B

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 67-1
Part B

REPORT OF ACTIVITIES,

Part B: November 1966 to April 1967

Price, $1.50

1967

CANADA

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

This report comprises forty-one brief papers that describe research carried out by members of the Geological Survey of Canada between November 1966 and April 1967.

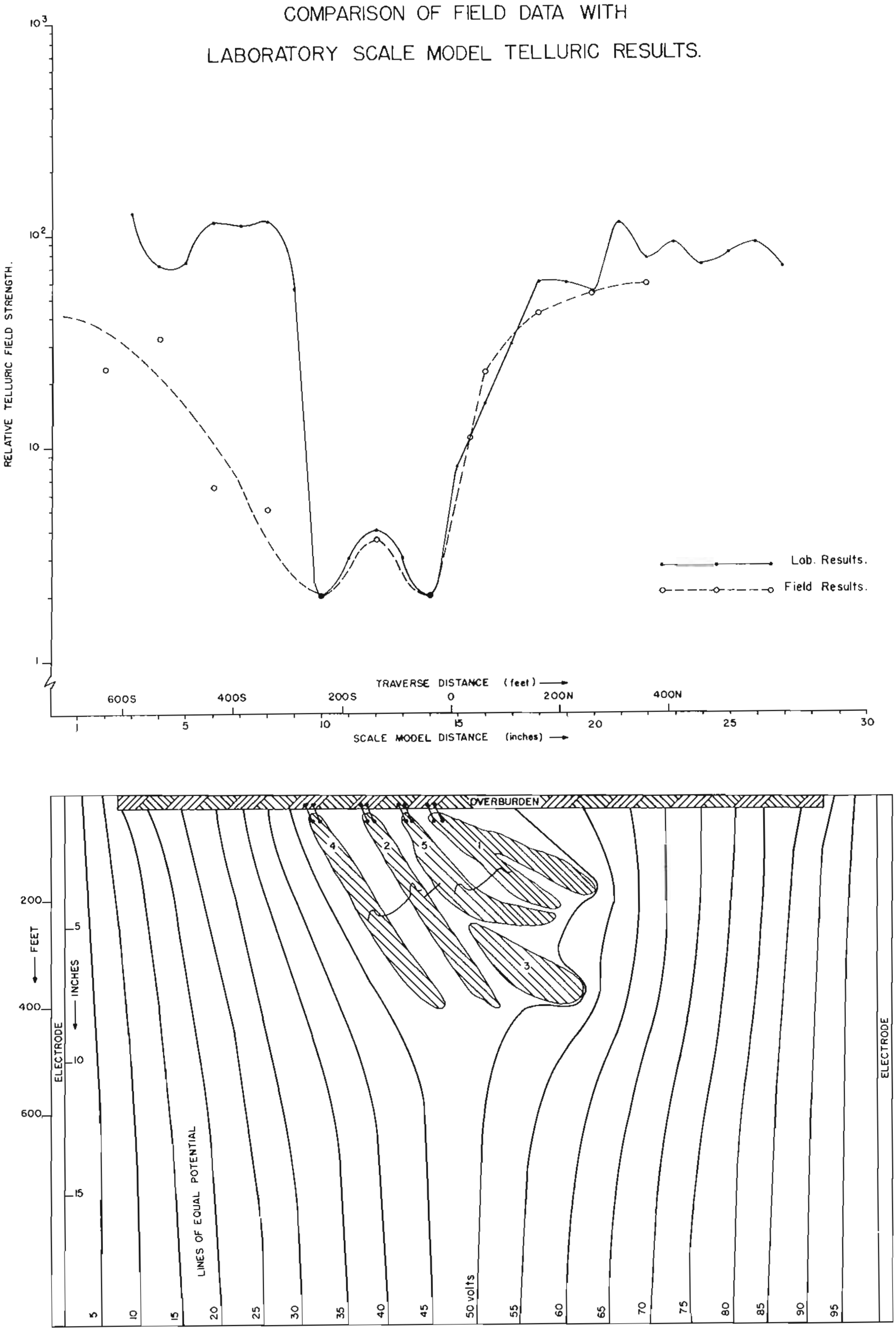
REPORT OF ACTIVITIES, NOVEMBER 1966 TO APRIL 1967

INTRODUCTION

This report comprises forty-one short papers in which the results of scientific studies carried out by members of the Geological Survey between November 1966 and April 1967 are presented. Many of the subjects discussed will be more fully described either in one of the Survey's publications or in one of the scientific journals. Illustrations accompanying this report are reproduced without change from material submitted by the authors.

The report of activities is at present a semi-annual publication. The section covering the period May to October consists primarily of reports of field work whereas this section includes reports on both field and laboratory investigations. Together with the volume of abstracts and the index of publications these reports provide an annual résumé of the major scientific activities of the Geological Survey.

This report was edited by R.G. Blackadar.



ESTIMATED SECTION, BARTOUILLE TWP. P.Q.

Figure 1.

A. Becker

EXPLORATION GEOPHYSICS

1. MAGNETO-TELLURICS

A. Becker

At the completion of the field season work was initiated towards the construction of a two dimensional scale model of the Bartouille Township sulphide mass which had been previously surveyed with the Geological Survey telluric equipment.

The results obtained (Fig. 1) verify the assumption of uniform planar current flow in the region. They also indicate that the mineralization proven by diamond drilling accounts reasonably well for the anomaly mapped with the field equipment.

Equipment development was restricted to the design and construction of a coil for sensing natural magnetic fields and 8 c/s. New coil design formulas were obtained and have been accepted for publication (Becker, in press). The sensor itself has a sensitivity of about a milligamma. Unfortunately it is somewhat cumbersome to use because of its diameter (80 cm) and its weight (75 lb.).

Becker, A.,
in press Design Formulas for Electromagnetic Sensing Coils. To be published in "Geoexploration".

2. DETECTABILITY OF DIABASE DYKES BY AEROMAGNETIC SURVEYS

Peter Hood

It is common experience to find on aeromagnetic maps of the Canadian Shield elongated magnetic anomalies due to diabase dykes which often run for many miles. It has also been noted that sometimes the diabase dykes mapped by field geologists have no magnetic expression on the aeromagnetic maps, whereas some that have a significant magnetic expression are often not mapped by the field geologist if he does not have the benefit of an aeromagnetic map. The reason for this may be as follows: the more magnetic dykes, such as the Sudbury Group (Fahrig et al., 1965; Larochelle, 1967) are usually olivine-bearing and these tend to weather out so that the outcropping diabase is rather sparse. The less magnetic dykes are more tholeiitic in composition, and because of their higher silica content are relatively resistant to weathering so that they are much more easily detected by the field geologist. There appears to be an inverse relationship between the silica and magnetite content of rocks, in general, so that tholeiitic diabase dykes usually contain less magnetite than the olivine-bearing variety. Thus the olivine-bearing diabase dykes are more magnetic because the magnetic properties of rocks can be ascribed to the presence of magnetite (more exactly titanomagnetite) alone.

Whether a diabase dyke will be apparent on an aeromagnetic map will, of course, depend on a number of other factors in addition to its magnetic properties. The diagnostic physical parameter indicative of the magnetic properties of rocks is the intensity of magnetization (J) due to both remanent and induced magnetization. The other factors which will influence the amplitude of the concomitant magnetic anomaly are the width (w) of the dyke, the distance between the survey aircraft and the top of the dyke (h), and the contour interval used in the aeromagnetic map. For an outcropping dyke the value of h is 1,000 feet in the standard GSC aeromagnetic map (because this is the survey flight elevation) and the contour interval used is 10 gammas.

The equation for the total intensity anomaly (ΔT) over an infinite dipping dyke is given by

$$\Delta T = 2Jbc \sin \theta \left[\sin \alpha \left(\tan^{-1} \frac{x + d}{h} - \tan^{-1} \frac{x - d}{h} \right) - \frac{\cos \alpha}{2} \log_e \frac{(x + d)^2 + h^2}{(x - d)^2 + h^2} \right]$$

... (Hood, 1964)

using the notation used in Figure 1 where:

T and I are the total field and inclination of the earth's field, and A is the horizontal angle between magnetic north and the line at right angles to the strike of the dyke of width w = 2d; i and a are the inclination and the horizontal declination angle between the vector J and the line at right angles to the dyke;

also $\alpha = (\lambda + \quad - \theta)$ where

$\tan \lambda = \dfrac{\tan I}{\cos A}$, $\tan \quad = \dfrac{\tan i}{\cos a}$, and θ is the dip of the dyke

$b = (\sin^2 i + \cos^2 i \cos^2 a)^{\frac{1}{2}}$ and

$c = (\sin^2 I + \cos^2 I \cos^2 A)^{\frac{1}{2}}$.

At high magnetic latitudes such as Canada, the value of c will approach unity within a few per cent as will b also because the remanent magnetization of Precambrian rocks tends to be of lesser importance than the induced

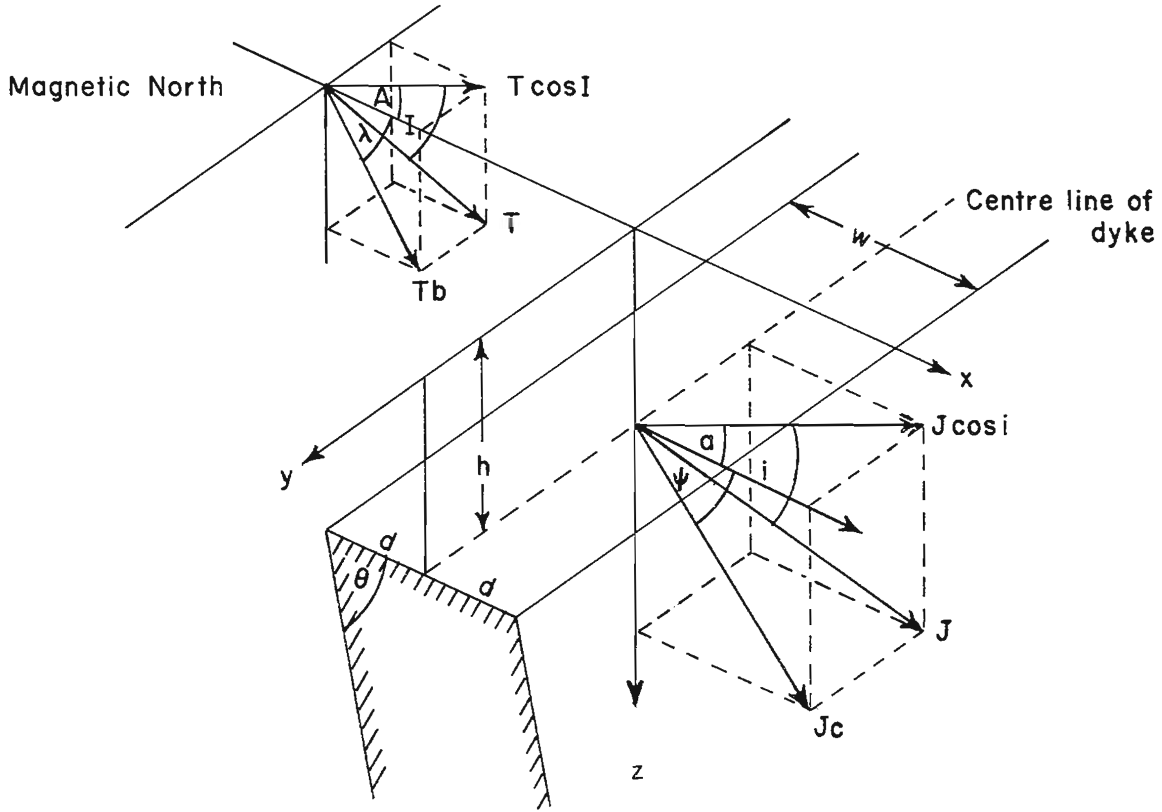


Figure 1. Oblique view of dipping dyke showing nomenclature used in the equation for the total intensity anomaly.

magnetization component which will be accurately aligned with the total field vector T. In many cases the natural remanent magnetization (which includes both the 'hard' and 'soft' components) will also be steeply-dipping. Thus for dykes which are close to being vertical the value of $\alpha \simeq 90°$, and the dipping dyke equation will reduce to

$$\Delta T = 2J \left(\tan^{-1} \frac{x + d}{h} - \tan^{-1} \frac{x - d}{h}\right)$$

which is the symmetrical dyke case.

The maximum value of ΔT is then given by

$$\Delta T_{max} = 4J \tan^{-1} \frac{w}{2h}$$

i.e. $w = 2h \tan \frac{\Delta T_{max}}{4J}$

Thus if ΔT_{max} is greater than 10 gammas, the dyke will be indicated on the standard 10 gamma GSC aeromagnetic map by at least two magnetic contour lines. In order to simplify matters further we put

$$J = k_e T$$

where k_e is the effective susceptibility of the dyke. This equation will be true if the natural remanent magnetization is negligible or is aligned parallel to the earth's total field T; it should be approximately correct for the majority of Precambrian rocks of the Canadian Shield.

Thus $w = 2 h \tan \frac{\Delta T_{max}}{4 k_e T}$,

For thin dykes the equation reduces to $w = \frac{h \Delta T_{max}}{2 k_e T}$

The graph shown in Figure 2 has been drawn to show the maximum physical parameters necessary for the dyke to be detected on the aeromagnetic map; namely the distance (h) from the top of the dyke to the survey aircraft, and the effective susceptibility (k_e) and width (w) of the dyke necessary to obtain a value of $\Delta T_{max} = 10$ gammas i.e. necessary for the dyke to produce a 10-gamma anomaly. The value of T has been chosen as 60,000 gammas which is about average for the Canadian Shield.

