations of organic matter were demineralized with hydrochloric and hydrofluoric acids. The samples were mounted in optically transparent epoxy pellets and analyzed under transmitted light to obtain their mean random vitrinite reflectance ($\%Ro_{rand}$) following the techniques outlined by England and Bustin (1986).

The degree of maturity of the strata, with respect to oil generation, was determined using the general correlation between vitrinite reflectance and hydrocarbon generation of Waples (1980). Waples (1980) placed the oil window between a vitrinite reflectance of 0.65 %Ro and 1.3 %Ro. Using specific boundaries for the oil window corresponding to kerogen type is not considered warranted at this preliminary stage of investigation. In order to predict the depth of the oil window in this study, the measured maturation gradients were extrapolated to depth. Such extrapolation assumes the maturation gradients are constant. The appropriateness of this assumption in the study area is unknown particularly in light of the thick succession of volcanics of the Masset Formation present at depth. Thus the calculated depth to and thickness of the oil window suggested here can only be considered as a first approximation. Similarly, the thickness of eroded strata has been calculated from extrapolation of the measured matu-

Table 1. List of onshore and offshore wells showing minimum mean random reflectance, maximum mean random reflectance, depth to the oil window, and thickness of eroded section. Location of wells shown in Figure 1.

Well name	Minimum reflect. ($\%Ro_{rand}$)	Maximum reflect. ($\%Ro_{rand}$)	Calculated depth to the top and base of the oil (m)	Calculated thickness of eroded section (m)
Cape Ball	0.18	0.42	2915-4762	615
Gold Creek	0.22	0.36	2560-4175	526
Nadu River	0.24	0.33	2226-3995	1156
Tlell	0.18	0.34	2892-4592	355
Tow Hill	0.28	0.72	1583-2927	984
Port Louis	0.81	1.38	432-1541	1687
Log Creek	0.52	—	—	—
Miller Creek	0.19	—	—	—
Skonun Point	0.11	1.19	—	—
Auklet*	0.32	1.05	1676-3206	1247
Harlequin*	0.45	1.25	2052-4183	2020
Murrelet*	0.38	1.00	2327-4304	1450
Osprey*	0.42	1.30	1777-3703	1902
Sockeye*	0.45	2.35	2684-4019	0
South Coho*	0.18	0.50	2785-3993	0
Tyee*	0.24	0.68	3170-5434	1154

* Modified from Yorath and Hyndman (1983).

ration gradients back to the zero level of maturation assumed here to be .15 $\%Ro_{rand}$ as described by (Bustin, 1986).

RESULTS

General results

Figure 1 summarizes the location of drillholes and outcrop samples together with the minimum and maximum vitrinite reflectance values, the calculated depths to the oil window, and the thicknesses of eroded section. In Table 1, the vitrinite reflectance data, calculated depth to the oil window, and thickness of eroded section are summarized.

The mean random vitrinite reflectance of the Skonun Formation, determined from the exploratory wells, ranges from 0.18 $\%Ro_{rand}$ through 1.38 $\%Ro_{rand}$ whereas values obtained from outcrops range from 0.11 $\%Ro_{rand}$ to 1.19 $\%Ro_{rand}$. The measured maturation gradients obtained from drillholes range from 0.18 $\log(\%Ro_{rand})$/km at the Cape Ball well to 0.30 $\log(\%Ro_{rand})$/km at the Port Louis well.

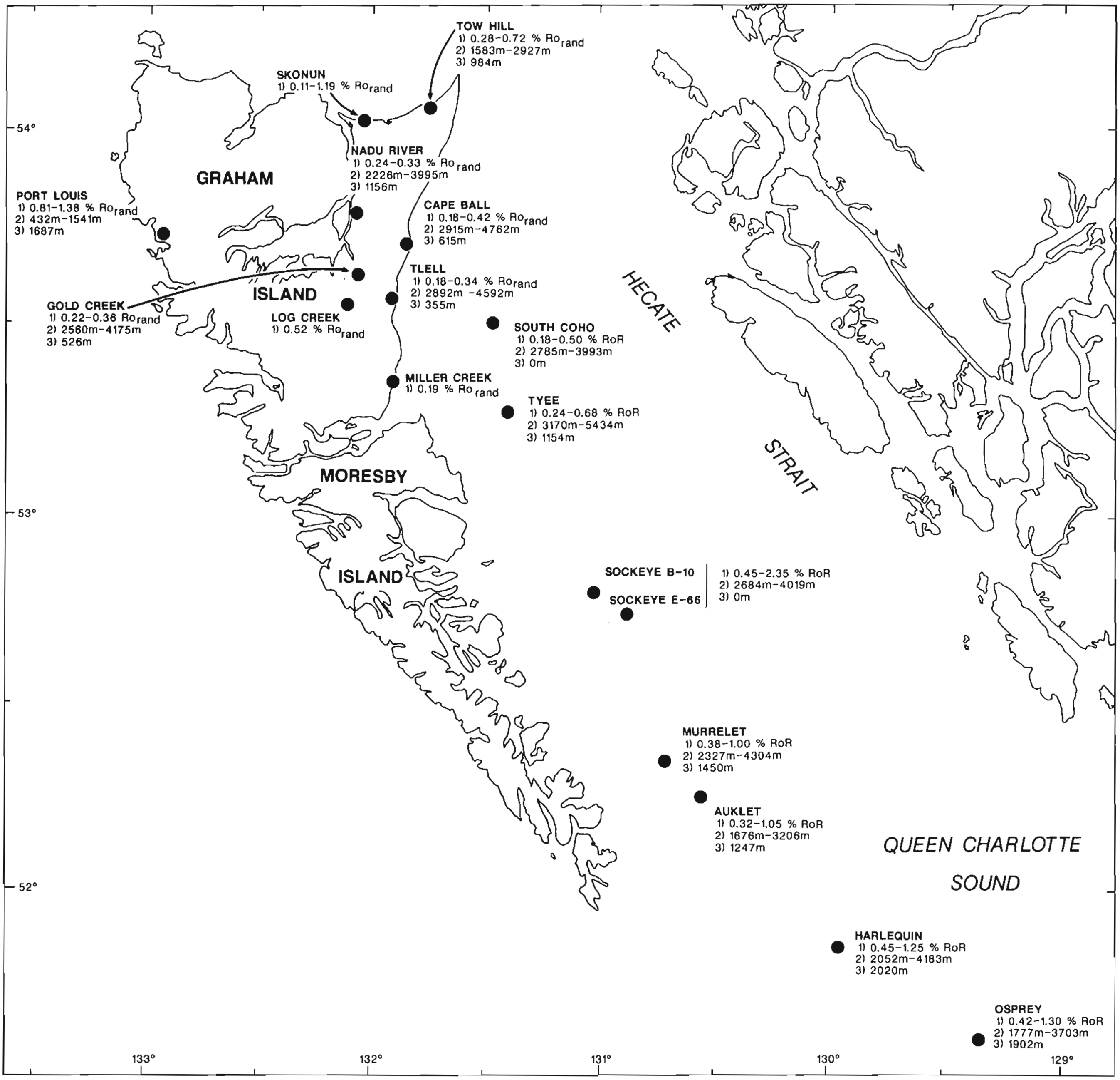


Figure 1. Location map of the Queen Charlotte Islands showing onshore wells, offshore wells, and outcrop samples. Offshore data modified from Yorath and Hyndman (1983). 1) Minimum and maximum vitrinite reflectance, 2) Calculated depth to the top and base of the oil window, 3) Calculated thickness of eroded section.

Depth to the oil window

In outcrop and in well sections, the Skonun Formation is immature with respect to petroleum generation, except in the Port Louis well and the basal section of the Tow Hill well. The higher levels of maturation in the Port Louis and Tow Hill wells reflect deeper burial of the strata together with higher maturation gradients, which in turn, probably reflect high heat flow in these areas.

The minimum predicted depth to the top of the oil window is 432 m at the Port Louis well and a maximum depth of 2915 m at the Cape Ball well (Table 1). Assuming a constant maturation gradient, the thickness of strata within the oil window ranges from a minimum of 1109 m at the Port Louis well to a maximum of 1847 m at the Cape Ball well (Table 1). The calculated depth to the oil window generally increases towards the south from the Tow Hill well to the Tlell well (Fig. 1). The Cape Ball well has a slightly greater depth to the top of the oil window than the surrounding wells.

Thickness of overburden removal

The calculated thickness of eroded strata ranges from a minimum of 355 m at the Tlell well to a maximum of 1687 m at the Port Louis well (Table 1). The calculated thickness of eroded section increases towards the north with the exception of the Nadu River well. The Nadu River well lies proximal to a structural high in the underlying Masset Formation (Sutherland Brown, 1968), and the greater thickness of eroded Skonun strata here (1156 m) suggests the area was differentially uplifted following deposition of the Skonun Formation.

Thermal effects of igneous intrusions

Anomalously high vitrinite reflectance values (up to 0.82 $\%Ro_{rand}$) occur near the top of the Tow Hill well and at Skonun Point. These vitrinite reflectance values are more than double the expected values and undoubtedly resulted from the thermal effects of the intrusion of the Tow Hill sills documented by Sutherland Brown (1968). Halos of thermally metamorphosed "baked" shale and siltstone in the Tow Hill well, evident from well core analysis (Sutherland Brown, 1968) and anomalous vitrinite reflectance values, suggest the presence of at least four intrusions in the upper 256 m of the well. The anomalous reflectance values are not included in the calculation of the thermal gradient for the well.

No thermal anomalies are evident from the reflectance values in the other studied wells.

Comparison between onshore and offshore wells

Loughman (pers. comm., 1987, Shell Canada Resources Ltd.) has indicated that the vitrinite reflectance data for wells drilled in Hecate Strait and Queen Charlotte Sound and published by Yorath and Hyndman (1983) have been revised therefore negating some of the earlier interpretations. Thus, only a general comparison between the onshore data reported here and the values published by Yorath and Hyndman (1983) can be made. The depth to the oil window, thickness of eroded section, and minimum and maximum vitrinite reflectance values for the offshore wells are shown in Figure 1 and Table 1.

The organic maturation gradients reported by Yorath and Hyndman (1983) are generally similar to those measured in this study; therefore, the higher levels of maturation obtained in the offshore wells (Table 2), for the most part, reflect greater depths of burial of the Skonun Formation offshore. According to results reported by Yorath and Hyndman (1983), a thick succession of the offshore Skonun Formation is in the oil window with the exception of the strata in the South Coho well and the upper part of Tyee well which are immature.

CONCLUSIONS

Preliminary analysis and interpretation of the organic maturation of the Tertiary Skonun Formation in the Queen Charlotte Islands indicates that the tested onshore strata are mainly immature with respect to petroleum generation. Mean random vitrinite reflectance values from six exploratory wells range from 0.18 $\%Ro_{rand}$ to 1.38 $\%Ro_{rand}$ and maturation gradients determined from the wells range from 0.18 to 0.30 $\log(\%Ro_{rand})/km$. Calculated depths to the oil window increase in a southerly direction from the Tow Hill well (1583 m) to the Tlell (2892 m) well and thickness of eroded strata increase in a northerly direction from the Tlell well (355 m) to the Tow Hill well (984 m). Anomalously high levels of organic maturation that occur in the upper 256 m of the Tow Hill well (0.82 $\%Ro_{rand}$) and in outcrop at Skonun Point (1.19 $\%Ro_{rand}$) are considered a result of high heat flow from adjacent intrusives.

REFERENCES

Bustin, R.M.
1986: Organic maturity of Late Cretaceous and Tertiary coal measures, Canadian Arctic Archipelago; International Journal of Coal Geology, v. 6, p. 71-106.

Bustin, R.M., Cameron, A.R., Grieve, D.A., and Kalkreuth, W.D.
1983: Coal petrology, its principles, methods, and applications; Geological Association of Canada, Short Course Notes, v. 3.

Cameron, B.E.B.
1987: Significance of Lower Jurassic hydrocarbon source rocks in the Cumshewa Inlet area, Queen Charlotte Islands, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 925-928.

England, T.D.J. and Bustin, R.M.
1986: Thermal maturation of the western Canadian sedimentary basin south of the Red Deer River: 1) Alberta Plains; Bulletin of Canadian Petroleum Geology, v. 34, p. 71-90.

Shouldice, D.H.
1973: Western Canadian continental shelf; *in* Future Petroleum Provinces of Canada, ed. R.G. McCrossan; Canadian Society of Petroleum Geologists, Memoir 1, p. 7-31.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; Bulletin 54, British Columbia Department of Mines and Petroleum Resources, 227 p.

Waples, D.W.
1980: Time and temperature in petroleum formation: application of Lopitan's method to petroleum exploration; American Association of Petroleum Geologists, Bulletin, v. 64, p. 916-926.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of the Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

A progress report on organic maturation and source rock potential of the Mesozoic and Tertiary strata of the Queen Charlotte Islands, British Columbia†

D. Vellutini[1] and R.M. Bustin[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Vellutini, D. and Bustin, R.M., A progress report on organic maturation and source rock potential of the Mesozoic and Teritiary strata of the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 259, 1988.

INTRODUCTION

In 1986, a study of the organic maturation and source rock potential of organic-rich Jurassic strata on Graham Island was initiated (Bustin and Macauley, in press). Through the Frontier Geoscience Program, the areal extent of the study has been expanded to encompass all of the Queen Charlotte Islands and to include the stratigraphic sequence from Mesozoic through Tertiary.

During the spring and summer of 1987, a sample collection program was initiated and completed; currently, laboratory analysis is proceeding. Below is a summary of the data collection and planned laboratory analysis program.

FIELD SAMPLE COLLECTION

Measured sections and spot samples were collected in order to establish lateral and vertical (stratigraphic) variations in organic maturation and source rock potential. One hundred and thirty two lignite and carbonaceous strata samples were collected from well core and well cuttings in the Tertiary Skonun Formation from the following exploratory wells on Graham Island: Richfield et al. Cape Ball a-41-l, Richfield Mic Mac Homestead Gold Creek 1, Richfield Mic Mac Homestead Nadu River, Richfield Mic Mac Homestead Tlell 1, Richfield Mic Mac Homestead Tow Hill 1, and Union Port Louis c-28-1. Outcrop samples were collected from the Skonun Formation on Graham Island at Skonun Point, Miller Creek, and Log Creek.

Three hundred and seventy-five lignite and carbonaceous shale outcrop samples were collected from the Cretaceous Long Arm, Haida, Skidegate, and Honna formations. The majority of samples were collected from Graham Island and spot samples were collected from Moresby Island. Two hundred and sixty limestone, argillite, and carbonaceous sandstone outcrop samples were collected from the Triassic Kunga Formation. Triassic samples were collected from South Moresby, Frederick and Graham islands.

Additional samples, together with stratigraphic data, from the Cretaceous Skidegate and Haida formations, and the Jurassic Maude and Yakoun formations were provided for the study by B.E.B. Cameron of the Geological Survey of Canada. Organic concentrates from the Triassic Kunga Formation were provided by M. Orchard, also of the Geological Survey of Canada.

LABORATORY ANALYSIS

Organic maturation

The collected sample suite is in various stages of preparation. Samples for organic maturation analysis are being prepared for vitrinite reflectance and kerogen fluorescence. Samples containing low concentrations of organic matter are demineralized in hydrochloric and hydrofluoric acids before being mounted in optically transparent epoxy resin for microscopic analysis. The vitrinite reflectance measurements of the Skonun Formation are complete and these data together with some preliminary interpretations are outlined by Vellutini and Bustin (1988).