The second graph (Fig. 3) shows the relationship between ΔT_{max}, k_e, and w for an outcropping dyke (h = 1,000 feet). It can be seen that an

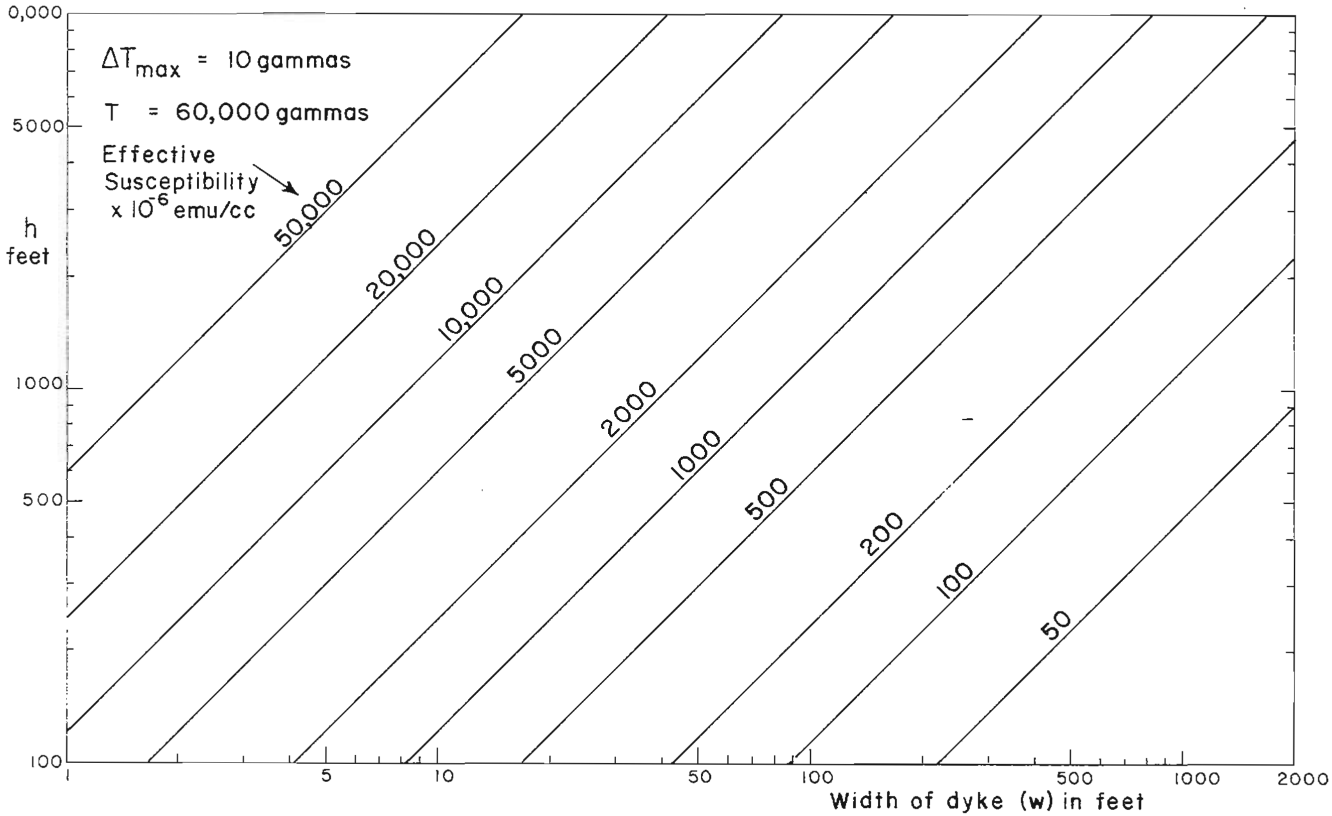


Figure 2. Detectability of dyke from Geological Survey aeromagnetic surveys.

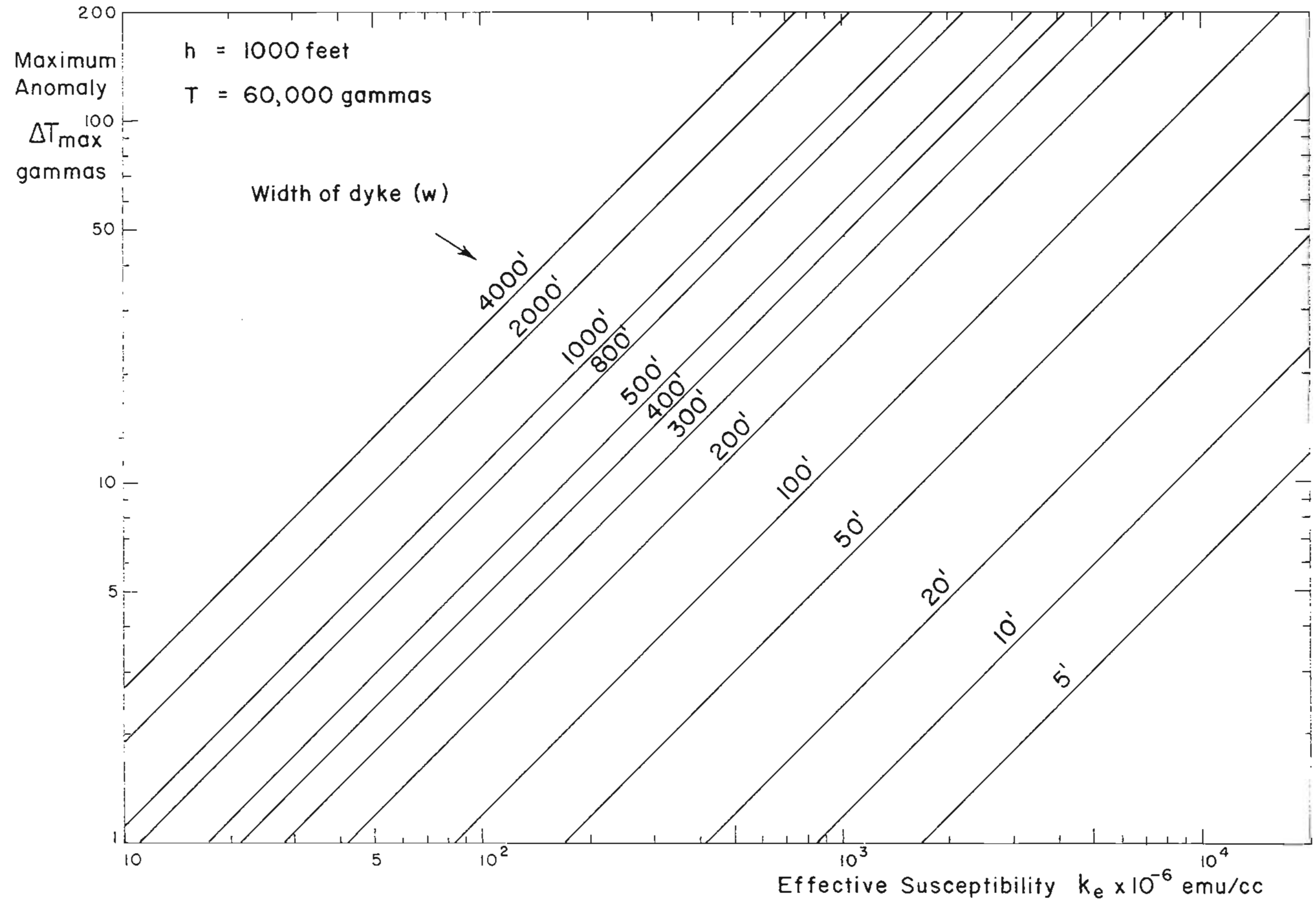


Figure 3. Detectability of outcropping dyke from Geological Survey aeromagnetic surveys.

aeromagnetic survey flown at 1,000 feet will record a 12-gamma anomaly due to an outcropping dyke 100 feet wide and having an effective susceptibility of 1,000 X 10^{-6} emu/cc. It would therefore be apparent on a GSC aeromagnetic map in which a 10-gamma contour interval is used.

I wish to thank B. Charbonneau, W.F. Fahrig, and T.N. Irvine for discussions concerning the relationship between composition and magnetic expression of diabase dykes on aeromagnetic maps. This is a topic that could be profitably pursued further.

Fahrig, W.F., Gaucher, E.H., and Larochelle, A.
1965: Palaeomagnetism of diabase dykes of the Canadian Shield; Can. J. Earth Sci., vol. 2, pp. 278-298.

Hood, P.
1964: The Königsberger ratio and the dipping-dyke equation; Geophys. Prospecting, vol. 12, pp. 440-456.

Larochelle, A.
1967: The palaeomagnetism of the Sudbury diabase dyke swarm; Can. J. Earth Sci., vol. 4, pp. 323-332.

3. PALAEOMAGNETISM OF LOWER PALAEOZOIC SEDIMENTS OF SOUTHERN ONTARIO

D.T.A. Symons

About 5 core samples were collected at each of 32 sites in Cambro-Ordovician to Middle Ordovician sediments of the Ottawa-Kingston area of southern Ontario (NTS: 31 B, C, F, G). By palaeomagnetic study of these samples, it was hoped to determine reliable pole-positions for the earth's magnetic field in lower Palaeozoic time. The natural remanent magnetization (NRM) of about half of the samples was measured. Their directions were found to be roughly aligned with the present earth's field direction, which suggests remanence instability. The NRM intensities were found to average about 10^{-6} emu/cc. Seven of the cores (i.e. 14 cylinders) were tested for remanence stability by demagnetization in alternating fields of 25, 50, 100, and 150 oersteds. At 150 oersteds the remanence intensities were reduced to 10 per cent of the NRM intensities, and their directions showed no evidence of approaching a stable direction. Further work on this project is not likely to be rewarding at present. Additional demagnetization tests will be attempted if and when a more sensitive magnetometer becomes available in future.

4. OVERHAUSER MAGNETOMETER PROGRESS REPORT

S. Washkurak

The following is a progress report on the development of an Overhauser magnetometer and possible application of magnetic resonance to a nuclear gyroscope.

Detector coil

A detector coil has been designed to increase the signal to noise ratio of the resonance signal by a factor of 15 to 1. The new coil has a sample volume of 2,500 cm^3 as compared to 250 cm^3 and by immersing the detector coil in the sample an improved filling factor of 1.5 is obtained.

The resonance signal "S" is proportional to

$$S = QV\, n\, \gamma^3\, T^2$$

where Q = Quality factor of the coil
V = Volume of sample
n = number of turns per centimetre of coil
γ = gyromagnetic ratio
T = magnetic field measured

Taking into consideration the minimum possible value of capacity of the tuned circuit used for detecting the resonance, the optimum signal that can be detected is given by formula

$$S_{opt} = Q\, V\, \gamma^2\, T$$

Since the proton has the highest gyromagnetic ratio of all known samples and it is desirable to have a low "Q" coil for a broad-band magnetic system, the volume of the sample has to be increased to improve the signal to noise ratio. The sample size is primarily limited by the magnetic gradient of both the measured field and radio frequency polarizing field.

MINERAL DEPOSITS

5. STUDY OF IRON DEPOSITS IN THE SOVIET UNION

G.A. Gross

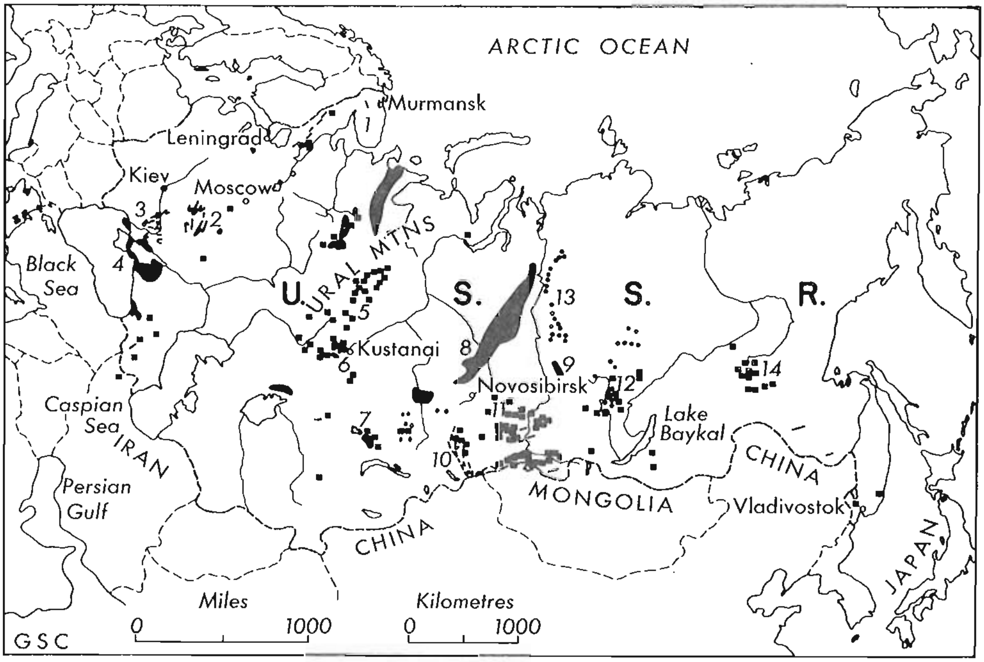
Study of iron deposits in the Soviet Union during the summer of 1966 revealed a wealth of geological information and experience that is directly applicable to understanding the origin and mode of occurrence of iron deposits in Canada and to the evaluation of potential ore. Detailed reports and papers covering this scientific liaison work have been prepared. Figure 1 which shows the distribution of major occurrences of different kinds of iron ore is based on information obtained during this visit and further examination of the literature.

The naturally enriched hematite geothite ore and magnetite quartz iron beds suitable for beneficiation which occur in Proterozoic iron formations in the Krivoy Rog and Kursk Magnetic Anomaly areas are the source for about 70 per cent of the iron ore mined. Iron formations in these areas are part of a major belt of Precambrian cherty iron sediments which extends north for considerable distance under the Russian Platform. The highly metamorphosed magnetite quartz beds exposed in the Precambrian areas of Karelia and the Kola peninsula appear to be a northern part of this major iron belt. Other Precambrian iron formations occur in the Aldan Shield in East Siberia. The thin banded jasper magnetite and hematite iron formations associated with volcanic rocks of Devonian age in Kazakhstan and northwest of the Mongolian border are of particular interest.

Oolitic limonite, chamosite, siderite beds of Cretaceous and younger age form vast concentrations of iron in the Soviet Union. About 7 million tons of ore per year are mined from the Oligocene deposits around Kerch between the Black and Azov Seas and considerable ore has been added to the large reserves in this area in recent years. Near shore facies of Cretaceous iron beds surround the Eastern and Southern perimeter of the West Siberian basin and probably form one of the greatest concentrations of iron in the world. Other deposits of this kind occur near the steel centre of Kustanai and in Eastern Siberia. All of these ores have an iron content of less than 45 per cent, are high in phosphorus, alumina and sometimes arsenic and are difficult to beneficiate. They are mined near Kerch and Kustanai for local use.

Contact metasomatic magnetite deposits are distributed along the central and southeastern part of the Ural belt. Many smaller deposits in this area have been worked for many years and are nearly exhausted but more recently a number of very large deposits such as Sarbai have been discovered

IRON DEPOSITS OF THE SOVIET UNION



Cherty iron-formation, iron quartzites . . . .
Oolitic iron sediments, brown ores . . . .
Magnetite deposits, other types . . . .
Magnetite in volcanic pipes . . . .
Bog iron areas . . . .

1. *Kola and Karelia*
2. *Kursk*
3. *Krivoy Rog*
4. *Kerch*
5. *Ural Mountains*
6. *Kustanai*
7. *Karadgal*
8. *West Siberian Basin*
9. *Angaro - Pitsk*
10. *Altay*
11. *Kemerovo - Kuznetsk*
12. *Angaro - Ilim*
13. *East Siberian Platform*
14. *Aldan*

which each contain nearly one billion tons of good ore. Other very large contact metasomatic deposits occur east of the Kusnetsov basin in Siberia where magnetite ore reserves are measured in billions of tons. Other sizeable magnetite deposits occur in the Aldan Shield in far Eastern Siberia.

A group of magnetite deposits of special geological interest occur along the southwest side of the East Siberian Platform and extend north along the Yenisey River. Magnetite with conspicuous spheroidal texture occurs in volcanic pipes and diatremes which pierce thousands of feet of Palaeozoic sediments and basalt sills. These deposits are a type that is rarely found elsewhere but magnetite deposits on Axel Heiberg Island in the Canadian Arctic appear to be similar.

Titaniferous magnetite deposits are widely distributed in basic to ultrabasic rocks along the east and northeast part of the Ural belt. Iron ore from some of these deposits is mined and concentrated and it is expected that considerably greater use will be made of titaniferous magnetite ore in the future.

6. TIN AND BERYLLIUM IN THE CASSIAR DISTRICT YUKON AND BRITISH COLUMBIA

R. Mulligan

Tin is concentrated in skarn silicates, notably ferroactinolite and epidote, 2 miles southeast and about 2 miles north of Ash Mountain. Lesser amounts are concentrated in clinopyroxene, axinite and vesuvianite from skarn at lat. 60°05'N, long. 131°29'W. Muscovitic granites in the Atsutla Range contain 10-15 ppm. tin, compared with 1-6 ppm. in Cassiar batholith samples. Granitic samples rarely contain more than 0-5 ppm. beryllium except in areas where beryl-bearing pegmatites occur. Vesuvianite, axinite and some other skarn minerals contain several hundred ppm. beryllium. Beryllium concentration is generally higher around the Seagull batholith than the Cassiar, and higher still around the stock west of Logjam Creek which probably represents the latest phase of granitic intrusion.

Mulligan, R., and Jambor, J.L.
1966: Tin-bearing garnet and pyroxene from skarn in the Cassiar District, B.C.; in Geol. Surv. Can., Paper 66-2.

7. TITANIFEROUS MAGNETITE AT PIPESTONE LAKE, MANITOBA

E.R. Rose

Pipestone Lake is an expansion of the Nelson River south of Cross Lake, about forty miles northeast of Lake Winnipeg, Manitoba. An occurrence of titaniferous magnetite on a bay in the south shore of Pipestone Lake was investigated by Noranda Mines Limited in 1959 and found to be vanadiferous. Geological mapping by C.K. Bell (1962) subsequently demonstrated the presence of a remarkably differentiated intrusion of gabbro-anorthosite at this locality. The intrusive is about 4,000 feet wide and several miles long; it trends east-west, dips vertically and faces south, lying between Bell's granodiorite-tonalite-gneiss complex on the south, and metamorphosed volcanic rocks on the north. All of these rocks are of Archaean age. According to Bell (1962), the 200-foot section of gabbro at the base (north side) of the sill is succeeded by about 400 feet of porphyritic anorthosite and gabbro porphyry, which is followed by a 100-foot zone of massive gabbroic anorthosite that is in turn succeeded by about 3,000 feet of massive grey anorthosite.

Massive lenses and disseminations of vanadium-bearing magnetite occur with the gabbroic and anorthositic rocks in the 'transitional zone' between gabbro and anorthosite according to Bell (1962). More detailed mapping by Rousell (1965) has suggested that the sill is a multiple intrusion involved in an area of isoclinal folding. Examination by the writer of thin sections and polished surfaces of the rocks and ore materials from the sill show that the main ore mineral is highly anisotropic vanadiferous titanomagnetite with intergrown, exsolved ilmenite. These opaque minerals occur interstitially to plagioclase crystals, along with dark blue-green, strongly pleochroic chlorite and hornblende. Titaniferous magnetite, chlorite and hornblende have crystallized after plagioclase, and appear to have remained sufficiently fluid to separate from one another as well as from plagioclase during the solidification of the sills.

Dip needle readings taken on magnetite-rich zones show strong magnetic attraction and commonly also indicate strong deflections of the north-seeking magnetic ends to the southeast. Aeromagnetic maps 2596 and 2597, issued by the Geological Survey in 1965, show a linear belt of positive aeromagnetic anomalies 6 miles long and one-half mile wide trending in an east-west direction south of Pipestone Lake. These anomalies are obviously associated with the titaniferous magnetite occurrences in the gabbro-anorthosite. Two oriented specimens of gabbroic host rock and one of titaniferous magnetite taken by the writer were sawn into cubes and measured magnetically in the Rock Magnetism laboratory of the Survey. Resulting data indicate that the host rock gabbro has a component of remanent magnetism directed obliquely downwards and northwesterly, whereas that of the titaniferous magnetite is directed obliquely downwards and southeasterly. These components of remanent magnetism form an angle of about 90° in the northwest-southeast plane, suggesting either that these components of magnetization were acquired at different times, and that the complex intergrowth of titanomagnetite and ilmenite has produced an anomalous effect, or that the two segments from which the sections were taken have been rotated by folding, one relative to the other, into their present positions. Until further evidence is obtained it seems impossible to resolve this problem.

Bell, C.K.
1962: Cross Lake map-area, Manitoba; Geol. Surv. Can., Paper 61-22.

Rousell, D.H.
1965: Geology of the Cross Lake area; Dept. Mines and Natural Resources, Manitoba, Mines Branch, Publ. 62-4.

8. NICKEL DISTRIBUTION IN SERPENTINITES FROM PUDDY LAKE, ONTARIO

P. R. Simpson and J. A. Chamberlain

Nickel in a serpentinite body of Archaean Age at Puddy Lake is partitioned variably between several spinel phases, sulphides and silicates. Serpentinites in which nickel is concentrated in magnetite contain less than 0.15 per cent total rock sulphur, and are notable for a near-absence of sulphides. Conversely, serpentinites in which magnetite is nickel-poor contain the following sulphides: chalcopyrite, pentlandite, sphalerite, siegenite, millerite and pyrite. Sulphur content of serpentinite is thus an important factor in nickel distribution at Puddy Lake.

Sulphide textures and sulphur distribution suggest that sulphur was present in the magma during emplacement and that nickel equilibriated between sulphides, silicates and oxides during the magmatic and serpentinization events. The nickel-rich magnetite, which on an average contains 1.25 per cent nickel, was formed during the serpentinization event in zones which were relatively sulphur-deficient. This nickel-rich secondary magnetite appears to have been partly remobilized by hydrothermal solutions into coarse veins near contacts with a younger granitic intrusion.

GEOCHEMISTRY

9. THE APPLICATION OF FACTOR ANALYSIS TO GEOCHEMICAL PROSPECTING

E. M. Cameron

Factor and component analysis methods promise to be of the greatest utility for interpreting geochemical prospecting data, particularly for orientation studies involving the interpretation of many different elements. The distribution of each element within a geological environment is usually determined not by one but by many processes; conversely each process usually affects a number of elements. Thus in geochemical prospecting, the variation of an element used as an indicator of ore may only in part be determined by its derivation from ore minerals; that part of its variation caused by other processes may obscure or confuse its use as an indicator of ore. By resolving the intercorrelations between the elements, factor analysis allows the geochemist to consider his data in terms of processes, such as the derivation of a group of elements from an ore deposit, rather than as variation in raw element data.

A program for the factor analysis of geochemical data has been written for a CDC 3200 computer (Cameron, 1967). Since the program requires only a 16K memory and is written in Fortran II, it should be readily adaptable to other computers. Principal components for up to 36 variables are extracted by the Jacobi method and up to 26 factors are rotated first to orthogonal simple structure using the Varimax criterion and then to oblique simple structure by the Promax method. For geochemical data it has been found particularly useful to then compute factor scores which may be plotted onto maps to show the areal variation of a factor or process. The program computes approximate factor scores by Harman's (1960) method of ideal variables. A separate program computes true factor scores by Kaiser's (1962) method.

Cameron, E. M.
1967: A computer program for factor analysis of geochemical and other data; Geol. Surv. Can., Paper 67-34.

Harman, H. H.
1960: Modern factor analysis; Univ. Chicago Press.

Kaiser, H. F.
1962: Formulas for component scores; Psychometrika, vol. 27, pp. 83-87.

10. ANALYSIS OF ROCKS USING A MULTICHANNEL EMISSION SPECTROMETER

E. M. Cameron and R. E. Horton

Direct-reading emission spectrometry is an excellent method for the rapid and precise analysis of many elements in rocks. By using an interrupted discharge for excitation, such as a high-voltage spark or condensed arc, it is possible to determine both major and trace elements, simultaneously if desired. To fully utilize the speed of the multichannel photoelectric spectrometer, it is desirable to automate sample preparation to as great a degree as possible and carry out the necessary computations by digital computer. Details are given for three methods that have been developed to determine:

(a) Major elements in a variety of rocks.
(b) Major and trace elements in a variety of rocks.
(c) Major and trace elements within a single rock type.

11. THE ADSORPTION AND COPRECIPITATION OF SILVER ON HYDROUS FERRIC OXIDES

Willy Dyck

Using silver-110 m as tracer, a detailed investigation was made of the adsorption of silver on freshly prepared hydrous ferric oxides at pH 4-8, and at a silver equilibrium concentration range of 10^{-4} to 10^{2} ppm. The results fit the Freundlich adsorption isotherms. Adsorption is instantaneous and is strongly dependent on both the pH and the manner in which the precipitate was prepared, but is independent of temperature in the range 0° to 50°C, moderate concentrations of sodium nitrate (~10g/l), and trace concentrations of sodium chloride ($\sim 1.5 \times 10^{-3}$g/l) during test periods ranging from 1 to 3 days.

Tests also showed that, under equilibrium conditions and similar chemical environments, the amounts of silver coprecipitated or adsorbed were identical. For example, raising to 6 the pH of 200 mls of aqueous solution containing 1.08 ppm Ag^{+} and 705 ppm Fe^{3+}, by the addition of a base, results in the precipitation of essentially all of the iron but only about 45 per cent of the silver. If the iron precipitate is prepared first and then added to the silver solution, essentially the same amount of silver is removed by the precipitate. Precipitates prepared by 'precipitation from homogeneous solution' (in this case by boiling iron solutions containing urea until the desired pH was reached) were nearly twice as dense as those prepared by the addition of base, and adsorbed 2 to 4 times less silver.

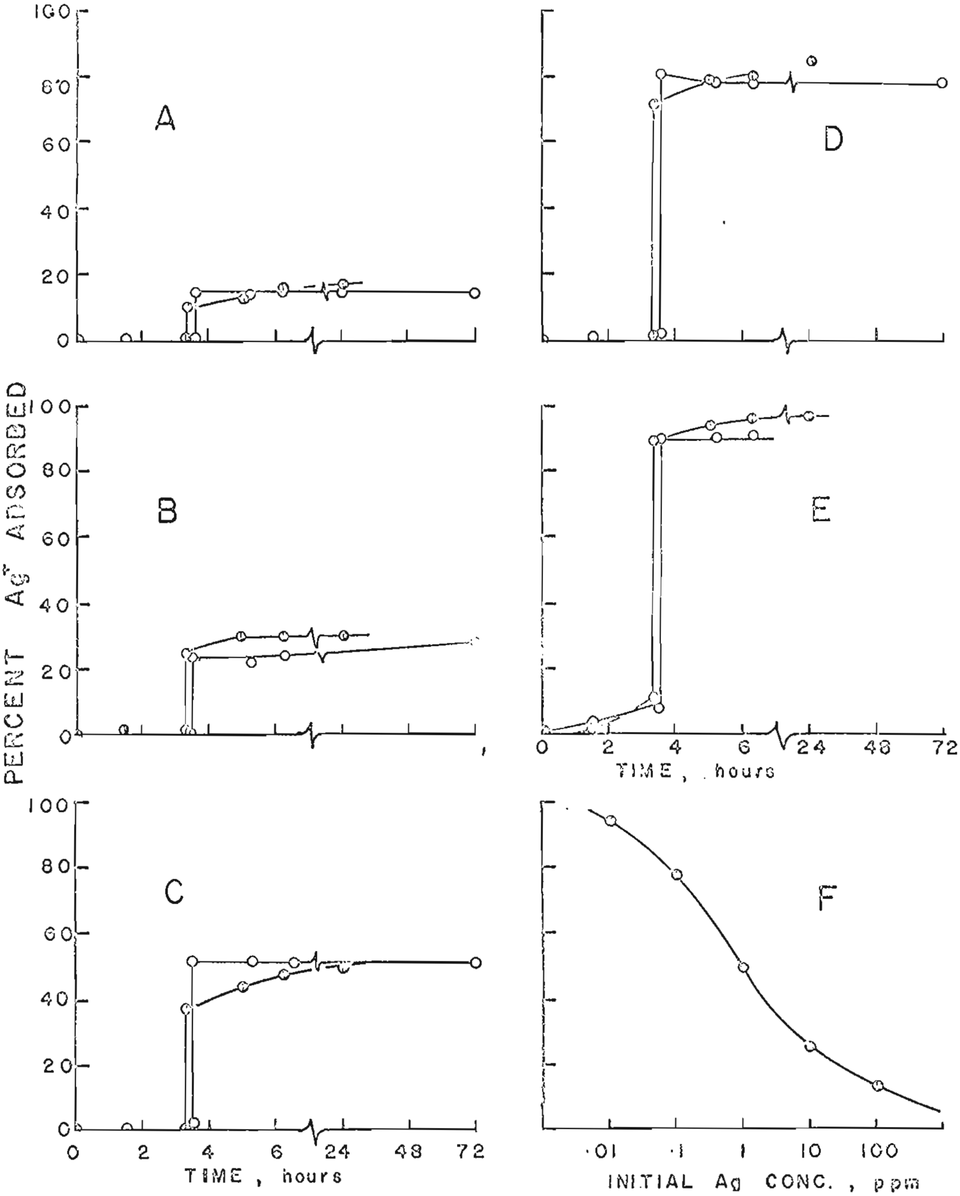


Figure 1.

W. Dyck

As an example, details of the experiments made at 2°C (empty circles) and 50°C (half filled circles) and at a constant pH = 6 are shown in Figure 1. Results of functions A to E were obtained by mixing freshly prepared hydrous ferric oxide (200 mg Fe_2O_3 equivalent) with 200 ml of 108, 10.8, 1.08, 0.108 and 0.011 ppm Ag^+ respectively and studying the change in the Ag^+ concentration with time. The sharp rise in graphs A to E occurs at the instant of mixing the silver solution with the iron precipitate. Graph F represents the average of the 2° and 50°C adsorption data about 3 hours after mixing.