Vitrinite reflectance analysis of Cretaceous strata are presently under way.

Source rock analysis

Samples for source rock analysis are being sized for Rock-Eval pyrolysis and total organic content analysis (TOC).

REFERENCES

Bustin, R.M. and Macauley, G.
— Organic petrology and Rock-Eval pyrolysis of the Jurassic Sandilands and Ghost Creek formations, Queen Charlotte Islands; Bulletin of the Canadian Society of Petroleum Geologists (in press).

Vellutini, D. and Bustin, R.M.
1988: Preliminary results on organic maturation of the Tertiary Skonun Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

† Contribution to Frontier Geoscience Program
[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

Cretaceous and Tertiary sedimentology, Queen Charlotte Islands, British Columbia†

Roger Higgs
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Higgs, R., Cretaceous and Tertiary sedimentology, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 261-264, 1988.

Abstract

A detailed facies analysis of Cretaceous and Tertiary sedimentary rocks in the Queen Charlotte Islands was begun in spring 1987. This note outlines the objectives and methods of research. The facies study, in conjunction with parallel studies by other geoscientists, will illuminate such aspects as basin type, depositional environment, paleogeography, reservoir geometry, and source-rock potential. The work is due for completion in April 1989.

Résumé

Une analyse détaillée de faciès des roches sédimentaires du Crétacé et du Tertiaire dans les îles de la Reine-Charlotte a été entreprise au printemps 1987. La présente note décrit les objectifs et méthodes de recherche. L'étude du faciès, conjointement avec des études parallèles accomplies par d'autres géoscientifiques, éclairera certains aspects comme le type de bassin, le milieu de sédimentation, la paléogéographie, la géométrie du réservoir et le potentiel comme roche mère. Ce travail doit prendre fin en avril 1989.

---

† Contribution to Frontier Geoscience Program

INTRODUCTION

Commercial hydrocarbon accumulations may exist beneath Hecate Strait and Queen Charlotte Sound, on Canada's western continental shelf (Fig. 1; Yorath and Cameron, 1982; Hamilton and Cameron, in press; Yorath, in press). This area is the site of the Tertiary Queen Charlotte Basin (QCB; Shouldice, 1973; Yorath and Hyndman, 1983), which also embraces northeastern Graham Island (Fig. 1). The QCB contains several kilometres of Tertiary sediments, including thick, reservoir-grade sandstones, as shown by fourteen exploratory boreholes drilled in the 1950s and 1960s (Fig. 1); these sediments constitute the Skonun Formation (Table 1; Sutherland Brown, 1968; Shouldice, 1973).

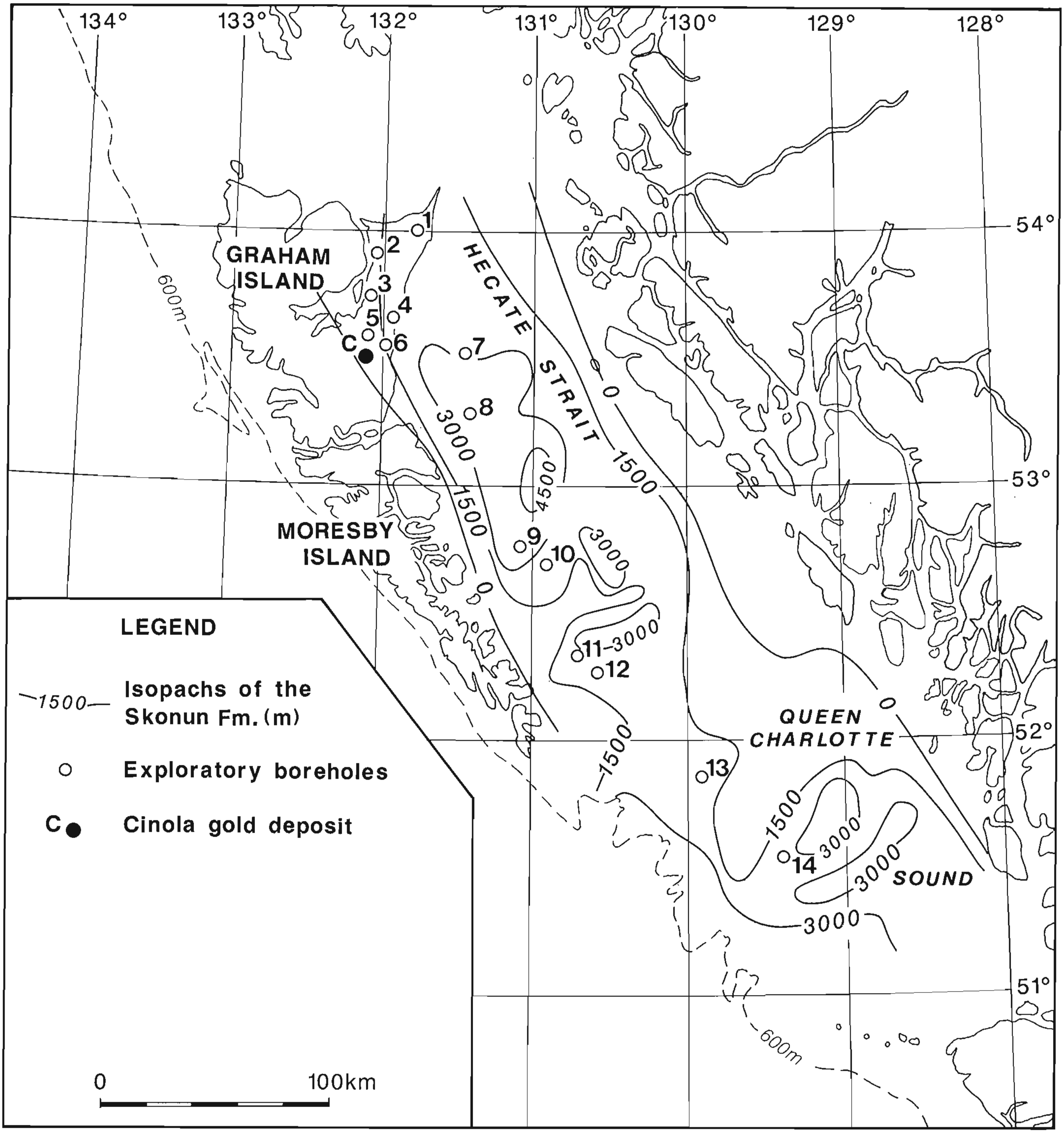


Figure 1. Isopach map of the Skonun Formation, Queen Charlotte Basin (after Shouldice, 1973). Contours in metres. Exploratory boreholes: 1 Tow Hill; 2 Masset; 3 Nadu River; 4 Cape Ball; 5 Gold Creek; 6 Tlell; 7 South Coho; 8 Tyee; 9 Sockeye B-10; 10 Sockeye E-66; 11 Murrelet; 12 Auklet; 13 Harlequin; 14 Osprey.

The mid-Cretaceous Queen Charlotte Group (Table 1) is likewise potentially hydrocarbon-bearing. These sediments were deposited in an older sedimentary basin under a different tectonic regime (Yorath and Chase, 1981); they outcrop onshore west of the QCB, and include thick (10s to 100s of metres) sandstone and conglomerate units (Sutherland Brown, 1968). The Queen Charlotte Group may extend offshore beneath the QCB, and may contain hydrocarbons there (Yorath and Cameron, 1982).

A multidisciplinary research program, an important objective of which is to assess the petroleum potential of the Queen Charlotte Islands region, was initiated by the Geological Survey of Canada in 1987 (Thompson, 1988). As part of this program, I have begun a facies analysis of the Queen Charlotte Group and Skonun Formation.

PREVIOUS WORK

Limited petrographic studies of the Queen Charlotte Group and Skonun Formation have been conducted by several authors (Sutherland Brown, 1968; Galloway, 1974; Yagishita, 1985a,b). In contrast, there have been no attempts at facies analysis, apart from a cursory examination of parts of the Queen Charlotte Group by Yagishita (1984, 1985a). The lack of rigorous facies studies has led to differences of opinion regarding depositional environments: for example, the conglomeratic Honna Formation (Table 1) is variously interpreted as (partly) alluvial fan (Sutherland Brown et al., 1983), shallow marine (Haggart, 1986), and deep-water fan deposits (Yagishita, 1984, 1985a).

OBJECTIVES

The objectives of the facies analysis are:

1) To determine the type of basin in which each of the two rock units accumulated. This knowledge will assist in unravelling the tectonic history of the region (Yorath and Chase, 1981), and by indicating the likely paleoheat flow regime, will allow improved predictions of organic maturation (see also Snowdon et al. 1988; Vellutini and Bustin, 1988a, b). By integrating the sedimentological results with data from companion studies of biostratigraphy, structure, igneous

Table 1. Cretaceous and Tertiary stratigraphy, Queen Charlotte Islands. After Sutherland Brown (1968), Cameron and Hamilton (1988), and Hamilton and Cameron (in press). Time-scale column shows correct relative durations of the epochs/ages (from Palmer 1983). Abbreviations: cong, conglomerate; sst, sandstone; sltst, siltstone; sh, shale; lig, lignite; sst-turbs, sandstone turbidites (cm-thickness).

TIME SCALE			FORMATION	LITHOLOGY	CONTINENTAL(C) OR MARINE(M)	MAX.THICKNESS (m)
QUATERNARY				clay, sand, gravel	C/M	150+
TERTIARY		PLIOCENE	SKONUN	sst, sh, cong, lig	C/M	1800+
TERTIARY		MIOCENE	SKONUN	sst, sh, cong, lig	C/M	1800+
TERTIARY		OLIGOCENE	SKONUN / MASSET	sst, sh, cong, lig / volcanics	C/M	1800+ / 7800+
TERTIARY		EOCENE	MASSET /	volcanics /	C/M /	7800+ /
TERTIARY		PALEOCENE				
CRETACEOUS	UPPER	MAASTRICHTIAN				
CRETACEOUS	UPPER	CAMPANIAN				
CRETACEOUS	UPPER	SANTONIAN				
CRETACEOUS	UPPER	CONIACIAN	HONNA (Q.CHARLOTTE GP.)	cong; sst	M	1200
CRETACEOUS	UPPER	TURONIAN	SKIDEGATE (Q.CHARLOTTE GP.)	sh, sst-turbs	M	600+
CRETACEOUS	UPPER	CENOMANIAN	SKIDEGATE (Q.CHARLOTTE GP.)	sh, sst-turbs	M	600+
CRETACEOUS	LOWER	ALBIAN	HAIDA (Q.CHARLOTTE GP.)	sst	M	800
CRETACEOUS	LOWER	APTIAN				
CRETACEOUS	LOWER	BARREMIAN				
CRETACEOUS	LOWER	HAUTERIVIAN	LONGARM	sltst, sst, cong	M	1200+
CRETACEOUS	LOWER	VALANGINIAN				
CRETACEOUS	LOWER	BERRIASIAN				

petrology, and geophysics, it will be possible to develop a detailed model relating Cretaceous and Tertiary sedimentation to tectonics.

2) To determine the depositional environments and paleogeography of the Queen Charlotte Group and Skonun Formation. An understanding of the paleogeography (and tectonic setting) will allow predictions of (a) how far the Queen Charlotte Group extends offshore, beneath the QCB, and (b) what is the likely distribution and geometry of potential reservoir facies in the offshore; companion seismic studies will assist in both these regards.

A complementary sedimentary-petrographic study of the Queen Charlotte Group and Skonun Formation will examine the diagenetic history of the two units, to evaluate the reservoir properties of sandstones and conglomerates.

METHODS AND DURATION OF STUDY

The proposed work includes three components: (1) field mapping and detailed sedimentological studies (June-August 1987 and 1988); (2) examination of (Skonun) core from petroleum-company boreholes onshore and offshore, and from the Cinola gold deposit (Fig. 1; cf. Champigny and Sinclair, 1982); and (3) laboratory studies including thin section examination, heavy mineral analysis, and carbon-sulphur ratio determination (for paleosalinity — cf. Berner and Raiswell, 1984). One field season has been completed; the data are being evaluated. Several cores have been examined at Cinola. The petroleum-company cores have been examined and sampled at the British Columbia Government core-storage facility in Charlie Lake and at the Institute of Sedimentary and Petroleum Geology in Calgary. Laboratory studies will commence in the autumn of 1987. The total project is due for completion in April 1989.

ACKNOWLEDGMENTS

I am grateful to City Resources (Canada) Limited for permission to examine cores at their Cinola gold property, and to Robin Tolbert, Exploration Manager of that company, for his kind assistance and hospitality during a visit to Cinola by GSC geologists in March 1987. Petro-Canada, Bow Valley Industries Ltd. and partners, and Unocal generously consented to sampling of their cores stored in Charlie Lake. B.E.B. Cameron, D.J. Tempelman-Kluit and C.J. Yorath offered helpful criticism of the manuscript.

REFERENCES

Berner, R.A. and Raiswell, R.
1984: C/S method for distinguishing freshwater from marine sedimentary rocks; Geology, v. 12, p. 365-368.

Cameron, B.E.B. and Hamilton, T.S.
1988: Contributions to the stratigraphy and tectonics of the Queen Charlotte Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Champigny, N. and Sinclair, A.J.
1982: The Cinola gold deposit, Queen Charlotte Islands, British Columbia; Canadian Institute of Mining and Metallurgy, Special Volume 24, p. 243-254.

Galloway, W.E.
1974: Deposition and diagenetic alteration of sandstone in northeast Pacific arc-related basins: implications for greywacke genesis; Geological Society of America, Bulletin, v. 85, p. 379-390.

Haggart, J.W.
1986: Stratigraphic investigations of the Cretaceous Queen Charlotte Group, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Paper 86-20, 24 p.

Hamilton, T.S. and Cameron, B.E.B.
— Hydrocarbon occurrences on the western margin of the Queen Charlotte Basin; Bulletin of Canadian Petroleum Geology (in press).

Palmer, A.R.
1983: The decade of North American Geology 1983 geologic time scale; Geology, v. 11, p. 503-504.

Shouldice, D.H.
1973: Western Canadian continental shelf; in Future Petroleum Provinces of Canada, ed. R.G. McCrossan; Canadian Society of Petroleum Geologists, Memoir 1, p. 7-35.

Snowdon, L.R., Fowler, M.G., and Hamilton, F.S.
1988: Progress report on organic geochemistry, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Sutherland Brown, A., Yorath, C.J., and Tipper, H.W.
1983: Geology and tectonic history of the Queen Charlotte Islands; *in* Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Joint Annual Meeting, Field Trip Guidebook Volume 1, Field Trip 8, 21 p.

Thompson, R.I.
1988: Introduction to the Frontier Geoscience Program, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Vellutini, D. and Bustin, R.M.
1988a: Preliminary results on organic maturation of the Tertiary Skonun Formation, Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.
1988b: A progress report on organic maturation and source rock potential of the Mesozoic and Tertiary strata of the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Yagishita, K.
1984: Development of a resedimented gravelly submarine fan; Geological Association of Canada, Program with Abstracts, v. 9, p. 117.
1985a: Mid- to Late Cretaceous sedimentation in the Queen Charlotte Islands, British Columbia lithofacies, paleocurrent and petrographic analyses of sediments; unpublished PhD thesis, University of Toronto.
1985b: Evolution of a provenance as revealed by petrographic analyses of Cretaceous formations in the Queen Charlotte Islands, British Columbia, Canada; Sedimentology, v. 32, p. 671-684.