Igneous rocks have an average Ag : Fe ratio of 1:500,000; aqueous mixture E in the figure below, a ratio 1:70,000. Assuming indiscriminate leaching for the two elements, subsequent precipitation of iron will carry with it essentially all of the silver in the absence of complexing agents. Hence natural waters near the neutral point cannot be expected to carry Ag^+ in solution in easily detectable quantities whenever there is evidence of iron oxide formation. Limonite, on the other hand, can be expected to contain silver if the ion was present in the solution from which the limonite precipitated.

12. A FIELD JACKET USED IN RECONNAISSANCE GEOCHEMICAL SURVEYS

C.F. Gleeson, R.W. Boyle and W.M. Tupper

Introduction

In 1964 and 1965 the Geological Survey of Canada conducted two large reconnaissance geochemical-heavy mineral surveys in the Keno Hill area, Yukon Territory and in the Bathurst area, New Brunswick. On both operations rivers, streams, and their tributaries were traversed on foot and samples of water and stream sediment were tested for cold extractable heavy metals on the spot at intervals of 1,500 feet. A series of 14 maps showing the results of Operation Keno have been published by the Geological Survey of Canada (Gleeson et al., 1965). Operation Keno (1964) was a helicopter supported program and covered 1,900 square miles of mountainous terrain. About 6,000 stream sediments were collected and tested. Operation Bathurst (Boyle et al., 1966) covered about 1,200 square miles and 3,600 sediment samples were collected and tested. The sediment samples were analyzed for 14 metals by colorimetric and spectrographic methods. At each station the temperature and pH of the water was measured, the composition of the sediment estimated, features of the stream described, and rock types in the vicinity of the sample points noted.

While working on the logistics of Operation Keno an immediate problem became obvious. In addition to standard geological field equipment the sampling crews would have to carry a variety of geochemical paraphernalia including test tubes, plastic bottles filled with chemicals for the field tests, sample bags, scoops, spatulas, graduated cylinders, thermometers, pH papers, notebooks, etc. Some means had to be devised by which this equipment could be carried with relative ease and have it readily at hand when required.

The solution was to design a geochemical field jacket which had sufficient pockets to carry the necessary geochemical field equipment. A prototype based on a design conceived by R. W. Boyle and used by the Geological Survey of Canada in a reconnaissance geochemical investigation of southwestern Nova Scotia in 1956 was used on Operation Keno and on the basis of experience gained was improved for use on Operation Bathurst.

The Geochemical Field Jacket

The jacket is sleeveless (Fig. 1), made of white cotton duck, and all pockets are double stitched with heavy thread.

The upper pocket on the right hand side is divided into 4 compartments. Three of these accommodate test tubes and the fourth pencils, pens, pocket thermometer, etc.

The large outer pocket on the left hand side serves a dual purpose; it will hold either a 100 ml graduated cylinder used in determining the metal content in water or envelopes for sediment samples. The lower left hand pocket will carry a 10 ml graduated cylinder used in the water test and the pocket next to it holds a 500 ml wash bottle for dithizone; pH paper is carried in a small pocket on the front of the latter pocket. The inside left hand pocket accommodates the note book containing geochemical field cards and note paper. The rest of the pockets on the right hand side carry plastic bottles containing buffers for the water or sediment tests, ammonium hydroxide, and a pH buffer for the pocket pH meters.

All pockets in which glass ware is carried are backed with a hard fibre card as a safety precaution against cuts in case of accidental breakage. All pockets have button down flaps to prevent their contents from falling out.

The jackets stood up well under field use and they proved to be an efficient and convenient method of carrying the geochemical equipment necessary for regional reconnaissance stream and water surveys.

Figure 1. Geochemical field jacket, front view showing inside left hand pocket. G.S.C. Photo 113504-B.

Summary and Conclusions

In the last two years the Geological Survey of Canada has carried out two major regional geochemical-heavy mineral surveys in Keno Hill area, Yukon Territory and Bathurst area, New Brunswick. In the process of doing this work certain field techniques were developed that greatly aided the efficiency of the operations.

A geochemical field jacket was designed to carry the necessary geochemical equipment for reconnaissance stream sediment and water surveys. The jacket is described in this paper. It was found that by using such equipment the geochemical surveys were carried out with greater speed and efficiency than would otherwise have been possible.

Gleeson, C.F. *et al.*
1965: Heavy metal content of stream and spring sediments and stream and spring waters, Keno Hill area, Yukon Territory; *Geol. Surv. Can.*, Maps 18-1964 to 31-1964.

Boyle, R.W. *et al.*
1966: Geochemistry of Pb, Zn, Cu, As, Sb, Mo, Sn, W, Ag, Ni, Co, Cr, Ba, and Mn in the waters and stream sediments of the Bathurst-Jacquet River district, New Brunswick; *Geol. Surv. Can.*, Paper 65-42.

13. BIOGEOCHEMICAL PROSPECTING METHODS

E.H. Hornbrook

To demonstrate the scope and effectiveness of biogeochemical prospecting methods, an investigation was carried out on a lead deposit in the vicinity of Silvermine, Cape Breton Island. The deposit occurs at, and adjacent to, the contact of the Mississippian-Pennsylvanian sedimentary rocks and is overlain by a few tens of feet of glacial till. Samples of soil and vegetation were collected in 1966 from 45 stations on a traverse line oriented at right angles to the contact over the deposit. The prepared samples have since been analyzed by colorimetric and spectrographic methods.

The biogeochemical prospecting method was successful in detecting the previously known lead deposit overlain by glacial till by means of anomalous concentrations of lead and associated elements in tree organs such as bark or twigs. An examination of all the analytical data shows that barium has a greater response than lead in tree organs, suggesting that barium be used as a pathfinder element in biogeochemical prospecting for lead in deposits of this type.

14. CONVERSION OF DIRECT READING SPECTROMETER TO DIGITAL OUTPUT IN QUANTOGRAPH LABORATORY

R.E. Horton and F.W. Jones

The conversion of the A.R.L., 'Quantograph', direct reading spectrometer to digital output has been completed. The integrated light energy falling upon the photomultiplier tubes was originally measured by a chart recorder. This has been replaced by a Hewlett Packard digital voltmeter model 3440A which is coupled to an IBM 024 card punch by a Dymec model 2540B coupler. The cards are then used as input for the departmental computer which calculates the concentration in per cent of the elements. This has resulted in a considerable saving in time compared to manual reading and calculation from the strip chart recorder and has, of course, eliminated transcription errors. An added benefit is that the digital voltmeter measures precisely over a much greater range than the chart recorder. This allows an increase of an order of magnitude in the analytical range at any particular setting of the element channel controls.

15. DETERMINATION OF SOME TRACE ELEMENTS IN SPHALERITE AND GALENA BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

J.J. Lynch

Atomic absorption spectrophotometry was found to be a very useful means of determining trace elements in galena and sphalerite. Zn, Cu, Ni, Co, Cd, Fe, Mn and Cr were determined in galena and Cu, Pb, Ni, Co, Ag, Cd, Fe, Mn, and Cr were determined in sphalerite. The instrumental estimation of these elements was very rapid and a high degree of precision was obtained on replicate analyses. In order to assess the accuracy of the technique, known amounts of standard solutions were added to a number of samples. Recovery of the added standards ranged from 84 to 110 per cent with an average recovery of 99 per cent. While the actual determination is done very rapidly, sample decomposition was found to be time consuming for both minerals and the procedure for galena produced a solution which was unsuitable for the determination of silver due to the loss of this element by precipitation. Work on this problem is continuing.

The galena samples were decomposed in the following manner. A 250 mg sample was weighed and transferred to a 50 ml beaker. Ten ml concentrated hydrochloric acid were added and the mixture was allowed to stand overnight, after which the hydrochloric acid was fumed off; the lead sulphide was thus converted to lead chloride. Five ml concentrated nitric acid were added and the solution evaporated to dryness. This step was repeated twice more, to convert the lead chloride to soluble lead nitrate. The residue from the nitric acid treatment was dissolved in 5 ml of 2.5 N nitric acid and transferred to a 25 ml volumetric flask. The beaker was rinsed with a further 5 ml of nitric acid, followed by several rinsings with metal free water; the rinse water was added to the volumetric flask and the solution was diluted to 25 ml and mixed to give a test solution that was 1 N with respect to nitric acid. The standards used to calibrate the instrument were also prepared in 1N nitric acid, and contained 13.8 mg/ml of $Pb(NO_3)_2$ which approximates the concentration of the $Pb(NO_3)_2$ in the sample solution. The addition of the $Pb(NO_3)_2$ to the standards was not found to be absolutely necessary; omission of the $Pb(NO_3)_2$ resulted in an enhancement of the signal of not more than 3 per cent, presumably due to the more efficient aspiration of the standard solution without $Pb(NO_3)_2$.

The following procedure was used for the decomposition of sphalerite. Weigh a 250 mg sample into a 25 ml platinum crucible and add 2 ml of concentrated hydrofluoric acid and 3 ml of concentrated perchloric acid. The addition of hydrofluoric acid will hasten the decomposition of the zinc sulphide. Heat the mixture on a sand bath until copious white fumes are produced. Wash down the sides of the dish with metal free water. Repeat the fuming and washing twice more and then fume to dryness. Add 5 ml of 2.5 N nitric acid to the dry residue, warm to dissolve the salts, and then transfer this solution to a 25 ml volumetric flask. Repeat this step as above, and finally rinse the dish two or three times with metal free water, adding these washings to the volumetric flask; dilute to 25 ml. Standard solutions are prepared similar to those used for the galena analyses, with zinc sulphate being added to each standard (29.6 mg $ZnSO_4 \cdot 7H_2O$/ml) to simulate the composition of the sample solution. This is not an exact approximation as the decomposition of sphalerite as described does not quantitatively convert the zinc sulphide to zinc sulphate. Some hydrogen sulphide is evolved during the acid digestion and presumably the final test solution is a mixture of zinc sulphate and zinc perchlorate; the determination of sulphate in a number of test solutions showed that only 50-70 per cent of the zinc sulphide was converted to zinc sulphate. As in the analyses of galena, the omission of zinc sulphate from the standards caused only a small error.

16. THE DETERMINATION OF SOME TRACE ELEMENTS IN WATER

J. J. Lynch

In connection with geochemical studies carried out in the Cobalt area of northern Ontario by R. W. Boyle, rapid methods for the determination of Cu, Pb, Ni, Co, Ag and Cd in the parts per billion range in water were devised. The method for the determination of these six elements consists of pre-concentration by solvent extraction and aspiration of the organic solution into the flame of a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer. Ten ml of a buffer solution (288 grams of citric acid and 17.6 grams of sodium hydroxide in one litre of solution) are added to a 100-ml water sample in a 250-ml separatory funnel. When diluted with 100 ml of water the pH of the resulting solution should be 2.8-2.9; if the water sample had been previously acidified it should first be neutralized with 2 N ammonium hydroxide before the addition of the buffer. To the separatory funnel add 2 ml of an aqueous solution of 1 per cent ammonium pyrrolidine dithiocarbamate, and mix. Add 10 ml of methyl isobutyl ketone and extract for 30 seconds. Allow the two layers to separate; drain and discard the aqueous layer. Drain the organic layer into a 15 ml centrifuge tube and centrifuge for 3 minutes in order to free the solvent of entrained aqueous solution. The solvent is then aspirated into the instrument. Since methyl isobutyl ketone is a combustible solvent, the fuel flow to the burner must be greatly reduced from that which would be ordinarily employed for aqueous solutions. Reference standards are prepared by adding measured volumes of standard solutions of each metal to 100 ml of metal-free water and proceeding as outlined above. The sensitivities found for the six elements are as follows:

Cu	1 ppb
Pb	5 ppb
Ni	1 ppb
Co	2 ppb
Ag	0.5 ppb
Cd	0.5 ppb

17. A SAMPLE SITE TEST FOR THE DETERMINATION OF NICKEL IN WATER

J. J. Lynch and Dianne K. Church

In order to study the distribution of nickel in surface and groundwaters of the Cobalt area of northern Ontario, a rapid sample site test for the determination of nickel in water was devised. The method described here is an adaptation of that described by Stanton and Coope for the determination of nickel in soils and rocks.

The method consists of buffering the water to ~pH 10 and reacting the nickel with a benzene solution of α-furildioxime. The nickel is extracted into the benzene layer and its concentration is estimated by comparing the intensity of the coloured nickel complex with artificial standards contained in small glass vials.

The buffer solution for the test is prepared by dissolving 20 g of triammonium citrate in metal-free water, adding 130 ml concentrated ammonium hydroxide and diluting to one litre. The α-furildioxime solution is prepared by dissolving 0.3 g of reagent in 10 ml absolute ethyl alcohol and diluting to 100 ml with benzene. This solution should be prepared weekly.

The nickel is determined by the following procedure. To 50 ml of water contained in a 100 ml graduated cylinder add 5 ml of buffer solution. Add 5 ml of α-furildioxime solution, stopper the cylinder and shake vigorously for two minutes. Allow the layers to separate and compare the colour intensity of the benzene phase with artificial standards. The following table shows a comparison of those results obtained on the sample site with those obtained by atomic absorption spectrophotometry.

Sample Number	Ni, ppb Sample Site	Ni, ppb Atomic Absorption
250001	70	52
250014	10	5
250037	30	18
260001	70	73
260007	1250	600
260017	5	4

The artificial standards are prepared by reading known amounts of nickel with α-furildioxime to produce the characteristic colours in the solvent phase. Coloured aqueous solutions are then prepared to match the intensity of the colours produced in the benzene layers. The analyst is free to choose any convenient set of concentration; those employed in this program corresponded to 0, 10, 20, 50, 100 and 200 ppb nickel in the water sample. Into six 100 ml graduated cylinders pipette 0.0, 0.1, 0.2, 0.5, 1.0 and 2.0 ml of a standard nickel solution ($5 \mu g/ml$). Dilute to 50 ml with metal-free water and proceed as in the test. The colours produced range from colourless through an increasingly intense yellow colour with increasing concentrations of nickel. The artificial standards corresponding to 10, 20, 50, and 100 ppb nickel are prepared by adding varying amounts of yellow drawing ink to metal-free water contained in glass screw-cap vials of 1-dram capacity (15 by 45 mm). Lemon extract is used for the 200 ppb nickel standard. Other types of colouring material may be used provided that the colours do not fade. The artificial standards described here are stable for one month but should be checked against known nickel solutions every two weeks.

Stanton, R.E., and Coope, J.A.
1958: Modified field test for the determination of small amounts of nickel in soils and rocks; Trans. Inst. Mining Met., vol. 68, Part 1, pp. 9-14.

18. CHEMICAL CHARACTER OF LEAD-ZINC DEPOSITS IN CARBONATE ROCKS

D.F. Sangster

The common major elements in lead-zinc deposits are Pb, Zn, Fe, Cu, and S. Of these, Pb, Zn, and Cu occur almost entirely as independent minerals. Iron is present in pyrite, marcasite, pyrrhotite, magnetite, chalcopyrite, and sphalerite; sulphur is, of course, common to all the sulphides. Hence, the definitive geochemical character of a lead-zinc deposit can be conveniently expressed in terms of its Cu-Pb-Zn ratio. The molecular ratios of these three elements in 24 lead-zinc deposits in carbonate rocks, representing all available data, are shown in Figure 1. Most of these are Canadian deposits but a few of the classical 'Mississippi Valley Type' of ores from other parts of the world have been included. From this plot, it is apparent that orebodies in the Cu-Pb-Zn 'system' occurring in carbonate rocks are almost entirely devoid of copper and show a strong tendency to be much richer in zinc than in lead (when expressed as molecular abundances). Copper-rich deposits in carbonate rocks are extremely rare, even on a world-wide basis.

Although it is commonly much less abundant than the elements mentioned above, silver is an economically important minor element in many lead-zinc deposits. Furthermore, it can occur as a "sweetener" in any of the three independent ore minerals in the Cu-Pb-Zn 'system'. Examination of the Pb-Zn-Ag ratios in 27 deposits (again mostly Canadian and limited by available data) reveals that high-silver deposits are generally those with a Zn-Pb molecular ratio greater than 2 (Fig. 2).

The orebodies represented in Figure 2 may be divided into three main types on the basis of co-existing minerals. Type I, with the lowest amount of silver, consists mainly of sphalerite and galena with subordinate amounts of other sulphides. Silver occurs in solid solution in the lead-zinc minerals. Type II, with intermediate silver content, contains copper and iron sulphides in addition to sphalerite and galena although, as demonstrated in Figure 1, the copper content rarely exceeds a few mol per cent. Silver in Type II deposits is partitioned between sphalerite, galena, chalcopyrite, and possibly pyrite. Type III orebodies, with the highest silver content, are characterized by the appearance of independent silver minerals which, of course, account for most of the silver content of these ores. Thus the trend is from Type I deposits with simple galena and sphalerite mineralization, through Type II with the addition of silver-bearing chalcopyrite, to Type III with sphalerite, galena, chalcopyrite, plus independent silver minerals.

From this preliminary examination of the geochemistry of lead-zinc deposits in carbonate rocks, it appears that Types I and II (Fig. 2) represent

Figure 1. Relative abundances of Cu-Pb-Zn in lead-zinc deposits occurring in carbonate rocks.

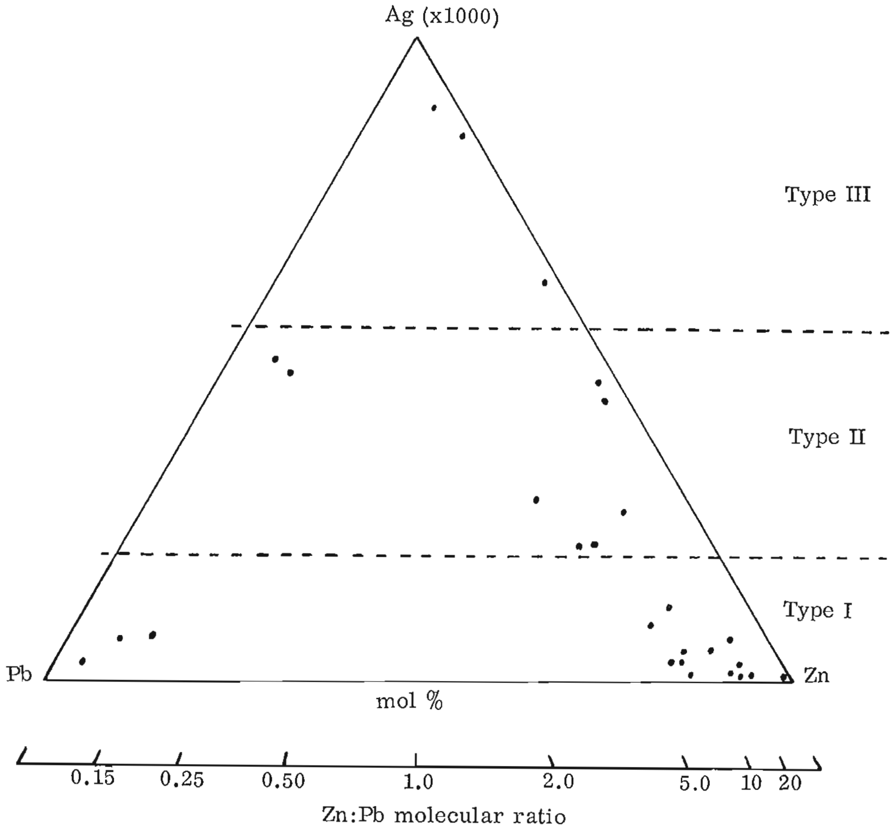


Figure 2. Relative abundances of Pb-Zn-Ag in lead-zinc deposits occurring in carbonate rocks. See text for explanation of three-fold grouping.

orebodies in the Cu-Pb-Zn 'system' which are undersaturated or just saturated with respect to silver. Type III bodies appear to be oversaturated in silver, giving rise to the appearance of independent silver minerals.

19. RELATIVE SULPHUR ISOTOPE ABUNDANCES IN STRATA-BOUND SULPHIDE DEPOSITS

D.F. Sangster

Average sulphur isotope abundances of 58 strata-bound sulphide deposits, occurring in rocks ranging from Precambrian to Tertiary, have been compiled. These averages were compared with published isotopic compositions of sulphides in the corresponding seas. For all deposits, the average relative sulphur isotope abundance in the ores parallel those of contemporaneous ocean water.

The data support the theory that all or most of the sulphur in strata-bound sulphide deposits was derived from ocean water sulphate and was reduced to sulphide by bacterial action.

The study demonstrates that average sulphur isotope abundances of strata-bound deposits should be compared with those of parental sulphate in ancient seas.

20. GEOCHEMICAL PROSPECTING TEST FOR TIN

A. Y. Smith

The standard, widely applied geochemical prospecting test for tin in soils and stream sediments developed by Wood (1956) and modified by Stanton and McDonald (1961), has frequently presented difficulties in application. Certain modifications are reported here which improve the operation of the test and eliminate most of the difficulties.

In the colorimetric test for tin described by Stanton and McDonald, samples are attacked with ammonium iodide, dissolved in dilute HCl and an aliquot taken for determination. Determination of tin is made in a chloroacetate-chloroacetic acid buffer with a pH of 2.65. The buffer contains hydroxylamine hydrochloride to reduce any iodine to iodide, and to maintain iron in the ferrous state. Gallein is added and reacts with tin to impart a pink colour to the solution. This colour is compared with standards and the amount of tin in the original sample is calculated.

Difficulties in the method stem from two sources. Firstly, the pH of the buffer is somewhat higher than that recommended by Wood (2.0-2.5), which occasionally results in the oxidation of iron to the ferric state where it can react with gallein to form a purple reaction product. This difficulty is overcome by lowering the pH of the buffer to approximately 2.4. Secondly, the reducing agent, hydroxylamine hydrochloride, is rather unstable and tends to deteriorate with time. Accordingly, ascorbic acid has been substituted for hydroxylamine hydrochloride with very satisfactory results. One further modification has been made to the test of Stanton and McDonald which has been found helpful. The presence of iodide has been found to affect the colour of the gallein added to the buffer solution. When iodide is added to the standards in the same concentration as in the sample solutions the matching of standards with samples is considerably easier.

The modified buffer solution is made as follows: Dissolve 15 grams sodium hydroxide in 400 ml of metal-free water in a beaker calibrated at 1 litre. When dissolved, cool this solution to below 20°C. Dissolve 106 grams chloroacetic acid in 400 ml of metal-free water. Immerse the beaker containing the NaOH solution in a cold water bath and slowly add the chloroacetic acid solution while stirring, keeping the temperature around 20°C. When mixing is complete add 5 grams of ascorbic acid, stir to dissolve and dilute to 1 litre with metal-free water. This buffer has a pH of approximately 2.4. The life of the buffer is increased, and yellowing of the solution due to decomposition of ascorbic acid is avoided by keeping in a cool dark place, preferably in a refrigerator.

Wood, G.A.
1956: Determination of tin in soils; 20th Int. Geol. Cong., Mexico, 1956 Resumenes de los Trabajos Presentados, 380.

Stanton, R.E. and McDonald, A.J.
1961: The determination of tin in geochemical soil and stream sediment surveys; Trans. Inst. Mining Met. London, 1961/1962, vol. 71, p. 27.

ANALYTICAL CHEMISTRY

21. ATOMIC ABSORPTION SPECTROSCOPY

Sydney Abbey

This new technique has been adapted to the accurate determination of magnesium in rocks and to the combined determination of magnesium and total iron in a single solution representing as little as five milligrams of sample of certain minerals. The method has also been used for determining lithium and zinc as traces in silicates. A Geological Survey Paper describing these applications is now in press.

Further work, partially completed, suggests future applications in rapid rock analysis, precise rock analysis and special determinations. Thus magnesium and sodium can be determined rapidly on a single solution where X-ray fluorescence is not applicable. Current experiments indicate that the classical determinations of calcium, magnesium, potassium, sodium (and possibly manganese) can be replaced by atomic absorption methods for most types of rocks, with great saving of time and no loss of accuracy. It is also expected that present methods for strontium, barium, rubidium and cesium, all of which require chemical separations, will be replaced by atomic absorption methods, applicable directly on the solution of the entire sample.

Additional accessory equipment for the atomic absorption spectrophotometer has been ordered to facilitate implementation of these new methods.

22. X-RAY FLUORESCENCE ANALYSIS

S. Courville

A rapid procedure for the simultaneous determination of the eight major constituents of rocks (Fe, Mn, Ti, Ca, K, Si, Al, Mg) by X-ray fluorescence spectroscopy, is now in routine use. A pellet is prepared by mix-grinding 1.7 grams of the rock powder with 0.3 gram of boric acid, for four minutes. The sample disc is then exposed to X-radiation for three one-minute periods. The averaged intensities are then converted to percentages. Major interelement effects in Fe, Al and Si are corrected by the application of factors derived from the Lachance-Traill formula.

The following table illustrates the precision and accuracy obtainable, at the 66 per cent confidence level (1 standard deviation) for each of the constituents determined by this method:

	Precision	Accuracy
Fe_2O_3	0.06 %	0.4 %
MnO	0.005%	0.03%
TiO_2	0.015%	0.05%
CaO	0.10 %	0.4 %
K_2O	0.03 %	0.1 %
SiO_2	0.80 %	1.2 %
Al_2O_3	0.30 %	1.0 %
MgO	0.30 %	0.5 %

A batch process makes it possible for two technicians to prepare and read 32 discs per day – a typical batch includes four standards, two laboratory reference samples and twenty-six samples.

MINERALOGY

23. RETENTION OF ARGON IN DEHYDRATED BIOTITES

J. Y. H. Rimsaite

Partly to completely dehydrated biotites were prepared from a homogeneous mica concentrate in order to study the properties of, and the retention of argon in, the dehydrated biotites. The present experiments confirmed previous observations on natural biotites. The following conclusions drawn from the results of this study are of considerable geological and geochemical interest:

(1) dehydrated biotites lose radiogenic argon and retain potassium;

(2) biotite heated in air loses less radiogenic argon than does biotite heated in vacuum and in an inert argon atmosphere;

(3) the quantity of argon lost cannot be directly correlated with temperature and degree of dehydration;

(4) argon can be introduced into the biotite by heating mica in an argon atmosphere;

(5) the results are applicable only to micas of similar chemical composition.

More detailed data on dehydration experiments and on the physical properties of the dehydrated micas are given in a paper prepared for publication in Clays and Clay Minerals, Proceedings of the Fifteenth National Conference, Pergamon Press, Ltd., Oxford, England (pp. 375-393).

Similar experiments are in progress on muscovite and phlogopite.

DATA PROCESSING

24. PHOTO NEGATIVE INDEX

K.R. Dawson

A card-oriented Electronic Data Processing System has been developed and placed in operation to replace the 3" x 5" card index to the Geological Survey Photonegative File. The new index, which is in book form, will be revised annually with quarterly supplements. The system is based on a concept list that will provide a more comprehensive cross-referencing scheme than the one available. Field officers are being asked to supply 4 to 6 concepts instead of a title consisting of two or three sentences for those negatives recommended for retention.

In practice the field officer will receive blank index forms when his negatives have been developed, printed, and returned. Negatives recommended for retention will be identified and indexed using the index form. The roll and exposure numbers, the decade and year in which the pictures were taken, and 4 to 6 concepts, will be entered depending upon the subject of the picture. The completed forms are returned to the Photo Librarian who will assign accession numbers and edit the list of concepts. The contents of the sheets are keyed into IBM cards, sequenced by accession number and listed. The list is edited, cards are corrected and the file is sequenced checked. Two lists are printed, the first sequenced by accession number, and the second sequenced alphabetically by the concepts. These are given to the Photography Section and they become the working index to the negative file. A search for specific negatives will be made through a book rather than through the drawers of a 3" x 5" card cabinet.

25. PRODUCTION OF PAPER 66-17

K.R. Dawson

An Electronic Data Processing System has been developed to semi-automate the printing of the Geological Survey K/Ar Age Report (Paper 66-17). The text is printed on 35-row, 80-column spread sheets, keyed into IBM cards, processed by unit record equipment and finally listed on white paper suitable for photolithography. The first edition was placed in the hands of the Survey's editors in December 1966.

All lines of text and spacer cards were suitably numbered to permit sequencing by province or territory, laboratory and the final publication number. The line length was limited to 64 characters and the page length to a total of 57 lines. The right margin was evened up and the left margin indentations for paragraphs were controlled by the positions of the text on the IBM cards. The 407 printer limited the type to capitals and made some compromises necessary in the characters used for punctuation purposes. The text of the report was keyed once into IBM cards with the exception of corrections. Chapters, paragraphs and lines were positioned by machine and listed on the printer.

The text was keyed in once thus avoiding a retyping of the whole of the manuscript, and errors were corrected simply by replacement of defective cards. The text units were then adjusted in their final position by means of the index number using the sorter or collator. The final print run was made after the pages were adjusted and, at the same time, the page number and name of the province or territory were printed at the top of the page. The control numbers were repressed so they did not appear on the final copy.