Yorath, C.J.
— Petroleum geology of the Canadian Pacific continental margin; American Association of Petroleum Geologists, Memoir (in press).

Yorath, C.J. and Cameron, B.E.B.
1982: Oil off the west coast?; GEOS, v. 11, p. 13-15.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas — a model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Stratigraphy, diagenesis and petroleum reservoir potential of the mid- to Upper Cretaceous Haida and Honna formations of the Queen Charlotte Islands, British Columbia†

J.A.S. Fogarassy[1] and W.C. Barnes[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Fogarassy, J.A.S. and Barnes, W.C., Stratigraphy, diagenesis and petroleum reservoir potential of the mid- to Upper Cretaceous Haida and Honna formations of the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 265-268, 1988.

Abstract

The mid- to Upper Cretaceous Haida and Honna formations of the Queen Charlotte Islands can be regionally subdivided into eight lithostratigraphic units. Thin section and scanning electron microscopic examination of outcrop samples indicate a complex diagenetic history involving chlorite and calcite growth as well as feldspar and quartz dissolution. Dissolution processes may be related to the thermal maturation of kerogen and accompanying production of carboxylic acids and carbon dioxide. The lowermost Haida Formation sandstones and conglomerates hold the best potential within the Cretaceous succession for being developed as petroleum reservoir rocks in the subsurface.

Résumé

Les formations de Haida et de Honna, datant du Crétacé moyen à supérieur, des îles de la Reine-Charlotte peuvent être subdivisées régionalement en huit unités lithostratigraphiques. L'examen de lames minces et au microscope électronique à balayage d'échantillons prélevés dans des affleurements met en évidence une histoire diagénétique complexe impliquant une croissance de chlorite et de calcite ainsi que la dissolution de feldspath et de quartz. Les processus de dissolution peuvent être liés à la maturation thermique du kérogène et la production concomittente d'acide carboxylique et de gaz carbonique. Les grès et les conglomérats du tout début de la formation d'Haida au sein de la succession crétacée présentent le meilleur potentiel de mise en valeur comme roches-réservoirs de pétrole dans le sous-sol.

† Contribution to Frontier Geoscience Program
[1] Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

INTRODUCTION

Examination of Cretaceous Haida and Honna Formation outcrops on the Queen Charlotte Islands of British Columbia during summer 1987 revealed the units and their respective lithofacies to be regionally correlatable. Thin section and scanning electron microscope/energy dispersive spectrometer (S.E.M./E.D.S.) observations indicate a complex diagenetic history probably related to the extremely carbonaceous nature of the strata, particularly the Haida Formation.

STRATIGRAPHY

Locations of outcrops measured and sampled range from Langara Island and northwest Graham Island to Skidegate, Cumshewa and Sewell inlets (Fig. 1). Gross regional lithostratigraphic correlations can be made throughout the region. The Haida Formation is subdivided into five informal lithological facies, whereas the Honna Formation is separated into three lithofacies (Fig. 2). Rarely are all eight lithofacies observed in a single area, but all lithofacies of each formation can be seen in three of the four regions studied.

The lowermost unit of the Haida Formation, called the Basal Haida lithofacies, is perhaps the most lithologically and diagenetically variable of the five units. Outcropping in Skidegate and Cumshewa inlets, it is a coarse grained, pebbly, friable, arkosic sandstone interbedded with well bedded granule pebble matrix supported conglomerates. At Cumshewa Inlet the Basal Haida lithofacies is a highly quartzose sandstone, with in excess of 80% quartz framework grains cemented extensively with calcite, creating a very hard and compact rock.

Above the Basal Haida lithofacies is the Lower Haida sandstone lithofacies. This is a grey-green fine- to medium-grained arkosic sandstone characterized by abundant carbonaceous material, trigoniid bivalves, ammonites and discrete coarsening up sequences with well developed planar cross stratification. Light brown weathering calcareous concretions ranging from 1 cm to 1.5 m are locally abundant and increase in number toward the top of the lithofacies. The Basal Haida unit grades, over tens of metres, into the transitional Haida lithofacies.

The transitional Haida lithofacies contains discrete decimetre interbeds of fine- to very fine-grained sandstones, shaly siltstones and silty shales. This lithofacies is seen in all studied areas except Sewell Inlet and ranges up to 200 m in thickness. Calcareous concretions, coalified and silicified wood fragments and logs, moderate to intense bioturbation and hummocky cross stratification typify this unit. It gradually fines, over tens of metres, into the upper Haida shale lithofacies.

The upper Haida shale lithofacies is a dark grey, very silty, concretionary, bioturbated shale. It contains rare interbeds of very fine to medium grained calcareous arkosic sandstones. Synsedimentary slump structures are abundant in the Beresford Bay-Langara Island region where the depositional slope appears to have been greater than in Skidegate and Cumshewa regions. Well developed spaced cleavage occurs within this argillaceous unit. The upper Haida shale lithofacies quickly grades upward, over a few tens of metres, into the upper Haida sandstone-siltstone lithofacies.

The uppermost lithofacies of the Haida Formation is an interbedded very fine- to medium-grained, well sorted, calcareous arkosic sandstone, siltstone and silty shale. It is characterized by abundant climbing ripple cross lamination, unidirectional ripples, moderate bioturbation and possible B-C-B Bouma sequences. Decimetre thick beds, with sharp upper and lower contacts, contain occasional shallow interformational channel scours.

The basal Honna lithofacies scours into the underlying upper Haida sandstone-siltstone lithofacies and the upper Haida shale lithofacies. The lowermost of the three lithofacies of the Honna Formation is composed of pebble to cobble clast supported conglomerates interbedded with lenses of medium- to coarse-grained feldspathic sandstone. It contains an admixture of well rounded granodioritic and aphanitic volcanic clasts and angular Triassic-Jurassic sedimentary clasts, suggesting derivation from a terrane underlain by diverse lithologies. Bedding thickness is 0.5 to 3.0 m, with many channel scours. Complete absence of crossbedding in the lenticular sandstones suggests deposition within submarine channels.

Gradationally overlying the basal Honna lithofacies is the middle Honna lithofacies. This unit was in part deposited

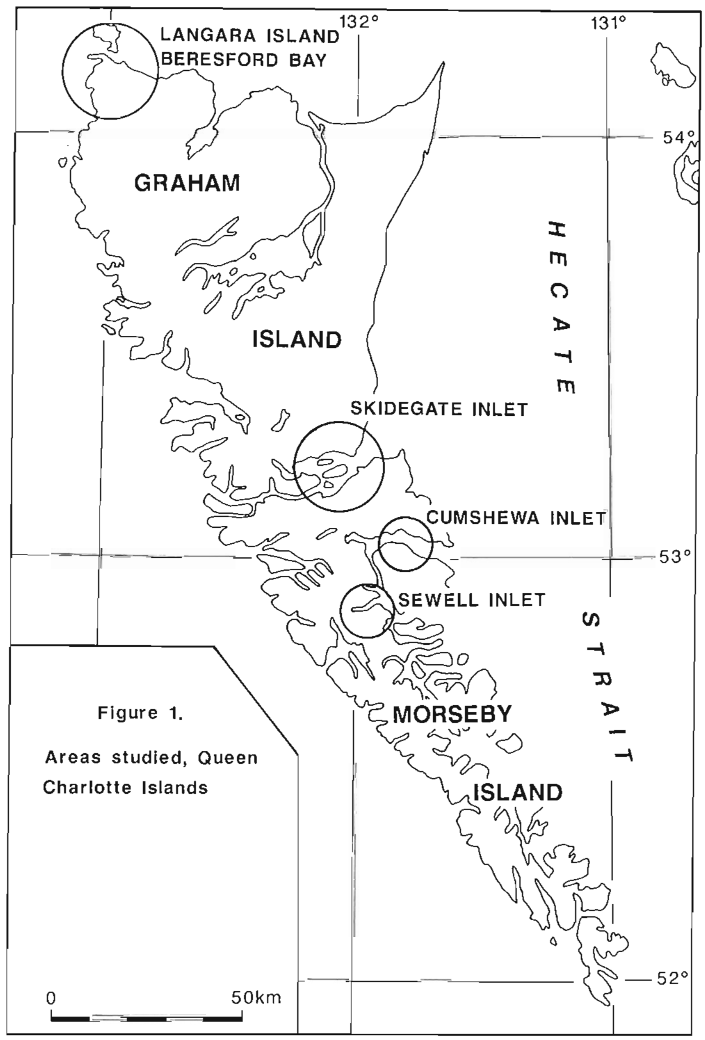


Figure 1. Areas studied, Queen Charlotte Islands.

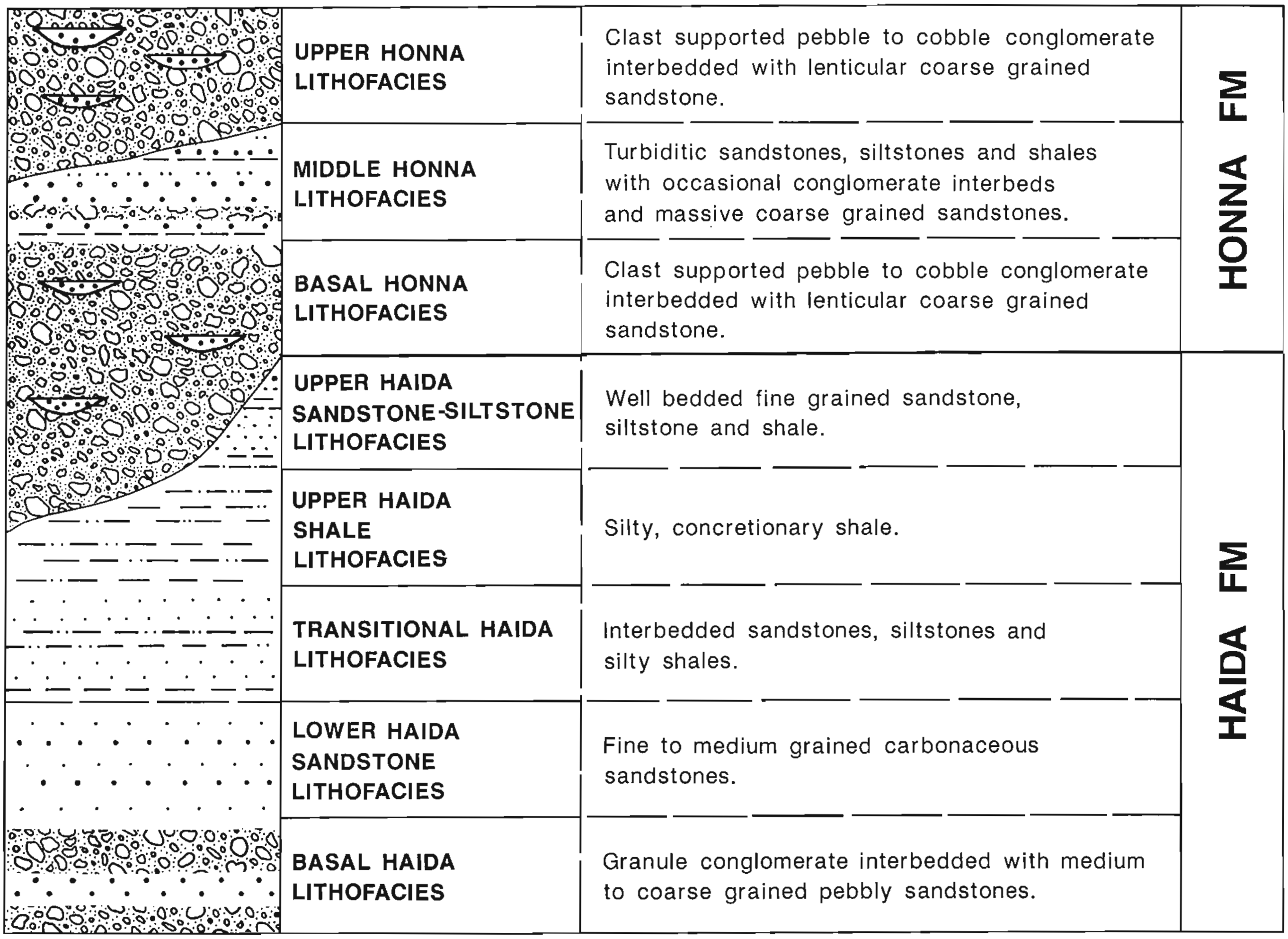


Figure 2. Lithofacies of the Haida and Honna formations, Queen Charlotte Islands.

by turbidity currents, as shown by excellent A-B-C and B-C Bouma sequences. Occasional interbeds of pebble to cobble clast supported conglomerates and argillaceous siltstones and silty shales are observed near the base. This unit is abruptly overlain by the upper Honna lithofacies conglomerates.

The upper Honna lithofacies scours tens of metres into the middle Honna lithofacies. It is a pebble to cobble clast supported conglomerate with lensoidal, coarse to very coarse, structurally featureless arkosic sandstone beds. Unlike the basal Honna lithofacies its clast lithology is mostly volcanic, with a corresponding decrease in granitic content. Though well bedded, good clast imbrication is rarely seen in outcrop.

SANDSTONE DIAGENESIS

Petrographic observations

Until recently the diagenetic history of the Haida and Honna formations has received little study (Yagashita, 1985). Thin section and S.E.M./E.D.S. examination reveals these Upper Cretaceous units to be diagenetically complex.

One hundred and forty-six thin sections were cut from representative conglomerates, sandstones and siltstones of each Haida and Honna lithofacies. Sections were impregnated with blue dyed epoxy to show porosity and stained with sodium cobaltinitrite and amaranth solution to aid in distinguishing potassium and calcium bearing feldspars respectively. Six rock samples, determined by thin section inspection, were analyzed with the S.E.M./E.D.S..

Thin section suites and S.E.M./E.D.S. analyses indicate the Basal Haida lithofacies sandstones and granule conglomerates to be the most petrologically variable and distinct. Increased quartz content and framework grain size in the Cumshewa Inlet area contribute to the greatest visual porosity observed in the Cretaceous section of the Queen Charlotte Islands. Less compositionally mature sandstones and conglomerates of the Basal Haida lithofacies at Skidegate Inlet and Beresford Bay — Langara Island have poor visual effective porosity. On the basis of framework grain composition, the Basal Haida lithofacies appears to become more permeable in a southerly direction.

Discussion: Petroleum reservoir potential

The amount and nature of quartz must be considered in the determination of which units of the Haida and Honna formations can be classified as reasonable petroleum reservoir rock. Increased quartz content has a good positive correlation with development of primary effective porosity. The reservoir characteristics of the outcropping Basal Haida lithofacies may be extrapolated to the offshore under Hecate Strait and possibly Queen Charlotte Sound. With Cretaceous strata lying at estimated subsea depths of 3000 to 6000 m, the Basal Haida lithofacies, of all the Cretaceous sandstone bodies, will probably have undergone the fewest diagenetic effects and subsequent porosity reduction.

The arkosic and argillaceous composition of other Haida and Honna lithofacies has created a complex diagenetic environment. Authigenic minerals, mainly chlorite, calcite and smectite, have formed at the expense of feldspars, quartz and labile framework grains such as biotite and rock fragments. Growth of these minerals has, to a large extent, included primary pores as well as creating sizable volumes of ineffective microporosity. Although this does not portend most of the Haida and Honna sandstones to be good hydrocarbon reservoir rock it should be noted that siliciclastic petroleum reservoirs with ample secondary porosity, forming from dissolution of chlorite, calcite, zeolites and feldspars, have been well documented (McDonald and Surdam, 1984).