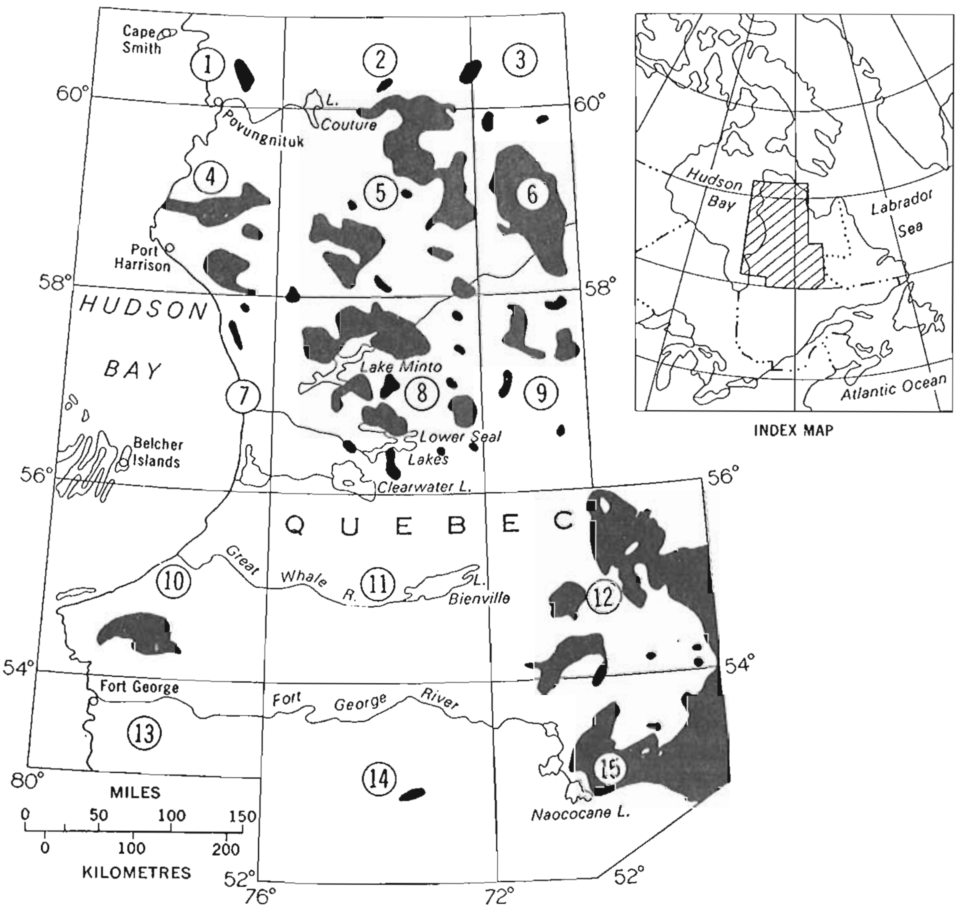


Figure 1. Areas of hornblende-granulite facies (black) and areas of amphibolite facies (unshaded) in New Quebec. (To accompany paper 26)

PRECAMBRIAN SHIELD GEOLOGY

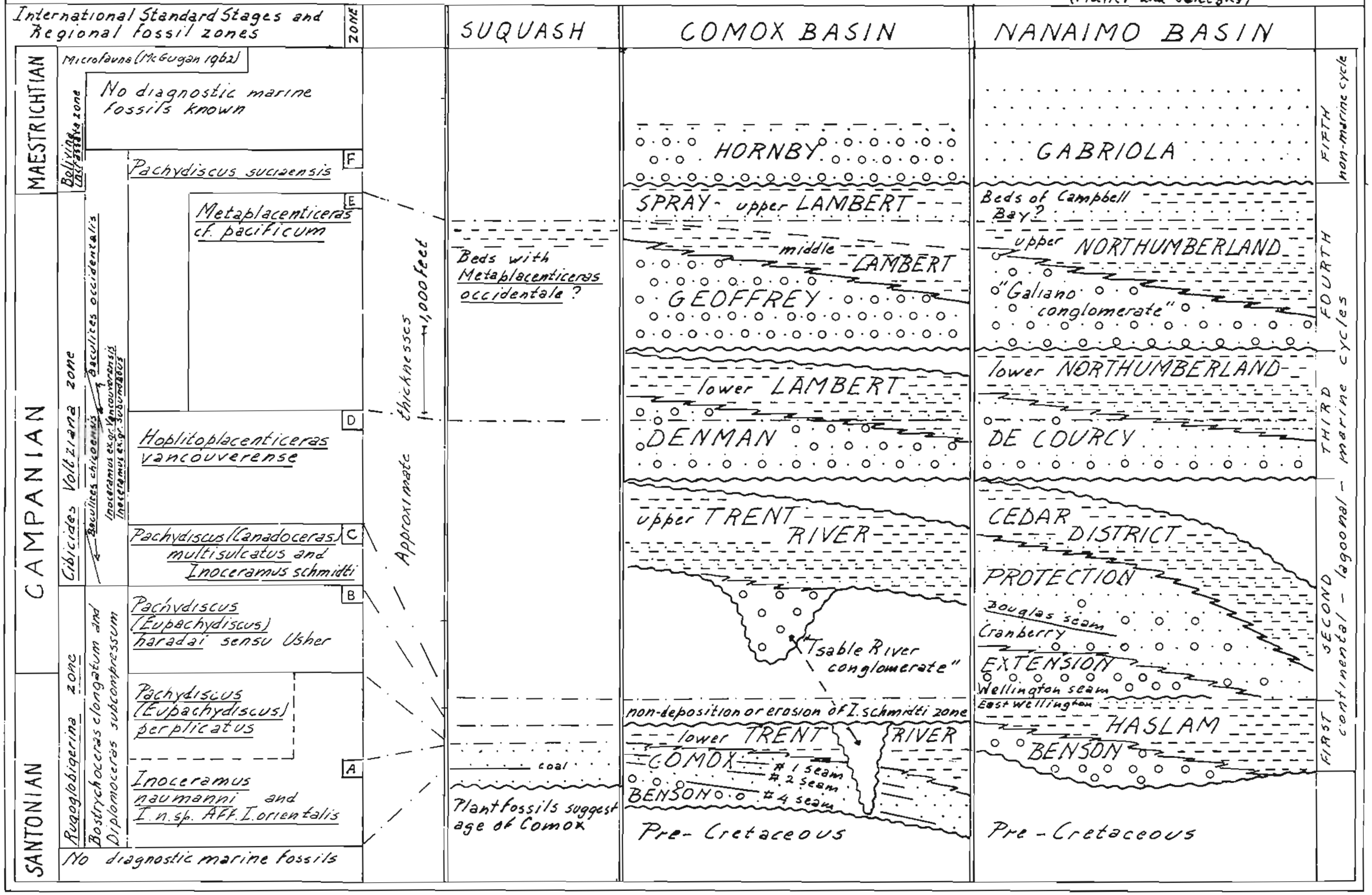
26. ABUNDANCE OF RADIOACTIVE ELEMENTS IN CRYSTALLINE SHIELD ROCKS

W.F. Fahrig, K.E. Eade and J.A.S. Adams

The average radioactive element abundances of the surface crystalline rocks of 200,000 square miles of Archaean gneiss in New Quebec have been determined. The values obtained are as follows: Th = 9.2 p.p.m., U = 1.1 p.p.m. and K = 2.3%. Th, U, and K are all less abundant in those rocks of the area that are of hornblende-granulite-metamorphic grade than they are in corresponding rocks of amphibolite grade (see Fig. 1) and Th/U ratios are higher in rocks of granulite facies than they are in rocks of amphibolite facies. These variations are attributed to fractionation of radioactive elements during deep-seated regional metamorphism. As the gneisses of New Quebec probably represent a deep crustal zone, the abundances of the radioactive elements in the surface rocks of this area may approach the abundance of these elements in the continental crust. Data on the abundance of these heat producing elements are useful in explaining heat flow in this part of the Shield. Radioactive element abundances have also been obtained for a number of other areas of the Shield which total some 200,000 square miles. These areas are of diverse ages and geological histories and their radioactive element values exhibit interesting contrasts with the values obtained for New Quebec.

A paper by W.F. Fahrig, K.E. Eade and J.A.S. Adams on the abundance of radioactive elements in the Shield of northern Quebec was published in Nature vol. 214, pp. 1,002-1,003.

Figure 1 Biochronological and lithological subdivisions of the Nanaimo Group, Vancouver Island and Gulf Islands. (Muller and Jeletzky)



CORDILLERAN GEOLOGY

27. STRATIGRAPHY AND BIOCHRONOLOGY OF THE NANAIMO GROUP, VANCOUVER ISLAND AND GULF ISLANDS, BRITISH COLUMBIA

J.E. Muller and J.A. Jeletzky

The writers have undertaken a re-examination of the Upper Cretaceous Nanaimo Group of western British Columbia, in the course of regional mapping on Vancouver Island by Muller since 1963 and stratigraphic-palaeontological studies by Jeletzky since 1965.

Coal seams in the Nanaimo Group have been mined for over 100 years, and geological reports date back to 1857, but the main field mapping was done by J. Richardson, J.D. MacKenzie, T.B. Williams, C.H. Clapp, A.F. Buckham and J.L. Usher, all in the service of the Geological Survey of Canada. The stratigraphic succession was originally worked out on lithology and Usher (1952) was the first to recognize faunal zonation. Later studies of micropalaeontology by McGugan (1962) and palaeobotany by Bell (1957), followed by the work of the present writers established with varying degrees of accuracy the lithological and biochronological sequence.

The Nanaimo Group is here divided into four complete transgressive cycles of sedimentation, starting with non-marine beds and grading up to a marine formation. They are similar to Upper Cretaceous formations on the eastern side of the Cordillera in general lithology and intertonguing relationships of marine and non-marine beds (e.g. Young, 1955). Young defined the megacyclothems of the Utah Upper Cretaceous as developing from marine shale at the bottom through littoral marine sandstone to lagoonal deposits with coal at the top indicating a regressive cycle. So far as can be judged from available information the Nanaimo Group shows this cycle in reverse, indicating gradual transgression.

The successive facies of the Nanaimo Group may be distinguished as follows: The Benson-type facies are fanglomerates and associated greywackes occurring in irregualr lenticular masses of small areal extent and extremely variable thickness. The components are unsorted subangular boulders, pebbles and grit, mainly of pre-Cretaceous volcanic material. Granitic clasts are locally rare even on a granitic substratum. Bedding is generally difficult to detect and the beds are dark green and brown. The material has been transported over only a short distance and the deposits are probably basal conglomerates, formed along shoreline cliffs during transgression or in in-shore valleys and canyons. The Benson Formation, basal to the Nanaimo Group, and some red conglomerates on Pender Island assigned to the Extension Formation, are representatives of this facies.

The Extension-type facies is another kind of coarse clastic facies where conglomerate, pebbly sandstone and arkosic sandstone are interbedded. The components are well-worn and well-sorted and consist mainly of resistant rock types like white quartz, black argillite and light green or grey chert. The sandstones are commonly crossbedded and consist mainly of quartz, feldspar, biotite and hornblende. It is suggested these rocks were transported and reworked along beaches by marine currents and finally came to rest in an environment of deltas and shore bars. In several instances such conglomerates derived from distant sources are mixed with larger, more angular clasts of Sicker-schist and volcanic or granitic rocks of nearby origin. The contrast between well-rounded quartz and chert and larger, subangular clasts of less resistant rocks is, in many instances, striking. It is most prominently displayed in the 'Galiano conglomerate' where single blocks of schist up to 6 feet in size have been noted within generally much finer conglomerate. The admixture was probably carried in by the local streams, the large blocks perhaps in the roots of trees carried down during floods. The Extension, the 'Tsable River conglomerate', the Denman, Geoffrey and the 'Galiano conglomerate' are mainly of this facies.

The Comox-type facies, a variant of the Extension-type facies, is represented by Comox, Wellington and Protection Formations. The clastic material is also quartzo-feldspathic, but it generally lacks the conglomeratic phase. On the other hand it contains numerous intercalations of carbonaceous shale and coal, here and there carrying plant fossils. This facies, which contains the coal seams of the Nanaimo Group, is thought to have originated in lagoons and swamps, closed off from the sea by shore bars. The rather special conditions occurred only at one time interval in the Comox Basin and again at a later time in the Nanaimo Basin. Formations belonging to this facies are the Comox, the Wellington and the Protection. The similarity of the facies of the Comox and Protection Formations readily explains why they were erroneously correlated by earlier workers.

The Haslam-type facies, represented by the lower few hundred feet of the Haslam, Trent River and Cedar District Formations is a littoral facies. The beds are massive, poorly bedded sandy shales and shaly sandstone with generally abundant fossils indicating near-shore deposition. These beds were laid down at shallow depths subject to disturbance by wave action.

Most of the Northumberland Formation and much of the Cedar district consist of typical turbidite sequences. They are varved fine-grained sandstones, siltstones and shales in which individual graded units are 1/4 inch to 6 inches thick. Individual units commonly exhibit complex overturned slump-folds between undisturbed subjacent and superjacent units. The slumps which occur in units ranging in thickness from less than 1 inch to several feet reflect sliding of the latest layer of sediments down the ancient sea floor, and thus are useful to determine the direction of the paleoslope of the basin. Distance of movement of these 'dimunitive overthrusts' ranges from a few inches for thin units to as much as 10 feet for sandstone beds of about one foot thickness. Similar structures in the coal seams were described by Clapp (1914), who attributed them to local folding and faulting. Predominantly shaly sections are also varved in units, 3 inches to 2 feet thick, consisting mainly of massive shale, but with a bottom layer of fine sand and silt less than 1/4 inch in thickness. Fossils in these rocks are quite rare and are always found at the parting of two varves. Calcareous concretions are locally common and may be products of diagenesis.

This facies was deposited in deeper water than the Haslam facies below the wave base where wave action could not destroy the fine laminations and intricate convolutions of the sediments. Each unit probably resulted from a flood of suspended material carried down the seaslope from the near-shore area, set in motion by a storm or similar trigger mechanism, and settling in ordered fashion according to the relative settling velocities. The rare remains of pelagic molluscs sank to the bottom in intervening times.

Though not all these facies may be found in one single section, the general progression from the shallower to the deeper facies may be recognized in each cycle. Slow subsidence of the basin was apparently not quite compensated by sedimentation and ultimately was interrupted by rapid re-emergence, generally not accompanied by sedimentation, and thereafter a new cycle followed. The lithological succession is schematically represented on the right hand side of Figure 1. Each cycle is shown with a horizontal base and with approximate thicknesses. Northeastward thinning of conglomerate-sandstone units coupled with thickening of siltstone-shale units is shown from left to right, but the apparent widening of the break between cycles in that direction is not truly representative; rather it is believed that the marine shale units may merge in the deepest part of the basin (see Fig. 2).