Franks and Forester (1984) and Surdam et al. (1984) have shown that thermal maturation of kerogen, and accompanying generation of carbon dioxide and carboxylic acids, creates appreciable secondary porosity by dissolution of feldspar, labile rock fragments and carbonate framework grains. The degree of porosity enhancement is dependent on a number of factors, including pH of pore fluids, chemical composition and amount of reactant minerals and kerogen type. Abundant carbonaceous material seen in the Haida Formation and to a lesser degree in the Honna Formation may thus have contributed to the generation of secondary porosity.

CONCLUSION

The Haida and Honna formations are lithologically divisable into eight facies. Only the basal Haida lithofacies exhibits reasonable petroleum reservoir characteristics in outcrop. The other lithofacies cannot be adequately evaluated as their complex mineralogical make-up may or may not significantly improve in the subsurface. Abundant interformational organic material may generate sufficient carbon dioxide and carboxylic acids to leach minerals, such as pore filling calcite and framework grain feldspar, creating secondary porosity.

ACKNOWLEDGMENTS

The Geological Survey of Canada, and R.I. Thompson, and R. Higgs are thanked for logistical and technical support. D. Mercer, J. Miller and D. Rhys provided excellent assistance in the field.

REFERENCES

Franks, S.G. and Forester, R.W.
1984: Relationships among secondary porosity, pore fluid chemistry and carbon dioxide, Texas gulf coast; *in* Clastic Diagenesis, ed. D.A. McDonald, and R.C. Surdam; American Association of Petroleum Geologists, Memoir 37, p. 63-79.

McDonald, D.A. and Surdam, R.C.
1984: Clastic diagenesis; American Association of Petroleum Geologists, Memoir 37, 434 p.

Surdam, R.C., Boese, S.W., and Crossey, L.J.
1984: The chemistry of secondary porosity; *in* Clastic Diagenesis, ed. D.A. McDonald, and R.C. Surdam; American Association of Petroleum Geologists, Memoir 37, p. 127-149.

Yagashita, K.
1985: Mid- to late Cretaceous sedimentation in the Queen Charlotte Islands, British Columbia: lithofacies, paleocurrent and petrographic analyses of sediments; unpublished PhD thesis, University of Toronto, Ontario.

Structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Columbia†

Catherine J. Hickson
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Hickson, C.J., Structure and stratigraphy of the Masset Formation, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 269-274, 1988.

Abstract

The Masset Formation is composed of intercalated, aphyric, mafic to felsic lava flows and pyroclastics. The extrusion of these rocks was rapid, with little time for sedimentation or weathering between eruptions. Epiclastic sediments occur, but are localized and, chiefly represent debris flow deposits. Based on K-Ar dating, the eruptions climaxed from 20 to 25 Ma with contemporaneous extrusion of both felsic and mafic magmas, but mafic magmas are volumetrically dominant and travelled farther from vent areas. These lavas, with minor intercalated felsic pyroclastic flows, underlie eastern Graham Island, but probably do not extend any great distance beneath Hecate Strait. Basaltic lavas found in offshore drilling in Queen Charlotte Sound and Hecate Strait are older and lithologically distinct from the bulk of Masset rocks. They probably represent one or more volcanic episodes distinct from the Masset eruptions.

Résumé

La formation de Masset se compose de roches pyroclastiques et de coulées de laves mafiques à felsiques, intercalées, aphanitiques. L'extrusion de ces roches a été rapide, et les éruptions étaient trop peu espacées pour que s'exercent les effets de la sédimentation ou de l'érosion. On rencontre des sédiments épiclastiques, mais seulement à certains endroits; il s'agit principalement de coulées boueuses. D'après la datation par la méthode K-Ar, les éruptions ont atteint leur apogée il y a 20 à 25 Ma, avec extrusion simultanée de magmas felsiques et mafiques; les magmas mafiques occupent un volume plus important, et se sont déplacés à plus grande distance des cheminées volcaniques. Ces laves, qui contiennent quelques intercalations de coulées pyroclastiques de caractère felsique, sont présentes dans le sous-sol de l'est de l'île Graham, mais ne s'étendent sans doute peu profondément dans le sous-sol du détroit d'Hecate. Les laves basaltiques rencontrées lors de forages en haute mer dans le détroit de la Reine-Charlotte et le détroit d'Hecate sont plus anciennes et se distinguent lithologiquement de l'ensemble des roches de Masset, et représentent probablement un ou plusieurs épiosodes volcaniques, distincts des éruptions de Masset.

† Contribution to Frontier Geoscience Program

INTRODUCTION

The Masset Formation, a volcanic succession on the Queen Charlotte Islands, was named by MacKenzie (1916) and first studied in detail by Sutherland Brown (1968). He characterized it as being composed of "thin flows of columnar basalt, basalt breccia, thick sodic rhyolite ash flow tuffs, and welded tuff breccias and breccias of mixed basalt and rhyolite clasts." (Sutherland Brown, 1968). Sutherland Brown subdivided the formation into the Tartu, Kootenay and Dana facies (Fig. 1). He also noted that the Masset Formation overlies all older formations with angular unconformity. It outcrops over much of Graham Island and islands to the south, but to the east it is conformably overlain by, or interfingers with, the Miocene-Pliocene Skonun Formation (Cameron and Hamilton, 1988; Sutherland Brown, 1968). On the basis of the conformable contact with the Skonun, noted by Sutherland Brown (1968), the Masset Formation was assigned an age of Paleocene to Miocene.

Eight exploratory wells were drilled in Hecate Strait and Queen Charlotte Sound in the early sixties by Shell Canada Ltd. Several intersected basaltic flows which have been correlated with the Masset Formation (Shouldice, 1971; Young, 1981). This would imply that the Masset Formation may at one time have extended all the way from Queen Charlotte Sound to Cape Knox.

Radiometric dates from onshore and offshore material range in age from less than 5 to 165 Ma (Young, 1981). More recent work on the Masset (Hamilton, 1985) produced a range of 17 to 29 Ma.

According to Sutherland Brown (1968) the Masset Formation consists of alkalic basalts and sodic rhyolites whereas Hamilton (1985) described the rocks as subalkaline tholeiites, basaltic andesites, dacites and metaluminous rhyolites.

The present study provides new data on the internal structure and stratigraphy, the duration, extent and type of volcanism and the relative volumes of different magmatic material (i.e. mafic vs. felsic volcanism). These data will be used to develop a physical model of the evolution of the Masset Formation.

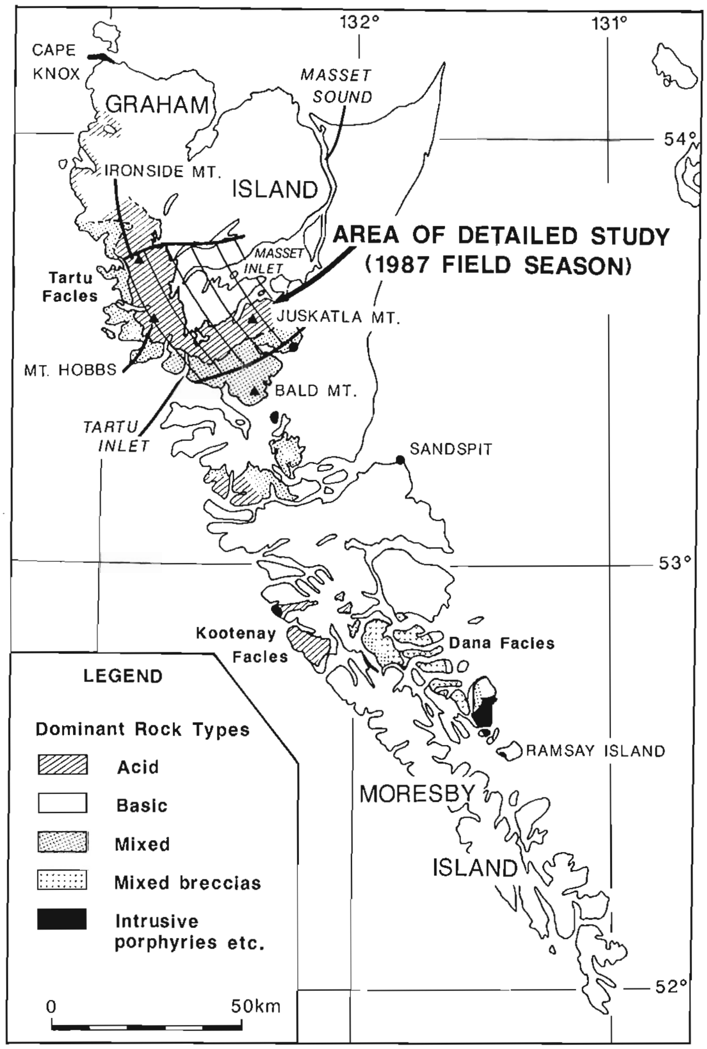


Figure 1. Distribution and facies of the Masset Formation (from Sutherland Brown, 1968; Fig. 17) and area studied in detail during the 1987 field season.

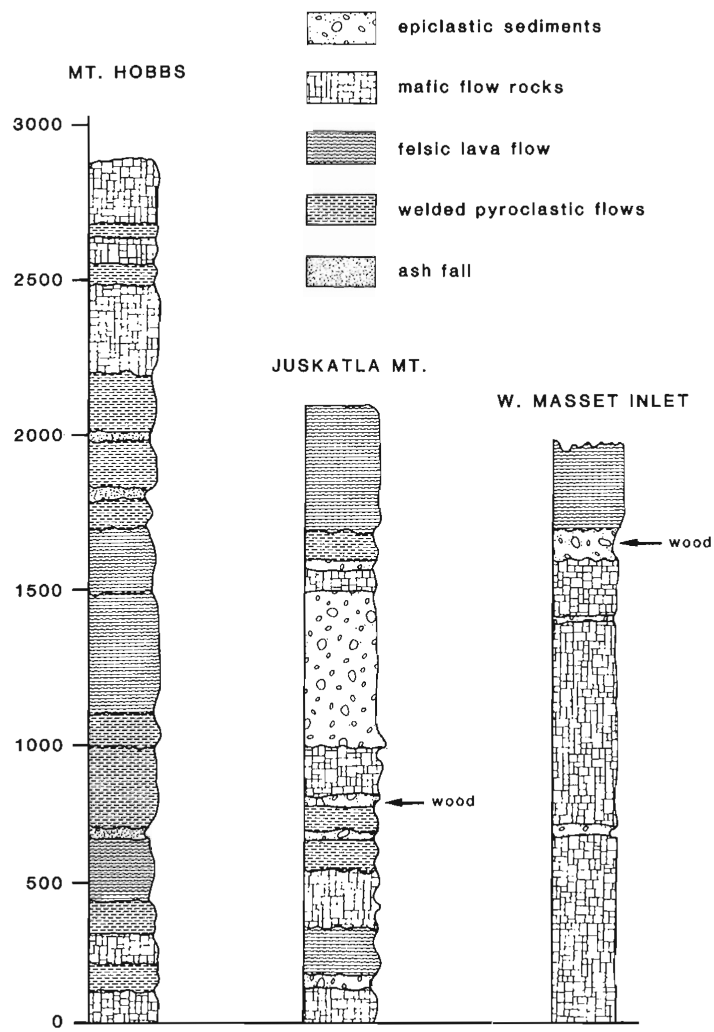


Figure 2. Idealized stratigraphic columns from the Mount Hobbs, western Masset Inlet, and Juskatla Mountain areas.

Figure 3. Lithophysae in the Mount Hobbs area.

Information on the Masset Formation is important in assessing hydrocarbon potential because of the possible effect of high level magma chambers and abundant dykes on thermal maturation. The flows themselves pose technical difficulties for any drilling program and the distribution and relative volumes of volcanic rocks will influence the interpretation of seismic and gravity data.

Outcrop amounts to less than 5 % in most areas, but an extensive network of new logging roads provides access to regions that previously were completely timbered. Mapping during the 1987 field season concentrated in an area between Masset Inlet and the west coast (excluding the coastal exposures) (Fig. 1). Data were recorded at a 1:50 000 scale over 65 days of traversing using vehicle, boat and helicopter support. Reconnaissance of areas to the south and north were also undertaken. Prior to starting fieldwork drillcore from onshore wells was examined at the provincial government core storage facility at Charlie Lake.

STRATIGRAPHY

A preliminary assesment of the 1987 fieldwork suggests that in the area of detailed study, rocks of the Masset Formation are mixed mafic and felsic flows. Localized areas are predominantly mafic or felsic, but over several hundred metres of section both rock types occur.

Mafic rocks form units of multiple flows. Individual flows range from 2 to 30 m thick and are associated with thin (a few tens of centimetres or less) interflow breccias. Intercalated sediments of a nonvolcanic origin are rarely found, but in some locations they are the dominant rock type although they have limited lateral extent. These deposits are diamictons and probably represent channellized debris flows. Some of the deposits contain carbonized and/or silicified wood.

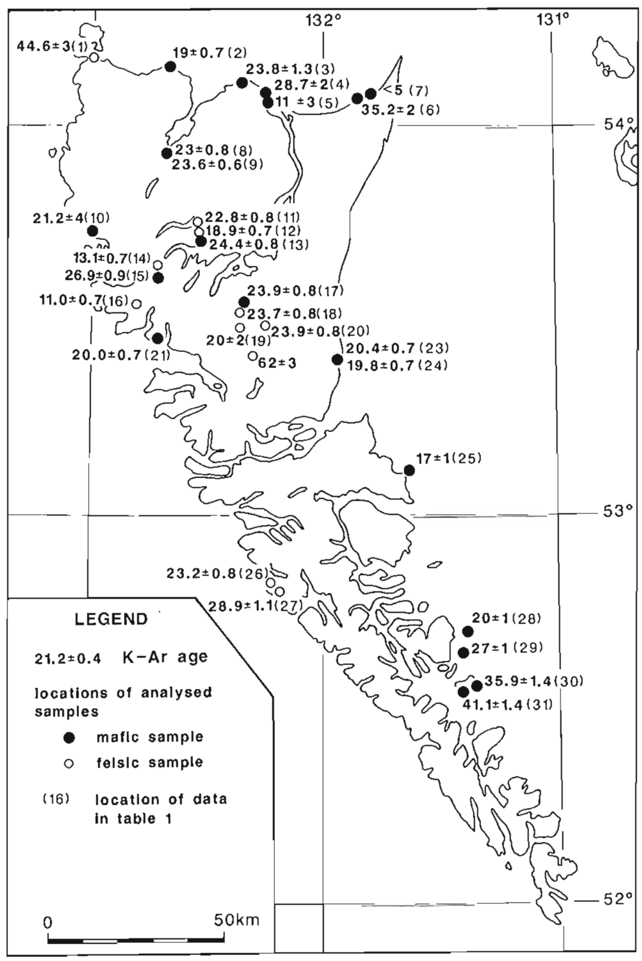


Figure 4. Location map for onshore K-Ar dates (for analytical details and references see Table 1).

Mafic dykes, which are locally abundant, have columnar jointing, vesicles and chilled margins suggesting high level emplacement. Extensive deposits of agglutinate are cut by high level dykes.

Felsic volcanic rocks include a few flows but are mainly pyroclastic in origin. The pyroclastics are dominantly welded lapilli tuffs and are commonly associated with pumaceous airfall material. The bases of both pyroclastic and lava flows are commonly vitreous, though perlitic fractures and associated devitrification is prevalent. Spherulites are found in many of the flows and range up to 3 cm in diameter. Lithophysae predominate in the pyroclastic flow rocks and were found up to 10 cm in diameter (Fig. 3). Gas devolatilization in the upper sections of many pyroclastic flows has destroyed the primary textures. The felsic lava and pyroclastic flows are much thicker (10 — 100 m) than the more mafic lava flows. Felsic magmas dominate locally such as around Ironside Mountain and the Mount Hobbs area (Fig. 2). Intercalated epiclastic sediments are uncommon within the felsic flows.

Marine sediments and/or evidence of subaqueous volcanism were not observed, but two regoliths were found. One, at the base of the section, is composed of weathered

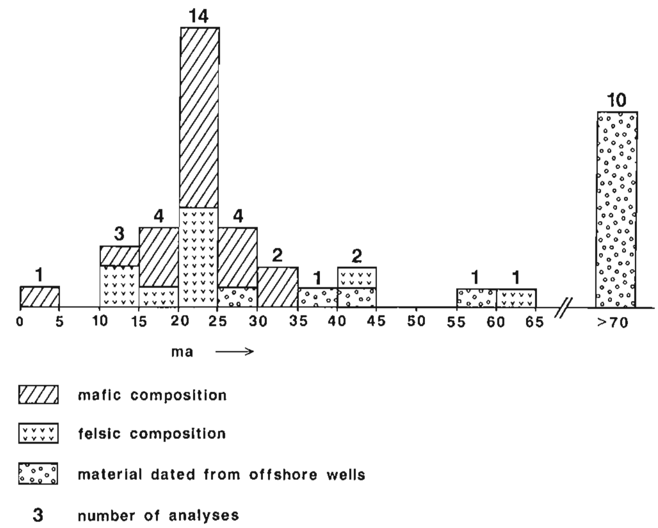


Figure 5. Histogram showing the distribution of dates from rocks correlated with the Masset Formation. See Table 1 for data and Young (1981) for details on the offshore dates.

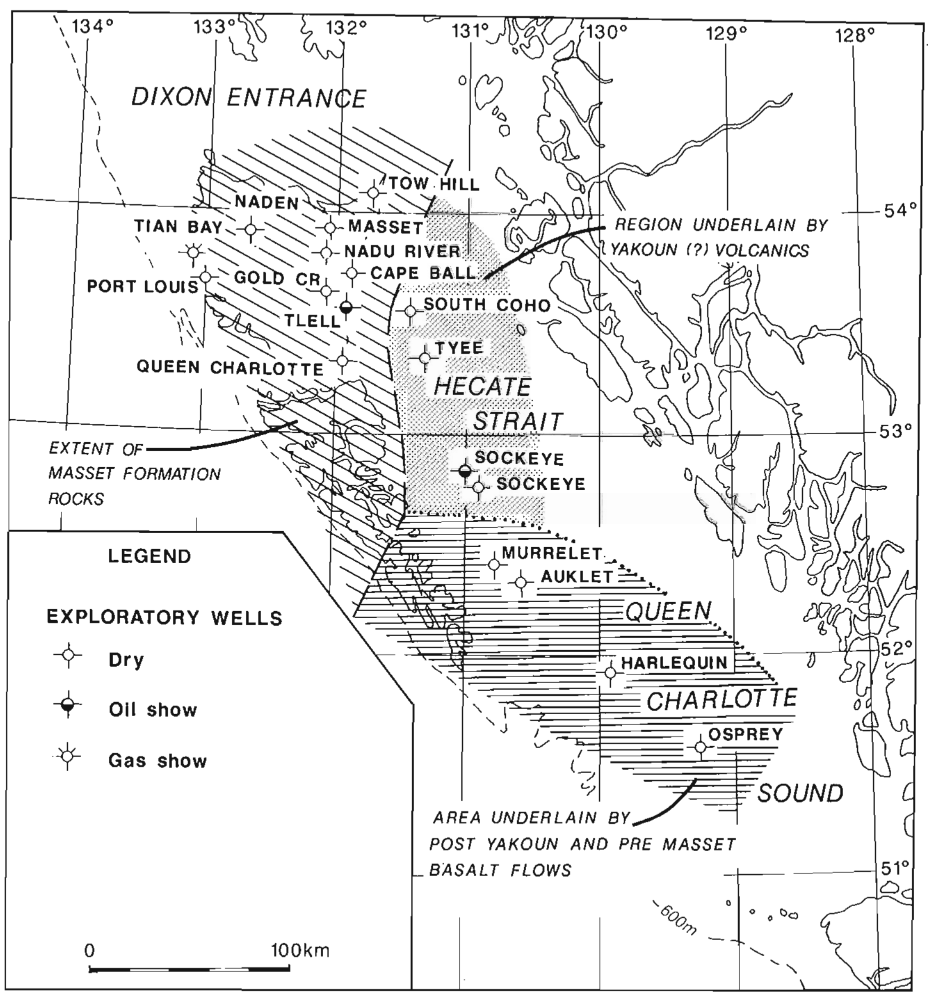


Figure 6. Location of offshore and onshore wells and inferred original extent of the Masset Formation (modified from Young, 1981, Fig. 16).

porphyritic rocks of the Yakoun Formation. The other, within the Masset sequence north of Juskatla Mountain, is of limited lateral extent and most likely represents an area that escaped inundation by lava flows for a longer period of time than surrounding areas.

The Masset volcanic rocks, whether felsic or mafic, are aphyric, commonly aphanitic and vary between grey and black. Eutaxitic textures, flow banding, or general weathering characteristics are commonly the only indication of rock composition. It was not possible, based on hand samples and field exposures, to determine the presence and/or volumes of intermediate rock types.

To date, conclusions that can be drawn from fieldwork are:

1) Evidence of localized felsic eruptive centres was not found within the mapped area; however, evidence of hydrothermal activity, silicification and quartz veining is present in the vicinity of Ironside Mountain, Juskatla Mountain and the Mount Hobbs areas.

2) Mafic flows were probably fed by fissure eruptions but venting may have become localized along the dyke, building up extensive scoria deposits in one place.

3) Mafic and felsic volcanism were contemporaneous but the volume of mafic material is much greater. Graham Island was emergent during the entire period of Masset volcanism. A topographic high existed parallel to, and possibly coincident with, the present topographic high. This resulted in the movement of the fluid basaltic flows eastward, and most probably westward as well. Felsic flows, due to their high viscosity did not travel far from vent areas. Only the most voluminous felsic pyroclastic flows travelled any distance to the east where they are found intercalated with basalt flows in drillcore. The entire formation thins to the east and may be largely absent beneath Hecate Strait.

4) There was no major hiatus in volcanic activity.

5) Drillcore data and surface outcrop pattern indicate that the Masset Formation may be thickest west of Masset Sound. The flows thin eastward across the sound and interfinger with the Skonun Formation.

6) hough the study area is cut by numerous fractures and faults, displacement is minor. The regional dip is east-northeast and is interpreted to be due largely to post-eruption tilting.

Table 1. K-Ar age data.

No.[1]	Rock Type	Age[2] (Ma±1σ)	Lat. N.	Long. W.	Sample No.[3]	Data Source[4]
1	rhyolite ash	44.6 ± 3	54°10.17'	132°58.0'	GS-49-66	b
2	basalt	19.0 ± 0.7	54°06.5'	132°22.1'	TMV33	d
3	basalt	23.8 ± 1.3	54°09.33'	132°39.0'	GS-51-66	b
4	basalt	28.7 ± 2	54°04.17'	132°14.25'	GS-54-66	b
5	basalt	11 ± 3	54°03.53'	132°14.33'	SD-256-N63	b
6	basalt	35.2 ± 2	54°04.4'	131°47.7'	GS-29-66	b
7	basalt	<5	54°04.73'	131°47.65'	SD-546-M63	b
8	basalt	23.0 ± 0.8	53°56.1'	132°42.1'	BVI203	d
9	basalt	23.6 ± 0.8	53°56.1'	132°42.1'	BVI3684	d
10	basalt	21.2 ± 4	53°42.08'	132°59.17'	GS-39-66	b
11	rhyolite	22.3 ± 0.8	53°44.6'	132°30.8'	300/495	d
12	dacite	18.9 ± 0.7	53°43.1'	132°30.9'	193/1815	d
13	basalt	24.4 ± 0.8	53°42.6'	132°29.7'	137/410	d
14	rhyolite	13.1 ± 0.7	53°38.6'	132°41.8'	163/225	d
15	basalt	26.4 ± 0.9	53°38.3'	132°41.2'	161/790	d
16	rhyolite	11.0 ± 0.7	53°34.8'	132°46.0'	70/2130	d
17	andesite	23.9 ± 0.8	53°30.6'	132°20.0'	MR 9	b
18	rhyolite ash	23.7 ± 0.8	53°30.6'	132°20.0'	MR 2	c
19	rhyolite ash	20 ± 2	53°31.68'	132°21.2'	SD-544-N63	b
20	dacite	23.9 ± 0.8	53°32.8'	132°17.6'	342/1020	d
21	basalt	20.0 ± 0.7	53°26.6'	132°43.3'	18/44	d
22	bio.fdspr.porp.	62 ± 3	53°24.2'	132°23.1'	AK 378	a
23	basalt	20.4 ± 0.7	53°24.6'	131°55.0'	TMV61.5	d
24	basalt	19.8 ± 0.7	53°34.6'	131°55.5'	MR 8	c
25	andesite	17 ± 1	53°06.8'	131°38.23'	SD-250-N63	b
26	rhyolite	23.2 ± 0.8	52°49.6'	132°12.1'	38/2310	d
27	basalt	28.9 ± 1.1	52°48.3'	132°09.7'	TMV21	d
28	basalt	20 ± 1	52°41.4'	131°23.27'	SD-252-N63	b
29	basalt	27 ± 1	52°40.4'	131°24.75'	SD-253-N63	b
30	basalt	41.1 ± 1.4	52°33.0'	131°21.4'	TMV10	d
31	basalt	35.9 ± 1.4	52°33.2'	131°21.0'	TMV50	d

1 Number refers to plotted locations on Figure 2
2 Refer to original source for details of analyses constants used
3 Original sample number
4 Source of dates:
a - Mathews, 1964
b - Young, 1981, unpublished data from Shell Development Corp. (Houston, Texas) and Pan-America Petroleum Corporation
c - Wanless et al., 1972
d - U.B.C. Geochron File. Samples collected by T. Hamilton and dated by J. Harakal under contract to the G.S.C.

AGE RELATIONSHIPS

Thirty-one K-Ar ages are available from rocks correlated with the Masset Formation (Table 1, Fig. 4). A histogram (Fig. 5) showing the spread of ages, suggests that eruption of the Masset Formation was restricted in time and climaxed during a five million year period between 20 and 25 Ma. Dates older than 30 Ma, on rocks lithologically similar to those in the study area, come from Ramsay Island (Fig. 4) (southernmost exposure of Masset Volcanics; Fig. 1) and drill samples from wells in Hecate strait and Queen Charlotte Sound (Fig. 6). Dates from Bald Mountain and Cape Knox are also greater than 30 Ma but those samples differ lithologically from the bulk of the Masset volcanics and may represent an older volcanic episode correlative with samples from wells in Queen Charlotte Sound. Dates from the wells range from 29 to 57 Ma (Murrelet, Auklet, Harlequin, and Osprey; Fig. 6, Young, 1981). The youngest date from the Hecate Strait wells (Sockeye; Fig. 6) was 72 Ma (Young, 1981).

This implies that older dates from porphyritic basaltic rocks represent volcanic activity prior to the Masset eruptions and this suggests, in corroboration with field evidence, that the Masset Formation may be more aerially restricted than previously thought. Figure 6 shows an estimate of the distribution. There is no compelling evidence that Masset flows formed a continuous sheet south of Graham Island. Based on work south of Graham Island, Souther (1988) noted that there is an increase in dyke density around areas of Masset outcrop; he suggested that the present distribution may correspond closely to the original accumulation around localized centres.

DISCUSSION

Postulated origins for the Masset volcanics include rifting (Yorath and Hyndman, 1983), possibly initiated by a mantle hotspot (Yorath and Chase, 1981). An "edge effect" of the subducted margin of the Farallon plate has been suggested (Stacey, 1974) as well as wrench tectonics along the Sandspit and Rennel-Louscoone fault systems (Young, 1981). Based on the coeval ages of volcanics and plutons in the Pemberton belt (35 Ma-16 Ma) J.G. Souther (pers. comm., 1987) has suggested that the Masset volcanics may be part of this same "Pemberton arc" system.

Whatever the origin of the Masset Formation it must explain an eruptive episode that climaxed 20 to 25 Ma ago with voluminous outpourings that included a range of magma types. The aphyric nature of the rocks is not typical of arc volcanics, nor of rocks which have undergone any degree of fractionation. They may represent eutectic melts. Sutherland Brown (1968) speculated that the Masset volcanics represent mantle melts only slightly modified by differentiation or crustal contamination. Rb/Sr values for the rhyolites indicate possible crustal contamination (Young, 1981). Hamilton (1985) has pointed out that the mafic rocks have chemical affinities with both MORB and orogenic basalts.

Significant to oil exploration is the possibility that the thermal effect of the Masset may have been minimal due to the apparent lack of high level magma chambers and the short duration of eruptive activity. These effects were most likely localized under the present day land mass of the Queen Charlotte Islands. The easterly thinning and interfingering of Masset flows with sediments of the Skonun Formation may also have relevance for offshore drilling in Hecate Strait as it is apparent that the wells there intersect rock from a volcanic event older than the Masset.

REFERENCES

Cameron, B.E.B. and Hamilton, T.S.
1988: Contributions to the stratigraphy and tectonics of the Queen Charlotte-Basin, British Columbia; *in* Current Research, Part E, Geological Survey of Canada, Paper 88-1E.

Gordon, R.G. and Jurdy, D.M.
1986: Cenozoic global plate motions; Journal of Geophysical Research, v. 91, B12, p. 12389-12406.

Hamilton, T.
1985: Volcanics of the Cenozoic Masset Formation: implications for geological and tectonic evolution of the Queen Charlotte Islands, British Columbia, Canada; Geological Society of America, Cordilleran Section Annual Meeting, Program with Abstracts, Vancouver, British Columbia, May 8-10, p. 359.

MacKenzie, J.D.
1916: Geology of Graham Island, British Columbia; Geological Survey of Canada, Memoir 88, 221 p.

Mathews, W.H.
1964: Potassium-argon age determinations of Cenozoic volcanic rocks from British Columbia; Geological Society of America, Bulletin, v. 75, p. 465-468.

Shouldice, D.H.
1971: Geology of the western Canadian continental shelf; Bulletin of Canadian Petroleum Geology, v. 19, p. 405-436.

Souther J.G.
1988: Implications for hydrocarbon exploration of dyke emplacement in the Queen Charlotte Islands, British Columbia; *in* Current Research, Part E.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands; British Columbia Department of Mines and Petroleum Resources Bulletin 54, 226 p.

Stacey, R.A.
1974: Plate tectonics, volcanism and the lithosphere in British Columbia; Nature, v. 250. p. 133-134.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and adjacent areas — a model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Young, I.F.
1981: Structure of the western margin of the Queen Charlotte basin, British Columbia; unpublished MSc thesis, University of British Columbia, Vancouver.