The biostratigraphic work by Jeletzky started from the basic palaeontologic work by Whiteaves and Usher. The faunal succession of many species of inoceramus was found to substantially complement Usher's zonation of ammonites and the latter was revised in some instances. The following zones and subzones were established:

G : Pachydiscus (Pachydiscus) suciaensis zone, upper part
F : Pachydiscus (Pachydiscus) suciaensis zone, lower part
E : Hopliplacenticeras vancouverense zone
D : Pachydiscus (Canadoceras) multisulcatus – Inoceramus schmidti zone
C, B, A : Bostrychoceras elongatum – Diplomeceras subcompressum zone
  C : Pachydiscus (Eupachydiscus) haradai sensu Usher subzone
  B : Pachydiscus (Eupachydiscus) perplicatus subzone (?)
  A : Inoceramus naumanni – I. n. sp. aff. orientalis subzone

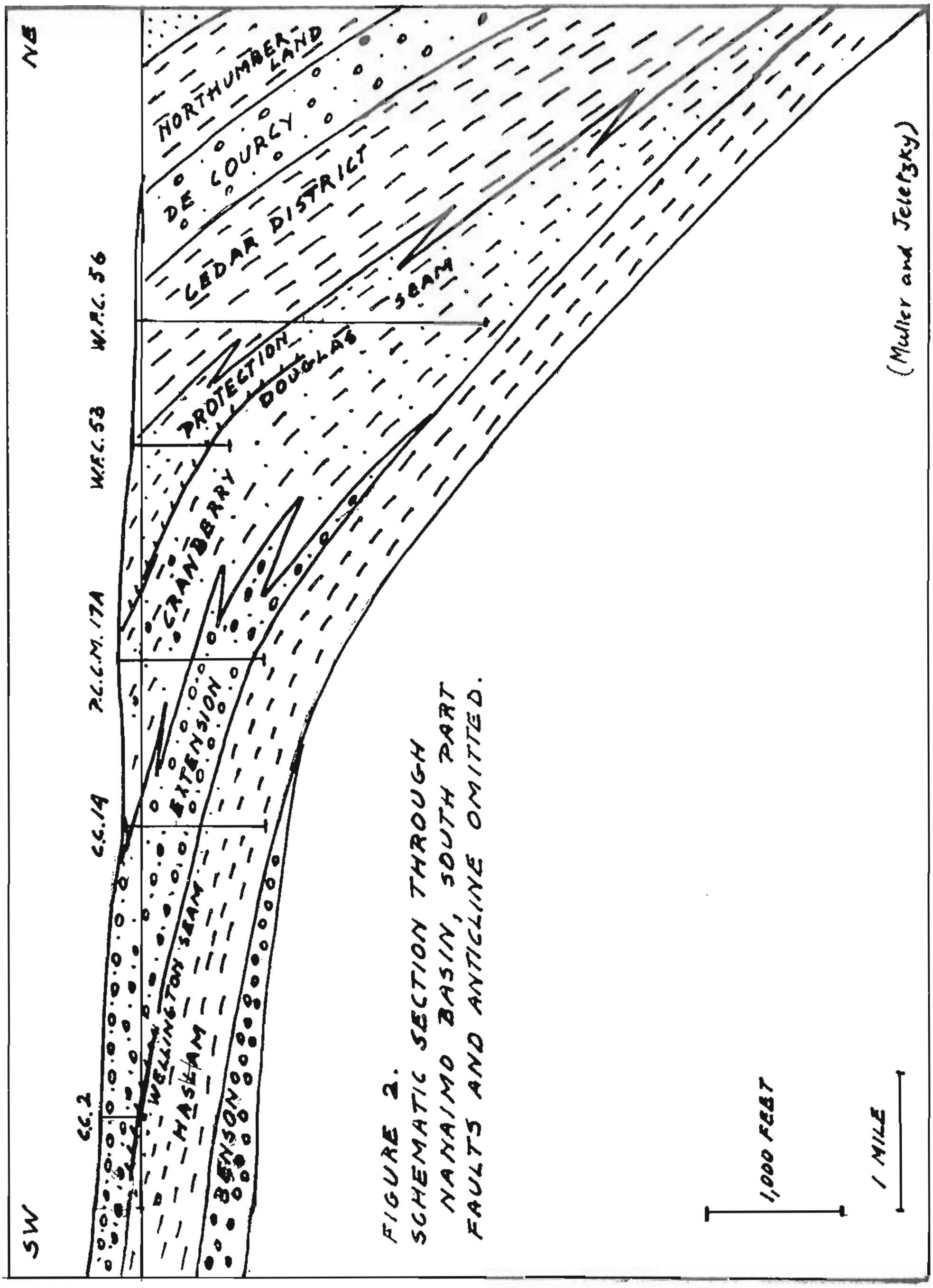


FIGURE 2.
SCHEMATIC SECTION THROUGH NANAIMO BASIN, SOUTH PART
FAULTS AND ANTICLINE OMITTED.

The zones are shown in Figure 1 and their faunal content in Table I. Zones A and B are assigned to the Santonian, C, D, E, and F to the Campanian and only G to the Maestrichtian International Standard Stage.

The lower zones A, B, C, and D of Haslam and Trent River Formations are exposed mainly on Vancouver Island streams and far more material was collected and studied from them than from the higher zones. The latter are mainly exposed along the shores of the Gulf Islands, where Usher's collections and determinations were mainly used. Apart from intentional emphasis in the writers' work on these lower formations this is also due to the sparse occurrence of fossils in the younger shale formations, consisting mainly of turbidites and to the constant raiding of these easily accessible locations by tourists and amateur geologists. Some revisions were made in previously published formational sequences (Table II).

The Qualicum Formation was earlier believed to underlie the Comox Formation. However, the Comox is missing in the Qualicum area and the "Qualicum" underlies the Nanaimo coal measures. On Little Qualicum River it lies directly on granitic rock and contains Inoceramus naumanni (Zone A) fauna. At Northwest Bay it contains Inoceramus schmidti (Zone D) fauna in sandy shale facies. The Qualicum is therefore equivalent to the Haslam, in the first depositional cycle.

The traditional correlation of Comox and Nanaimo coal measures is in error; the former is in the first depositional cycle (faunal Zone A), the latter in the second cycle (faunal Zones D to E).

A 'Tsable River conglomerate', known from drill holes and some outcrops is believed to separate the Trent River Formation in lower and upper parts, equivalent to Haslam and Cedar district Formations. It occurs only locally and is missing on Trent River.

A "Galiano conglomerate" occurring on parts of Galiano and Mayne Islands divides Northumberland Formation in lower and upper parts, and with a tentative revision of the Hornby Island sequence, the Geoffrey conglomerate is placed between lower and middle Lambert Formation.

The Spray Formation and the upper part of the Lambert, both containing a Maestrichtian microfauna (McGugan, 1962) are probably identical and may be correlative to a shale formation occurring in Campbell Bay on Mayne Island.

The existence of at least two main basins of deposition, the Comox and Nanaimo Basins was soon recognized by early workers. However, formerly it was assumed that sedimentation started earlier in the Nanaimo Basin, and that formation of coal was more or less concurrent in both basins. New faunal zonation has proved the reverse; sedimentation started

TABLE I. AMMONITE AND INOCERAMUS FAUNA OF NANAIMO GROUP

ZONES	A	B	C	D	E	F		A	B	C	D	E	F
Anisoceras cooperi Gabb	-	-	-	-	X	X	Inoceramus ex gr. vancouverensis Shumard	x	x	x	X	-	-
Baculites chicoensis Trask sensu Usher	x?	x	x	X	x	-	Metaplacenticeras cf. pacificum (Smith)	-	-	-	-	x	-
Baculites occidentalis Meek sensu Usher	-	-	-	x?	X	X	Neophylloceras ramosum Meek	-	-	-	-	X	X
Botrychoceras elongatum (Whiteaves)	X	X	-	-	-	-	Nostoceras hornbyense (Whiteaves)	-	-	-	-	-	x
Bostrychoceras sp.aff. B. otsukai (Yabe)	x	-	-	-	-	-	Pachydiscus binodatus Whiteaves	x?		-	+	-	-
Damesites damesi var. intermedius Matsumoto	X	X	X	-	-	-	Pachydiscus buckhami Usher	x	-	-	-	-	-
Diplomoceras notabile Whiteaves	-	-	-	-	x	-	Pachydiscus elkhornensis Usher	x	x	x?	-	-	-
Diplomoceras subcompressum (Forbes)	X	X	-	-	-	-	Pachydiscus (Eupachydiscus?) haradai sensu Usher	-	X	-	-	-	-
Diplomoceras? sp.	-	-	-	x	-	-	Pachydiscus jacquoti Seynes	-	-	-	x?	-	-
Epigonoceras epigonum (Kossmat)	X	X	X	x?	-	-	Pachydiscus (Canadoceras) multisulcatum (Whiteaves)	-	-	X	-	-	-
Gaudriceras denmanense Whiteaves	-	x	x	X	x	-	Pachydiscus neevesi Whiteaves	-	-	-	x	-	-
Gaudriceras sp.	x	-	-	-	x	-	Pachydiscus (Canadoceras) newberryanum (Meek)	-	-	x	X	-	-
Hauericeras gardeni (Baily)	X	X	-	-	-	-	Pachydiscus ootacodensis (Stoliczka)	-	-	-	-	X	X
Hoplitoplacenticeras cf. plasticum Paulke	-	-	-	x	-	-	Pachydiscus (Eupachydiscus) perplicatus Whiteaves	x	-	-	-	-	-
Hoplitoplacenticeras vancouverense (Meek)	-	-	-	x	-	-	Pachydiscus suciaensis (Meek)	-	-	-	-	X	X
Inoceramus ex gr. chicoensis Anderson	X	X	X	x	-	-	Pachydiscus (Canadoceras) yokoyamai (Jimbo)	-	-	X	x?	-	-
Inoceramus ex aff. cordiformis Sowerby	x	-	-	-	-	-	Puzosia (Parapuzosia) sp.	x	-	-	-	-	-
Inoceramus elegans Sokolov	-	-	X	-	-	-	Phyllopachyceras forbesianum d'Orbigny	-	-	-	-	-	x
Inoceramus ex aff. lobatus Goldfuss	X	-	-	-	-	-	Pseudobyloxeras cf. lineatum (Gabb)	x	x	x?	x?	-	-
Inoceramus naumanni Yokoyama	X	x	-	-	-	-	Pseudophyllites indra (Frobes)	-	-	-	-	X	X
Inoceramus orientalis Sokolov emend. Nagao and Matsumoto	x	X	x	-	-	-	Pseudoschloenbachia brannani Usher	-	x	-	-	-	-
Inoceramus orientalis var. ambiguus Nagao and Matsumoto	x	X	x	-	-	-	Pseudoschloenbachia cf. umbulazi Boyle	-	-	-	x?	-	-
Inoceramus n.sp.aff. orientalis	X	x	-	-	-	-	Ptychoceras vancouverense Whiteaves	X	-	-	-	-	-
Inoceramus sachalinensis	-	-	X	-	-	-	Ryugasella ryugasensis Wright and Matsumoto	x	x	-	x?	-	-
Inoceramus schmidti Michael s.str.	-	-	X	-	-	-	Schluteria selwyniana (Whiteaves)	x	x	x	x	-	-
Inoceramus ex gr. subundatus Meek	x	x	x	X	-	-							

- - no occurrence   x = occasional occurrence   X = general to mass occurrence   x? occurrence in this zone uncertain

TABLE 2 PRESENT AND EARLIER CORRELATIONS OF NANAIMO GROUP SUCCESSION IN COMOX AND NANAIMO BASINS

Richardson 1873	McKenzie Williams	Clapp 1912-1917	Buckham, 1947 Usher, 1952			McGugan, 1962 Williams-Burk, 1964			Muller-Jeletzky (this paper), 1967			
COMOX	COMOX	NANAIMO		COMOX	NANAIMO		COMOX	NANAIMO		COMOX	NANAIMO	
upper conglomerate	ST JOHN	GABRIOLA	MAESTRICHTIAN	HORNBY	GABRIOLA	MAESTRICHTIAN	HORNBY	GABRIOLA	MAES-TRICHTIAN	HORNBY	GABRIOLA	FOURTH CYCLE
upper shales	TRIBUNE			SPRAY	NORTH-UMBERLAND		SPRAY			SPRAY-upper LAMBERT	Campbell Bay beds ?	
middle conglomerate	HORNBY			GEOFFREY			GEOFFREY		CAMPANIAN	middle LAMBERT	upper NORTH-UMBERLAND	
							upper LAMBERT			GEOFFREY	"Galiano conglomerate"	
Middle shales	LAMBERT	NORTH-UMBERLAND		LAMBERT		upper CAMPANIAN	lower LAMBERT	NORTH-UMBERLAND		lower LAMBERT	lower NORTH-UMBERLAND	THIRD CYCLE
lower conglomerate	DENMAN	DE COURCY	CAMPANIAN	DENMAN	DE COURCY		DENMAN	DE COURCY		DENMAN	DE COURCY	
lower shales	TRENT RIVER	CEDAR DISTRICT		TRENT RIVER	CEDAR DISTRICT		upper TRENT RIVER	CEDAR DISTRICT		upper TRENT RIVER	CEDAR DISTRICT	SECOND CYCLE
coal-measures	COMOX	PROTECTION		COMOX	PROTECTION			PROTECTION		"Tsable River conglom-erate"	PROTECTION	
		NEWCASTLE	– – –	QUALICUM ~?~?~	NEWCASTLE	– – –		NEWCASTLE			(NEWCASTLE)	
		CRANBERRY	lower CAMPANIAN or ? SANTONIAN		CRANBERRY	CAMPANIAN to SANTONIAN		CRANBERRY			(CRANBERRY)	
		EXTENSION			EXTENSION			EXTENSION			EXTENSION	
		WELLINGTON			WELLINGTON		lower TRENT RIVER	upper HASLAM			WELLINGTON	
		HASLAM			HASLAM			lower HASLAM	SANTO-NIAN	lower TRENT RIVER	HASLAM	FIRST CYCLE
		BENSON			BENSON		COMOX	BENSON		COMOX	BENSON	
							QUALICUM					

simultaneously, or perhaps a little earlier in the Comox Basin; coal was formed in Comox Basin in the first depositional cycle; and in the Nanaimo coal basin in the next cycle.

The discovery of outliers of Nanaimo marine sediments to 5,000 feet elevation also reveals that the present 'basins' of occurrence are in part determined by late- to post-Cretaceous block faulting. Thus the Alberni 'basin' may have been a continuation of the Comox Basin. On the other hand facies variations in the lower faunal zones, directly overlying the pre-Cretaceous 'basement' strongly suggest that north-striking ridges existed. These ridges are more or less coincident with elongated uplifts where the entire Mesozoic mainly volcanic sequence had been removed in pre-Nanaimo time and Permian (and older?) rocks have come to the surface. Two such ridges separate Nanaimo and Comox Basins. The ammonite fauna leaves no doubt that these basins were connected with the Pacific Ocean.

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PETROLOGY

28. PETROLOGICAL STUDIES

K. L. Currie

The solubility of microcline (Or_{83}) from Bathurst township, Ontario was determined in supercritical water in the range 375-600°C and 750-3,500 bars. Analysis of the data has not been completed, but initial inspection shows that results for Si and Al are virtually identical to those for albite, while the pressure dependence of the solubility of K is stronger than that for Na.

Preliminary studies in the system Or-Ab-Q-H_2O show that the solutions behave as the sum of the solutions of the components, at least in the sub-liquidus range.

Solubility studies on albite have been extended to 750°C and 7,500 bars. The results show that the extrapolations from data at lower P-T conditions are reasonably reliable. In particular the retrograde solubility of Al above 600° was confirmed.

A re-examination of the Franck theory of solubility showed that solubility equations in the supercritical range could be expressed in the form

$$\log X_i = (a + bP)/T + c/v + d\log V + e\log T + f$$

assuming that (a) the solubility is low, (b) species i forms only one quantitatively important complex with the solvent, (c) the volume dependence of free energy of formation of the complex can be represented by terms linear in the volume, and (d) the formation of the complex involves only weak bonding, so that the properties of solvent and solute portions are essentially unchanged. This equation is in a format suitable for regression analysis. Computer analysis of experimental data shows that only three stages of regression are significant. Analysis of data for albite by this technique yields the following results

$$\log X_{SiO_2} = 2.478/V + (30.09P - 2400.6)\ T - 2.020$$

$$\log X_{Al_2O_3} = 157.15 - 17160/T - 4.081\log T - 4.241\log V$$

$$\log X_{Na_2O} = 1.324/V - 2.275\log V - 1.884.7/T - 2.300$$

where X is in mols per mol, V in cc per gram, P in kilobars and T in K°. These equations express the experimental data within 5 per cent, which is within the experimental error.

Experiments were conducted on the pressures attainable between quartz fragments. Square quartz pistons were cut one half inch on a side by three quarters inch long. The upper half inch was held in a massive steel holder, and the lower end was unsupported. A square face 3/16" on a side was ground on the lower end, with the shoulders tapering 8°. Two such pistons were opposed to each other, and the triangular space between the shoulders filled with a moistened mixture of quartz and hematite ground to -150 mesh. Such a set up will support over 23,000 pounds, which is a nominal pressure of over 20 kilobars on the faces. Two modes of failure were observed. (1) The pressure on the set up slowly declined due to fine granulation of the faces. In these runs small amounts of non-birefringent, low index material are always observed in the powder (glass?). (2) The set up failed suddenly by a longitudinal crack through the piston. Attempts to run experiments at elevated temperature by embedding a resistance wire in the quartz-hematite gasket consistently failed because of pinch-off of the wire before the highest pressures were reached. These experiments show that where sharp edged fragments are present, the maximum hydrostatic pressure (1500 bars in this case) has no relation to the pressures locally reached in the system. Minute areas in brecciated rocks, for example, may reach pressure orders of magnitude above the ambient pressure.

29. CRATER STUDIES

K. L. Currie

A geochemical reconnaissance of the Brent, West and East Clearwater, and Manicouagan structures showed them to be characterized by (1) high potash content in the glassy breccias, together with high MgO, (2) similar but less marked anomalies in the rocks of igneous appearance, (3) high heavy metal content, in some cases amounting to anomalies of potential commerical interest. Alnoite was identified in the Brent crater, together with potassic alkaline trachyte. A re-examination of carbonate veinlets from New Quebec discloses presence of columbite, suggesting that carbonatitic rocks may be present in this crater also. The composition of the 'melt rocks' and 'glass rich' breccia is significantly different from the wall rocks in all craters examined.

Glass rich breccias from the Carswell structure, Saskatchewan show similar anomalies to the craters noted above. Shock metamorphosed basement rocks in this structure are overlain by unshocked Athabasca sandstone, but the stratigraphic relations show that shock-metamorphism took place after deposition of the Athabasca. Since the shock impedance of the sandstone and altered basement are virtually identical, this shows that shock metamorphism in the Carswell structure did not result from a shock wave propagating downward through the Athabasca Formation.

The igneous rocks of the Manicouagan complex, Quebec fall into three categories (1) ultrabasic (SiO_2 36-39% MgO 25-30%) (2) basaltic (SiO_2 49-51%), and (3) doreitic (SiO_2 54-58%). The rocks differ markedly in style of occurrence, and the chemical analyses are marked by considerable gaps in composition between different groups.

30. GRANITOID ROCKS IN THE REGION OF LOUGHBOROUGH LAKE, ONTARIO

K. L. Currie

Granitoid rocks in sizeable masses occur in sheet like plutons near the contact of granulite and amphibolite grade gneisses. The material involved is thought to be derived mainly from the top of the granulitic complex, which was reactivated by the water in the overlying lower grade metamorphic rocks, but in the case of the Crow Lake mass, much of the material may have come from amphibolite grade rocks. The mineralogy of the granitoid plutons depends on the water pressure, which is conceived to have increased upward, so that those bodies solidifying within the amphibolite grade rocks contain biotite, while those resting directly on the granulites contain pyroxene (pseudomorphs). All of the granitoid rocks are believed to have solidified from a melt, as evidenced by their chemical and petrographic similarity. The degree of 'intrusiveness' of the plutons however depends on the structural style of the surroundings, those in tightly folded zones showing pronounced discordance. Chemical analyses along sections across the two major plutons have defined chemical gradients suggesting that material below the plutons stratigraphically has been basified. Where this material lies within the amphibolite grade rocks biotite gabbro is the result, while pyroxene gabbro appears in the same relative position in granulite facies rocks.

COAL RESEARCH

31. PETROGRAPHY OF CANADIAN COALS IN RELATION TO ENVIRONMENT OF DEPOSITION

P.A. Hacquebard, T.F. Birmingham, J.R. Donaldson

A relationship has been established between the petrography of six coal seams and the depositional aspects of their respective coal basins, namely those of Sydney, St. Rose, Píctou and Springhill in Nova Scotia, and Nanaimo and Telkwa in British Columbia.

The basins have been studied with respect to their position relative to the sea, their morphological shape and their geological origin. Three paralic and three limnic basins are represented. In each, cross-sections through several seams over the entire extent of the coalfield have been constructed. These sections portray the development of the coal and indicate the type of depositional environment.

The petrographic analyses were made on column samples in terms of microlithotypes and macerals, and the coal facies has been interpreted from their relative proportions. In the paralic basins the seams are more variable in petrographic composition than in the limnic basins.

In the paralic basins it was found that coal laid down in central part of a flood-plain is high in clarite and contains much well preserved exinite (Sydney coalfield); when deposited at margin of flood-plain, it is characterized by a high content of resinite, much of which occurs in fusinized form as sclerotioids, together with a high concentration of finely disseminated pyrite (St. Rose coalfield). A lagoonal environment produced a coal high in collinite (Nanaimo coalfield).

In the limnic basins, a very bright coal high in telinite accumulated in a shallow basin of probable diapiric origin (Springhill coalfield), whereas a finely banded semi-dull coal high in inertinite was formed in a steep basin of graben origin (Pictou coalfield). The sapropelic, canneloid coal from Telkwa is considered to represent a subaquatic lacustrine deposit that was formed in an erosional depression.

This study illustrates the value of a petrographic evaluation of coal for the interpretation of sedimentary basins. It can probably be used on isolated and restricted coal occurrences also.

The results of this investigation were presented at the "Symposium on the Science and Technology of Coal", held in Ottawa, from March 29-31, 1967, and will be published in the proceedings of this Conference.

32. COAL MINE GEOLOGY AND EVALUATION OF COAL RESERVES

J.R. Donaldson and P.A. Hacquebard

The structural contour plan of the Springhill coalfield, N.S., which was compiled in 1965, has been updated by incorporating information from newly advanced workings. As this mine lies in an area which is intersected by several faults, continued mining depends on accurate forecasts of type and displacement of these dislocations (c.f. Paper 66-2, p. 61, No. 33). The new data were obtained from several underground visits, and indications are that the mining is proceeding towards a less disturbed part of the area.

Progress has been made in finding an additional reserve of mineable coal in the Pictou coalfield, N.S. (c.f. Paper 66-2, p. 60, No. 32). Detailed petrographic and chemical studies on the coal cores from three bore-holes drilled on the Foord seam have revealed the presence of a small block of virgin coal situated on the margin of old workings. Although there is a general deterioration of the 40 foot thick Foord seam in the marginal areas of the Albion syncline, this deterioration affects the seam at different levels in different locations. In the area outlined by the drilling, a middle part that is about 8 feet thick, which still has a sufficiently low ash content to warrant exploitation, is present.

33. THE DEVELOPMENT OF COAL PETROLOGY IN NORTH AMERICA

A.R. Cameron

A paper entitled "The Development of Coal Petrology in North America" was prepared in cooperation with W.F. Berry of Bituminous Coal Research, Inc., Monroeville, Pennsylvania and B.N. Nandi of the Mines Branch, Ottawa. In the first part of the paper the history of coal petrology is summarized stressing particularly the contributions made by the United States Bureau of Mines, the Illinois Geological Survey, the Geological Survey of Canada and the Pennsylvania State University. The increasing use of petrology in industry is an important aspect of this historical background and this development is reviewed along with the techniques and changes in classification which have accompanied it.

The remaining parts of this paper present specific examples of the direct application of coal petrography. Its geological use in the identification and correlation of coal seams is illustrated. In the area of the utilization of coal examples of the following applications are given:

1. prediction of metallurgical coke quality,
2. evaluation of product yield from coal and coal blends during gasification,
3. coal preparation practice,
4. determination of degree of oxidation,
5. pyrite removal,
6. combustion and boiler design,
7. land evaluation and development studies.

34. CHRONOLOGY OF COAL IN THE GEOLOGICAL SURVEY OF CANADA

T.F. Birmingham

A detailed report on coal chronology has been compiled for the purpose of assisting Dr. M. Zaslow, University of Western Ontario, in his preparation of an official history of the Geological Survey. For this report nearly all existing references pertaining to coal in Survey publications and by GSC authors have been collected and arranged in a bibliography. The latter has well over 200 references, which are listed geographically by provinces, by Canada in general and in an addenda containing recent and associated publications.

An historical chart on coal chronology, listing all authors, number of coal references and year of publication is included, as well as four descriptive chapters. These describe the geological aspects of coal research, its history and development within the Geological Survey, and its specialization as presently carried out in the fields of coal petrology and palynology by the Coal Research Section.

35. AGE AND STRATIGRAPHY OF THE PICTOU GROUP IN THE MARITIME PROVINCES AS REVEALED BY FOSSIL SPORES

M.S. Barss and P.A. Hacquebard

In the Maritime Provinces terrestrial sediments of Upper Carboniferous age are widely distributed. Lithologically these sediments are very similar, consisting entirely of red and grey clastic rocks with intercalated coal-bearing members. They occur in a number of disconnected basins and their stratigraphic relationship can be determined only on the basis of contained fossils.

The youngest unit of the Upper Carboniferous sediments, the Pictou Group, is widespread in the Maritime Provinces. It includes two distinctly different facies, namely a grey coal-bearing series and a partially red, mainly non-coal bearing sequence of clastic rocks. In the non-coal bearing facies a general scarcity of megafossils precludes any time zonation, hence, interbasinal correlations have been difficult. On account of the general abundance of miospores in terrestrial sediments a palynological study was undertaken to establish more precise correlations and age determinations of strata assigned to the Pictou Group and its equivalents.

Five zones, the Vestispara, Torispora, Thymospora, Potonieisporites, and Vittatina zones, each characterized by a distinctive assemblage of miospores have been established. These zones are recognizable throughout the Maritime region and range in age from Westphalian C to Permian in ascending order. The limits of these zones have been delineated as accurately as possible in twenty stratigraphic sections of the Pictou Group and equivalent strata.

PLEISTOCENE GEOLOGY

36. STRATIGRAPHY AND CHRONOLOGY OF QUATERNARY DEPOSITS OF ASSINIBOINE RIVER VALLEY AND ITS TRIBUTARIES

R. W. Klassen

Information that refines and confirms present concepts concerning local and regional Quaternary events was obtained by stratigraphic drilling, study of exposures, and radiocarbon dating of deposits within and adjacent to Assiniboine, Qu'Appelle and Shell River valleys in southwestern Manitoba and southeastern Saskatchewan (Fig. 1) during the 1966 field season.

The fill within Assiniboine River valley above Assiniboine Delta and within the lower part of Qu'Appelle River valley consists largely of clay, silt, and some sand 100 to 200 feet thick (Figs. 2 to 4). Gravels have a limited distribution, suggesting they are primarily channel deposits. Coarse gravels are generally restricted to valley segments cut in till, whereas, segments cut mainly in shale contain a fill essentially devoid of gravel (Fig. 4, lines LM and NO). This condition suggests that most coarse gravel was derived locally by water erosion of drift. Much of the fill in this part of Assiniboine River valley apparently was deposited before Lake Agassiz 11 drained some 8,000 years B.P., as spruce wood associated with flood plain type deposits just above the present flood plain near Shellmouth, Manitoba yielded a radiocarbon age of 10,690 ± 190 years B.P. (GSC-677) and wood at a depth of 15 feet below the surface of the modern flood plain about 10 miles downstream from Shellmouth an age of 6,320 ± 140 years B.P. (GSC-280). An interval of river degradation associated with the draining of Lake Agassiz 11 was followed by an interval of aggradation that has continued to the present and is represented by some 20 to 30 feet of alluvium.

Where Assiniboine River valley crosses Assiniboine Delta the fill consists mainly of silt and sand 20 to 40 feet thick overlying lake clay. The valley here is incised through an earlier fill of silty alluvium and estuarine silts and clays, in part preserved as terraces along the valley walls. Shells in silt underlying a terrace 50 feet (1,050 feet ASL) above the modern flood plain in NE 1/2 sec. 28, tp. 8, rge. 11 (Fig. 1), yielded a radiocarbon age of 10,670 ± 160 years B.P. (GSC-492). Another terrace 80 feet (1,000 feet ASL) above the modern flood plain about