Wanless, R.K., Stevens, R.D., Lachance, G.R., and Delabio, R.N.
1972: Age determinations and geological studies, K-Ar isotopic ages, Report 10; Geological Survey of Canada, Paper 71-2, 96 p.

Preliminary investigations of structural styles in Mesozoic strata of the Queen Charlotte Islands, British Columbia[†]

P.D. Lewis and J.V. Ross[1]
Cordilleran and Pacific Geoscience Division, Vancouver

Lewis, P.D. and Ross, J.V., Preliminary investigations of structural styles in Mesozoic strata of the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 275-279, 1988.

Abstract

Structures developed in Mesozoic strata in the Skidegate Inlet/Skidegate Channel area of the Queen Charlotte Islands indicate that the major deformation comprised southwest-northeast directed shortening. On northwest Graham Island, structural styles are dominated by several generations of steeply dipping strike-slip faults. No evidence is seen for large transverse offsets in either area. In both locations, deformation is largely controlled by the fluid aided processes of pressure solution and hydraulic fracturing.

Résumé

Des structures mises en place dans les strates mésoïques de la région de l'inlet Skidegate et du détroit de Skidegate des îles de la Reine-Charlotte indiquent que la déformation principale contenait un raccourcissement orienté sud-ouest-nord-est. Au nord-ouest de l'île Graham, les styles structuraux sont dominés par plusieurs générations de décrochements à pendage abrupt. On ne relève aucune preuve de grands déplacements transversaux dans l'une ou l'autre de ces zones. Dans les deux endroits, la déformation a subi très fortement l'influence des processus liés aux fluides de dissolution par pression et de fracturation hydraulique.

---

† Contribution to Frontier Geoscience Program

1 Department of Geological Sciences, University of British Columbia, Vancouver, B.C. V6T 2B4

INTRODUCTION

Regional geological mapping in the Queen Charlotte Islands by Sutherland Brown during the period 1958-1963 culminated in the publication of a geological map (Sutherland Brown, 1968) which outlines several areas of structural complexity (Rennell Sound/Louscoone fault system, Sandspit Fault, and Beresford Bay Fault). The present study was undertaken to examine different structural levels exposed across these complex areas to elucidate the relationship between major structural features and mesoscopic deformational styles. An understanding of this relationship, together with the deformational processes active through time, is important to developing a model for the evolution of the Queen Charlotte Basin.

This report is a summary of detailed structural mapping completed during summer 1987. Fieldwork concentrated on two locations: the northwest Graham Island (Beresford Bay) area was mapped at 1:20 000 and 1:1 000 scales, and the Skidegate Channel/Skidegate Inlet area was mapped at 1:20 000 scale.

MACROSCOPIC/MESOSCOPIC STRUCTURES

Mesozoic strata in the Queen Charlotte Islands may be divided into a Triassic/Jurassic succession (Karmutsen Formation, Kunga Group, Maude Group, and Yakoun Group) separated by a regional unconformity from a Cretaceous succession (Longarm Formation, Haida Formation, Honna Formation, and Skidegate Formation). In the areas covered by this study the Triassic/Jurassic section is exposed most completely along the west coast of the islands, and all of this section except the Karmutsen Formation is exposed in the southeast Skidegate Inlet area in the vicinity of Maude Island. The present distribution of Cretaceous rocks is strongly controlled by variable original stratigraphic continuity related to basin configuration and localization of pre- to syn-depositional volcanism and deformation.

Skidegate Channel/Skidegate Inlet

Two approximately east-trending structural sections were completed through the Skidegate Channel/Skidegate Inlet region (Fig. 1). The more southerly section illustrates structural styles along a transect from Chaatl Island to Sandspit (Fig. 2a); a second section shows these same structures to the north along a section between Long Inlet and Queen Charlotte City (Fig. 2b).

These sections differ from earlier interpretations (Sutherland Brown, 1968; Yorath and Chase, 1981; Young, 1981) in their lack of large horizontal displacements along discrete fault surfaces. Most map scale faults are northwest-trending

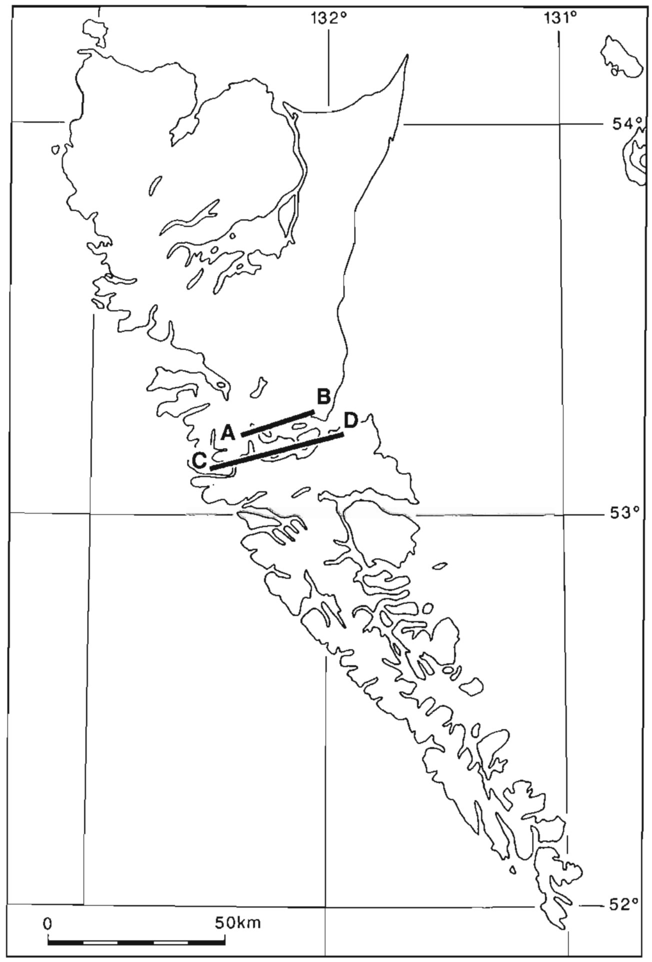


Figure 1. Location of cross-sections through Skidegate Channel area (Fig. 2) and detailed mapping on northwest Graham Island.

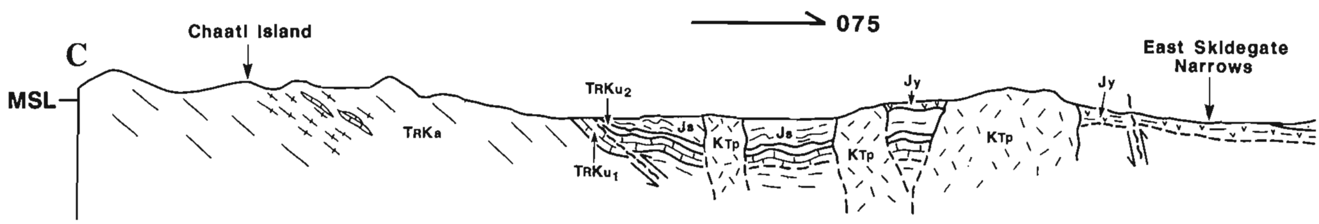


Figure 2. Structural sections through Skidegate Inlet/Skidegate Channel area:
a) Chaatl Island-Sandspit section,
b) Long Inlet-Queen Charlotte City section.

STRATIFIED ROCKS

TERTIARY or CRETACEOUS

KTv — Andesitic flows, flow breccias

CRETACEOUS

KHo — Honna Formation

KHa — Haida Formation

Ks — Skidegate Formation

KL — Longarm Formation

JURASSIC

JY — Yakoun Group

JM — Maude Group

JURASSIC and TRIASSIC

Kunga Group

Js — Sandiland Formation

TRKu2 — Black bedded limestone

TRKu1 — Massive grey limestone

TRIASSIC

TRKa — Karmutsen Formation

PLUTONIC ROCKS

CRETACEOUS or TERTIARY

KTP

JURASSIC ?

JP

Bedding form lines

Mylonitic foliation

Fault, with apparent offset

0 1 2 miles

0 3000 metres

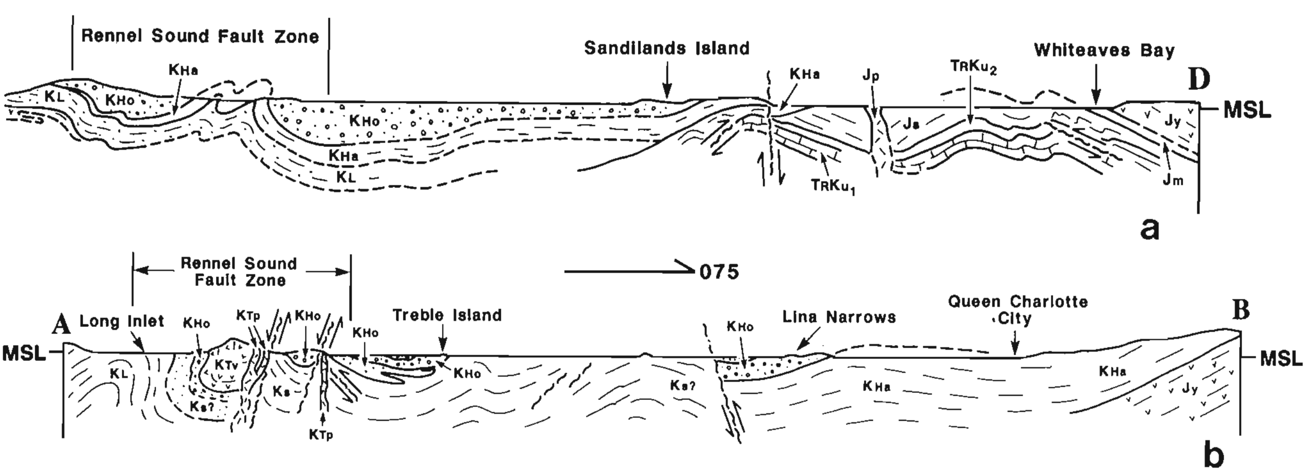


Figure 3. Tight buckle fold in argillites of Jurassic Sandilands Formation near Chaatl Island.

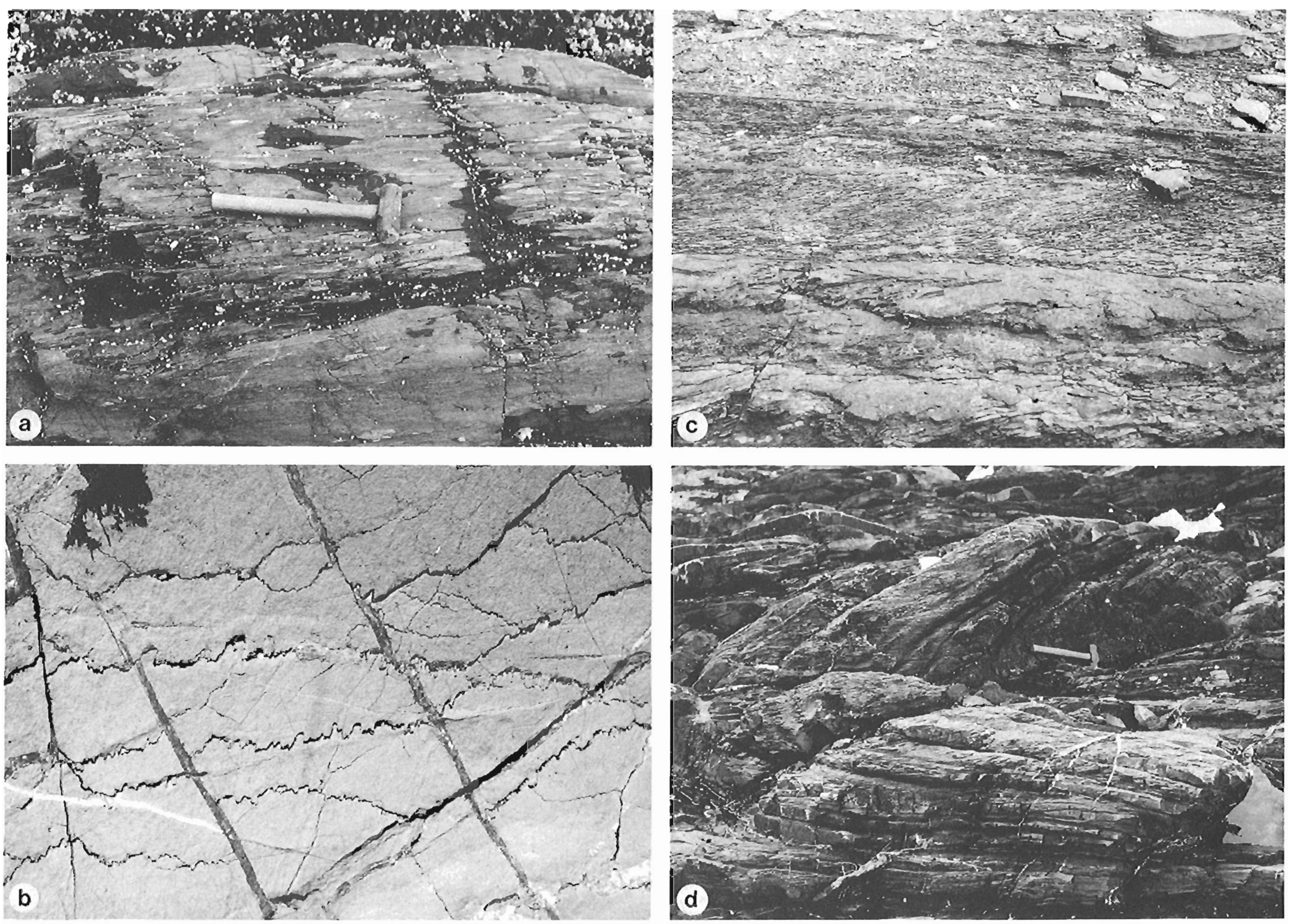


Figure 4. Mesoscopic fabrics developed in different rock types in the Skidegate and northwest Graham Island areas:
a) Mylonitic foliation in Karmutsen Formation on Chaatl Island.
b) Stylolites viewed on bedding surface in Kunga limestone above Whiteaves Bay.
c) Pressure solution cleavage in siltstones of the Skidegate Formation west of Queen Charlotte City. Bedding is subhorizontal, cleavage dips gently to the left.
d) Axial-planar cleavage in fault drag fold in Kunga Group calcareous siltstones, northwest Graham Island.

and steeply dipping, with at most 100s or 1000s of metres of dip-slip offset. The dominant map scale structures are northwest-trending open to tight buckle folds recording moderate amounts of shortening in a northeast-southwest direction. In these sections the ''Rennell Sound Fault Zone'' of Sutherland Brown (1968) is simply an area of more intense structural development reflected in tight, overturned map scale folds. Several steep faults with probable normal offset cut these structures in the Long Inlet area. However, in Skidegate Channel, a single stratigraphic contact may be traced across all previously inferred traces of the Rennell Sound fault system.

Earliest mesoscopic structures consist of soft sediment folds, slumps, and clastic dykes formed in unlithified or partially lithified sediments. Subsequent tectonic shortening of lithified strata was accommodated on the mesoscopic scale by mechanisms of flexural-slip folding, associated low-angle detachment, and bulk shortening. Well-layered Triassic and Jurassic lithologies display the most intense folding, commonly about northwest-trending axes (Fig. 3). Massive rocks display a variety of deformational styles. Greenstones of the Karmutsen Formation on Chaatl Island contain both brittle fractures and a foliation which is locally mylonitic (Fig. 4a). The overlying massive limestone of the Kunga Formation has shortened dominantly through pressure solution as shown by stylolites of variable orientation and associated extension veins (Fig. 4b). In homogeneous clastic rocks a penetrative cleavage is locally developed at moderate to low angles to bedding. This cleavage is axial planar to large scale folds, and is defined by pressure solution surfaces and planar arrangements of platy minerals observed in thin sections (Fig. 4c). Synkinematic calcite-filled extension fractures formed at the same time through a cyclic hydraulic fracture mechanism.

Fold geometry and intensity of structural development indicate greater amounts of shortening occurred in the Triassic/Jurassic sequence than in the overlying Cretaceous rocks. Little, if any, slip has occurred along the unconformity separating these groups of rocks.

Northwest Graham Island/Beresford Bay

Continuous exposures along wave-cut benches facilitated detailed mapping of Mesozoic strata on northwest Graham Island. Deformation within the Triassic/Jurassic sequence there is characterized by several generations of steeply dipping strike-slip faults. The earliest of these strike 060-070° and are offset by a conjugate set with strikes 090 and 170°. Most mesoscopic folds are related to movement along fault surfaces. At one location (south Sialun Bay) northeast-verging thrust faults locally repeat strata and antedate all strike-slip faults. Northwest-trending drag folds along these thrusts have an incipient axial planar pressure solution cleavage (Fig. 4d).

Cretaceous rocks on northwest Graham Island are gently warped about northwest-trending axes and cut by east-trending faults of probable normal separation.

DISCUSSION

Mesozoic rocks in the Queen Charlotte Islands record a deformational history involving variable amounts of initial shortening and later minor faulting. Numerous unconformities at several stratigraphic levels, lesser shortening in younger rocks, and soft sediment structures suggest that much of this deformation accompanied deposition of the Mesozoic sequence. The ''Rennel Sound Fault Zone'' represents a zone of locally intense structural development where greater amounts of shortening occur than in surrounding areas. This strain localization may be linked to irregularities in the configuraion of the underlying Jurassic/Triassic ''basement'' strata; this is also reflected in the unusually thick Cretaceous sequence here.

The relationship of strike-slip structures on northwest Graham Island to deformation in the Skidegate Inlet area is not yet known. Correlation of mesoscopic and macroscopic structures to a regional tectonic setting is uncertain. The northwest trends of fold axes and northeast shortening direction are consistent with shortening in a wrench fault tectonic setting related to oblique movement along the Queen Charlotte Fault.

Deformation in all rocks was accomplished through fluid biased processes. Pressure solution surfaces, hydraulic fracture veins, and fluid escape soft-sediment structures are all evidence of pore fluid migration during deformation. The effect this fluid movement may have had on any hydrocarbon migration is at present uncertain.

ACKNOWLEDGMENTS

We are indebted to Bob Thompson and Roger Higgs of the Geological Survey of Canada for technical and logistic support. D. Mercer, A. Huntley, and J. Miller provided much appreciated field assistance.

REFERENCES

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 54.

Yorath, C.J. and Chase, R.L.
1981: Tectonic history of the Queen Charlotte Islands and surrounding areas — a tectonic model; Canadian Journal of Earth Sciences, v. 18, p. 1717-1739.

Young, I.F.
1981: Geological development of the eastern margin of the Queen Charlotte Basin; unpublished MSc thesis, University of British Columbia, Vancouver.

Surficial geology and geohazards on the continental shelf off Western Canada†

J.L. Luternauer, J.V. Barrie[1], and K.W. Conway[2]
Cordilleran and Pacific Geoscience Division, Vancouver and Sidney, B.C.

Luternauer, J.L., Barrie, J.V., and Conway, K.W., Surficial geology and geohazards on the continental shelf off Western Canada; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 281, 1988.

The objectives of this component of the Frontier Geoscience Program are to map and describe the surficial geology of the Vancouver Island shelf (Fig. 1) and the three principal areas of concern, Queen Charlotte Sound, Hecate Strait and Dixon Entrance where attention will also be focused on geohazards to hydrocarbon exploration and development.

Field activities this past summer were performed exclusively in Queen Charlotte Sound. Approximately 800 line km were surveyed by side scan sonar and Huntec Deep-Tow high resolution seismic profiler. In addition, 124 grab samples, 20 vibrocores, 3 piston cores and 5 dredge samples were collected. The data will contribute to our knowledge of shelf scour and the nature and distribution of shallow gas.

Maps of the physiography, sample and geophysical data coverage and surficial sediment distribution are being completed at a scale of 1:250 000 for all areas. Shallow subsurface geology of Queen Charlotte Sound and Hecate Strait will be interpreted and displayed as stratigraphic cross-sections. Geological hazards of particular concern, such as shallow marine gas, Quaternary faulting and sediment erosion and transport, will be mapped.

Stratigraphic samples and shallow high resolution seismic data are limited for most areas of the Vancouver Island shelf and all of Dixon Entrance at present. Consequently, research cruises have been scheduled during March and May-June, 1988 to initiate investigations in Dixon Entrance and complete surveys in Queen Charlotte Sound and Hecate Strait. Completion of the data collection for areas of the Vancouver Island shelf will be left until a later time.

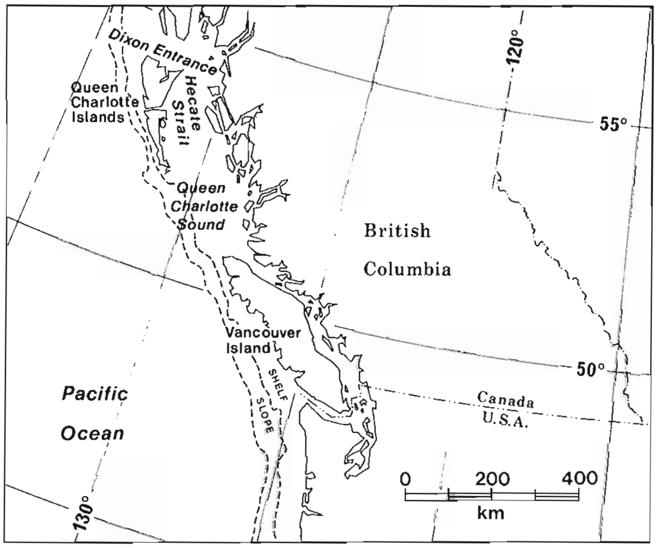


Figure 1. Location of major continental shelf areas off western Canada.

† Contribution to Frontier Geoscience Program
[1] Centre for Cold Ocean Resources Engineering (C-CORE) and Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5
[2] Geomartec Services, 1067 Clarke Road, Brentwood Bay, B.C. V0S 1A0

Gravity measurements on the Queen Charlotte Islands, British Columbia†

D.A. Seemann, A. Collins, and J.F. Sweeney
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Seemann, D.A., Collins, A., and Sweeney, J.F., Gravity measurements on the Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 283-286, 1988.

Abstract

During July 1987, 135 gravity measurements were taken on and near Graham Island. Besides infilling the regional anomaly field at 10- to 12-km spacing, two detailed transects were completed along Skidegate and Masset inlets approximately normal to major structural trends. The new measurements define a 10- by 20-km northwest-trending Bouguer anomaly high (residual amplitude about 20 mGal) along a gravity gradient between Skidegate and Masset inlets. A northeast-trending low of similar dimensions (residual amplitude about 10 mGal) is present between Rennell Sound and Masset Inlet. The former could be caused by Karmutsen Formation mafic volcanics in the subsurface adjacent to an apparent east-facing basement scarp and associated eastward thickening of sediments within the Queen Charlotte Basin. The anomaly low is associated with an area of exposed siliceous volcanic rocks up to 1 km thick.

Résumé

En juillet 1987, 135 mesures de gravité ont été prises dans l'île Graham et les environs. En plus de couvrir le champ d'anomalies régionales suivant des espacements de 10 à 15 km, deux coupes tranversales détaillées ont été réalisées le long des inlets Skidegate et Masset, plus ou moins perpendiculairement aux grandes tendances structurales. Les nouvelles mesures définissent un maximum d'anomalie de Bouguer de 10 km sur 20 km de direction nord-ouest (amplitude résiduelle d'environ 20 mGal) le long d'un gradient de gravité entre les inlets Skidegate et Masset. Un minimum de direction nord-est de dimensions semblables (amplitude résiduelle d'environ 10 mGal) est observé entre la baie Rennell et l'inlet Masset. Le premier pourrait être causé par des roches volcaniques mafiques de la formation de Karmutsen dans la subsurface adjacente à un escarpement apparent du socle orienté vers l'est par un épaississement associé vers l'est des sédiments dans le bassin de la Reine-Charlotte. Le minimum est associé à une zone de roches volcaniques siliceuses exposées ayant jusqu'à 1 km d'épaisseur.

† Contribution to Frontier Geoscience Program

INTRODUCTION

Gravity measurements were first observed on the Queen Charlotte Islands by personnel from the Dominion Observatory (Earth Physics Branch, now Geological Survey of Canada (GSC)) in 1963. Regional coverage was extended both onshore and offshore in 1966, 1967 and in 1977 (Stacey et al., 1969; Earth Physics Branch, 1982). Most of the early land stations are located along shorelines because access to and positioning within the interior of the archipelago is difficult, particularly on Graham Island.

The intent of the 1987 GSC gravity survey was to complete the regional coverage on western Graham Island at approximately 10-km station spacing and, where feasible, to measure gravity at about 1-km intervals along transects normal to large-scale geological structure. The latter was an attempt to identify density variations in the upper crust and to assess their relationship, if any, with mapped surface features. A concurrent gravity survey by Chevron Canada Resources Limited was carried out on eastern Graham Island. Over 300 gravity observations were made, the results of which are not reported here.

GSC GRAVITY SURVEY

A total of 37 stations was added to the regional coverage (Fig. 1). Two transects were completed, including 44 stations along the shores of Skidegate Inlet and 54 stations on a profile along the north shore of Masset Inlet and extending to the west coast of Graham Island (Fig. 3).

Gravity measurements were observed using Lacoste-Romberg gravimeters G009 and G444. Instrument readings were reduced to Bouguer anomalies using the International Gravity Standardization Net. 1971 (IGSN71) and the Geodetic Reference System 1967 (GRS67). A standard density of 2.67 g/cm^3 was used in the Bouguer correction.

Horizontal coordinates of gravity stations were determined from 1:50 000 NTS maps on which the location of logging roads had been transferred from 1986 aerial photographs. The northing and easting coordinates of each station were scaled off the maps using a template. Location accuracies are estimated to be within 25 m.

Vertical coordinates were derived using two methods. For gravity stations along the coast, elevations were measured using a hand-held AIR altimeter continuously referenced to sea level. Using tide tables furnished by the Canadian Hydrographic Service, tidal corrections were applied to reduce these measurements to mean sea level. The accuracy of this method is expected to be within a few metres.

Elevations for interior stations were determined by altimetry traverses tied either to Geodetic control or to sea level. With few exceptions the traverses were completed within 60 minutes and were carried out within a vertical envelope of a few hundred metres. Temperature, humidity and altimetry values were recorded electronically at each station using a recently developed digital data acquisition system. These data were downloaded to a portable computer for on-site processing. Historically, the success of using altimeters for elevation control has been marginal, especially in mountainous terrain. Although it is difficult to estimate the accuracy of this method, previous experience in similar Cordilleran terrain suggests that an elevation accuracy within 5 m can be achieved. Regional terrain effects have been removed from Bouguer values using a 1-km digital elevation grid and computational software developed by the National Gravity Data Centre, Geophysics Division, Geological Survey of Canada, Ottawa. For a select number of stations, local terrain effects within a few kilometres will be determined more precisely. The regional approximation however, as shown elsewhere within the Cordillera, typically contributes 85 per cent or more to the overall terrain effect. Most of the regional terrain corrections are less than 5 mGal ranging to a few that exceed 20 mGal. Preliminary Bouguer anomalies in Figures 2 and 3 are therefore considered to contain residual terrain effects of less than 0.8 mGal in most cases and no more than about 3 mGal in the extreme case.

GRAVITY FIELD

East to west, the regional gravity field is characterized by strong negative anomalies, locally exceeding -100 mGal, over the high elevations of the mainland coast mountains (Fig. 2). The field becomes steadily more positive to the west across

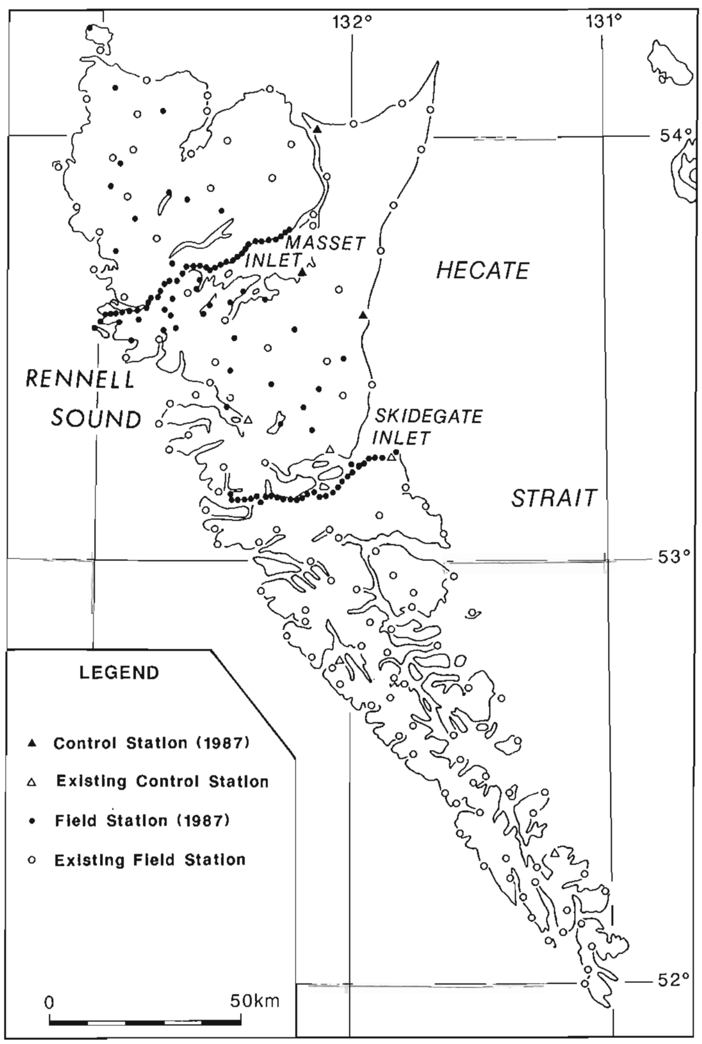


Figure 1. Gravity station distribution on the Queen Charlotte Islands.

Hecate Strait and culminates in a linear high of up to 80 mGal along the western rim of the Queen Charlotte archipelago. The high closely parallels a pronounced offshore gravity low, exceeding -90 mGal in places. The steep anomaly gradient between the high-low pair lies over the Queen Charlotte Fault, the boundary between the Pacific and North American plates.

Low anomalies over the mainland are attributed to thickened continental crust beneath the coast mountains (Stacey and Stephens, 1969; Forsyth et al., 1974). The paired high-low anomaly belt associated with the plate boundary is partly an edge effect produced by the abrupt transition from continental to oceanic crust (Stacey and Stephens, 1969). The low anomaly is enhanced by the presence of seawater and a low density accretionary wedge on the oceanic side of the plate boundary (Hyndman et al., 1982). The high anomaly on the continental side could reflect in part the presence of thick mafic units of the Masset and/or Karmutsen formations. Yorath and Hyndman (1983) suggest that the gravity high along the continental edge reflects flexural uplift produced over the last 6 Ma by oblique convergence and underthrusting of the Pacific Plate beneath North America in the Queen Charlotte region.

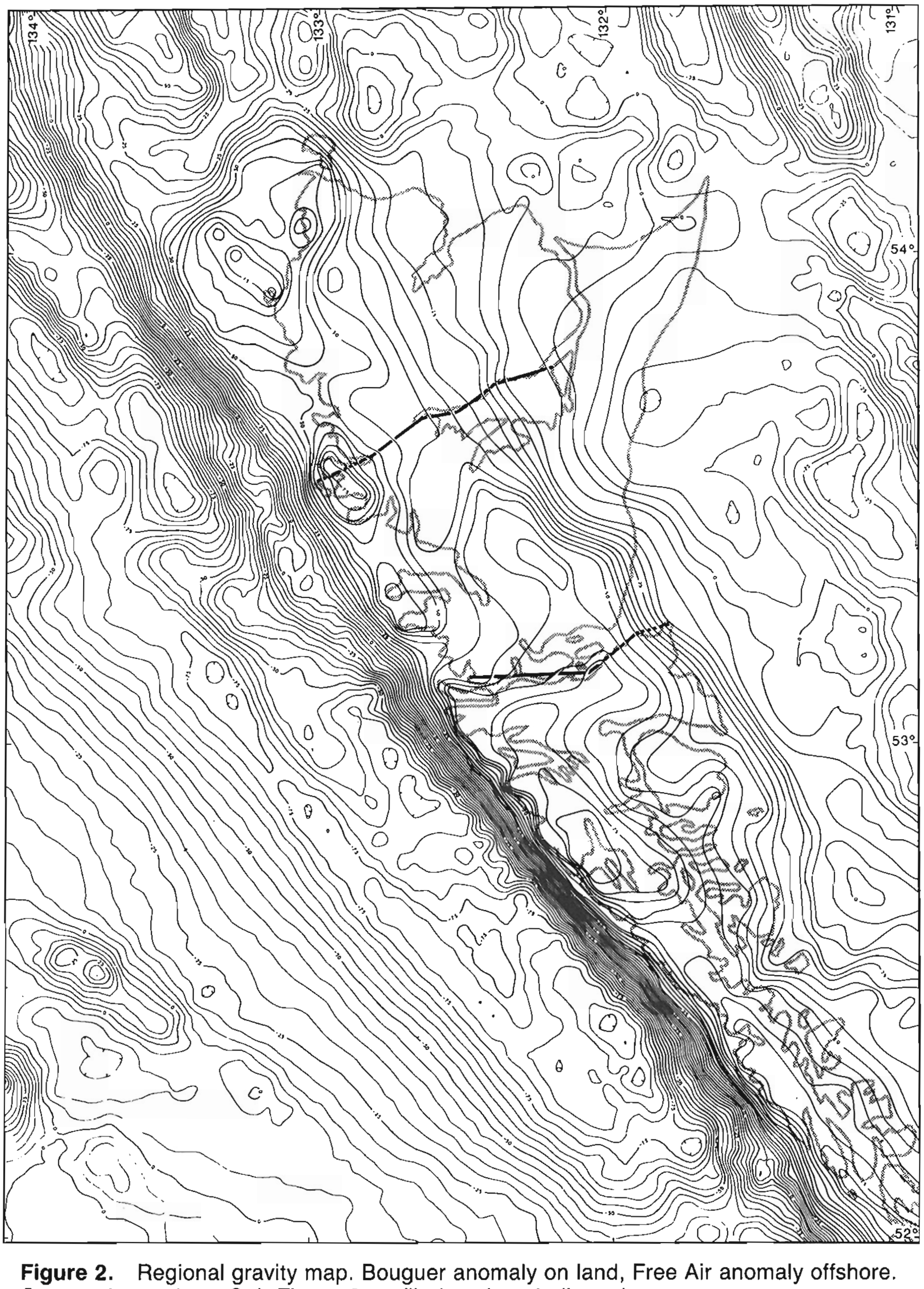


Figure 2. Regional gravity map. Bouguer anomaly on land, Free Air anomaly offshore. Contour interval 5 mGal. Figure 3 profile locations indicated.

Figure 3. Bouguer anomaly profiles along Skidegate Inlet and Masset Inlet. Profile locations shown in Figure 2.

The 1987 GSC gravity survey improved the definition of two anomaly zones on southern Graham Island and identified a significant Bouguer anomaly gradient extending northwest across Masset Inlet (Fig. 2). The anomaly zones are both elliptical, about 10 km by 20 km, and opposite in sign. The positive anomaly lies between Skidegate and Masset inlets and extends south of Graham Island (Fig. 2). Peak Bouguer values exceed 60 mGal. Preliminary separation of the residual anomaly from the longer wavelength (regional) gravity field indicates that about 20 mGal can be attributed to nearby sources within the upper crust. The anomaly axis is subparallel to and about 25 km east of the major gravity high along the plate boundary (Fig. 2, 3).

The negative anomaly lies between Rennell Sound and Masset Inlet. Minimum measured Bouguer values are below 40 mGal. The residual amplitude is estimated at about -10 mGal but, as no control exists in the central part of the anomaly, this value is considered a minimum. The low anomaly axis is northeasterly, oblique to the axes of the gravity highs (Fig. 2).

The anomaly gradient of up to 2.5 mGal/km, identified over Masset Inlet, may extend along much of the eastern side of the archipelago, but its signature is masked by the eastern flank of the positive anomaly across Skidegate Inlet (Fig. 2). The gradient zone is undetected in the regional gravity field north of Masset Inlet.

A brief assessment of these gravity anomaly features follows. The high anomaly on south-central Graham Island indicates an accumulation of dense rocks within the upper crust. South of Skidegate Inlet the gravity high lies over exposed Karmutsen Formation mafic volcanics (Sutherland Brown, 1968) and these rocks may continue north in the subsurface. Correspondingly, the low anomaly on southwestern Graham Island occurs over relatively less dense siliceous volcanics up to one kilometre thick within the Masset Formation (Sutherland Brown, 1968; C. Hickson, pers. comm., 1987). The gravity gradient between Masset and Skidegate inlets may reflect an abrupt eastward thickening of the Skonun Formation which underlies eastern Graham Island and Hecate Strait (Sutherland Brown, 1968; Shouldice, 1971). This

Figure 4. A gravity station on the south shore of Skidegate Inlet.

would imply the presence of an east-facing basement scarp (Sandspit Fault?), subparallel with regional geological structure, in the subsurface.

Computer modelling of the above features as well as density measurements of surface rock samples are now well underway. An offshore gravity survey in northwestern Hecate Strait is planned for 1988.

REFERENCES

Earth Physics Branch
1982: Open File Map 82-15.

Forsyth, D.A., Berry, M.J., and Ellis, R.M.
1974: A refraction survey across the Canadian Cordillera at 54°; Canadian Journal of Earth Sciences, v. 11, p. 533-548.

Hyndman, R.D., Lewis, T.J., Wright, J.A., Burgess, M., Chapman, D.S., and Yamano, M.
1982: Queen Charlotte fault zone: heat flow measurements; Canadian Journal of Earth Sciences, v. 19, p. 1657-1669.

Shouldice, D.H.
1971: Geology of the western Canadian continental shelf; Bulletin of Canadian Petroleum Geology, v. 19, p. 405-436.

Stacey, R.A. and Stephens, L.E.
1969: An interpretation of gravity measurements on the west coast of Canada; Canadian Journal of Earth Sciences, v. 6, p. 463-474.

Stacey, R.A., Stephens, L.E., Cooper, R.V., and Brule, B.G.
1969: Gravity measurements in British Columbia, Gravity Map Series 88; Publications of the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, 11 p.

Stacey, R.A., Boyd, J.B., Stephens, L.E., and Burke, W.E.F.
1973: Gravity measurements in British Columbia, Gravity Map Series 152-155, Publications of the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, 13 p.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p.

Yorath, C.J. and Hyndman, R.D.
1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.

Magnetics component of the Frontier Geoscience Program on the West Coast of Canada†

R.G. Currie[1] and D.J. Teskey[2]

Currie, R.G. and Teskey, D.J., Magnetics component of the Frontier Geoscience Program on the West Coast of Canada; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 287, 1988.

During 1987 the first phase of the magnetics component of the FGP on the West Coast was completed. Approximately 43 000-line-km of aeromagnetic data were acquired over the Queen Charlotte Islands and adjacent offshore areas in 1985. These data were compiled, integrated with aeromagnetic data provided by Shell Canada Ltd. in 1986 and published as Geological Survey of Canada Geophysical maps (9 at 1:250 000 and 68 at 1:50 000) in 1987. The digital data for this region north of 53°N have also been released. The balance of the aeromagnetic data and maps (south of 53°N) will also be released.

The interpretation of these data will occupy the next 18 months. Routine interpretation techniques such as depth to source, vertical gradient, source strike, Werner deconvolution and forward modelling will be applied to the data. In addition, more innovative techniques are being investigated with geophysicists at the University of British Columbia and Brock University. It is anticipated that the aeromagnetic data when combined with gravity and seismic data will provide an additional constraint on the crustal structure of the basin. In particular, it should help to elucidate the extent and thickness of the Massett Formation and; indirectly, the material between the Massett and "true basement".

REFERENCES

Geological Survey of Canada Aeromagnetic maps of the Queen Charlotte Islands, British Columbia
1:250,000 7720G, 7721G, 7736G-7738G, 7752G, 7753G, 7762G, 7763G
1: 50,000 9434G-9465G, 9469G-9474G, 9478G-9482G, 9487G-9490G, 9495G-9499G, 9504G-9507G, 9512G-9516G, 9522G-9525G, 9531G-9533G; Digital data are available from the Geophysical Data Centre, Geological Survey of Canada, Ottawa K1A 0E8

† Contribution to Frontier Geoscience Program
[1] Cordilleran and Pacific Geoscience Division, Sidney, B.C.
[2] Geophysics Division, Ottawa

Lithospheric structure from earthquake depth, Queen Charlotte Islands, British Columbia[†]

G. Rogers, B. Horner, and D. Weichert
Cordilleran and Pacific Geoscience Division, Sidney, B.C.

Rogers, G., Horner, B., and Weichert, D., Lithospheric structure from earthquake depth, Queen Charlotte Islands, British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 88-1E, p. 289-290, 1988.

Two additional seismograph stations have been installed in the Queen Charlotte Islands area and these, when used with stations of the existing network, will enable epicentres to be determined more precisely and for the first time allow the routine determination of focal depth. The Queen Charlotte Basin is one of the few sedimentary basins in the world that has continuing earthquake activity beneath it and this study will use these to infer the temperature regime at depth. The maximum focal depth of earthquakes is controlled by temperature and thus an estimate of the temperature beneath the sedimentary basin can be made if the maximum focal depth is determined. This project will improve the ability to assess seismic hazard, it utilizes a new technique for temperature estimation at depth and, by constraining temperature estimates in the basin, information will be gathered that is appropriate for assessing the maturation of hydrocarbons.

The first installations of the present network of seismograph stations began in the Queen Charlotte Islands region in 1982; the objective is to assess earthquake hazard on the islands and in Hecate Strait and Queen Charlotte Sound. Specifically, the question to be addressed is: does seismicity inland from the Queen Charlotte Fault indicate active faulting, or is the hazard in the region only from earthquakes on the Queen Charlotte fault where all large earthquakes have occurred in historic time? By the summer of 1987 seven stations had been installed on the islands and several more on

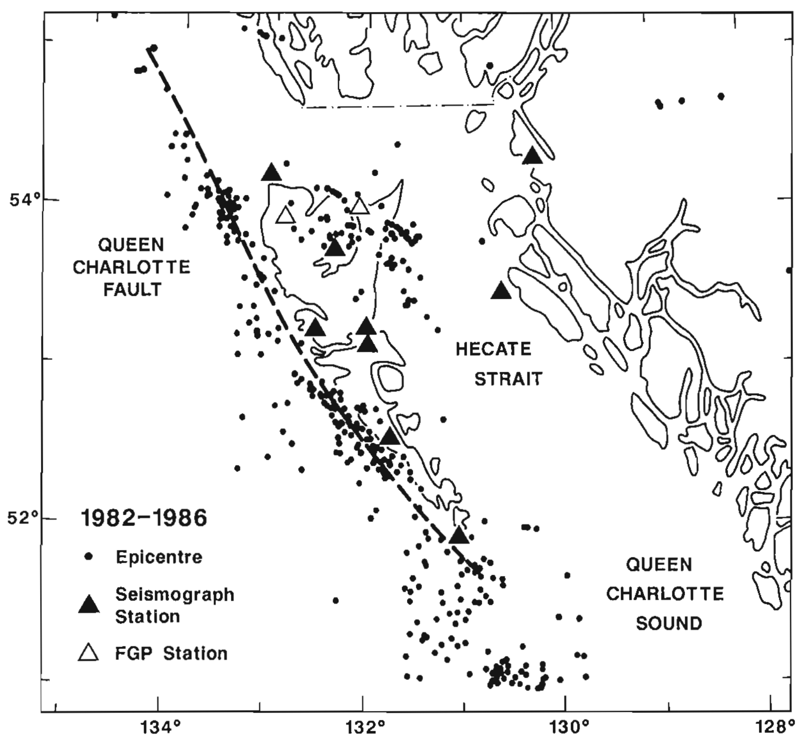


Figure 1. Circles are small earthquakes that occurred between September 1985 and April 1986. Solid triangles denote seismograph stations installed up to 1987 and open triangles indicate stations recently installed.

[†] Contribution to Frontier Geoscience Program

the adjacent mainland. The results to date indicate no alignment of epicentres that would suggest any of the major mapped faults are active. However, the data have revealed considerable continuing microearthquake activity over Graham Island and into Hecate Strait. Most of activity could not be detected before the local seismic network was installed (Fig. 1).

The original local seismograph network, while sufficient to locate the microearthquakes in latitude and longitude did not have the station density to determine the depth of the earthquakes accurately. The additional two stations (Fig. 1) will allow the determination of the depth of earthquakes on much of northern Graham Island and a short distance into Hecate Strait. The maximum depth of earthquakes in the region will determine the approximate position of the 450 degree isotherm. This will put constraints on thermal modeling used to gauge the thermal maturation of potential hydrocarbons. The temperature regime will also dictate the strength of the lithosphere and thus provide a constraint on modeling the tectonic history of the basin.

The two new seismograph stations were installed during the fall of 1987. After preliminary processing to identify earthquakes the seismograms collected are sent to the Pacific Geoscience Centre where the earthquake locations are determined. All earthquake locations are published quarterly in the National Earthquake Summary of the Geological Survey of Canada. At the rate of microearthquake activity seen in the first few years of detailed local monitoring in the region, it is expected to take two to five years to record a sufficient number of earthquakes to confidently determine the maximum depth at which microearthquakes occur.

Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada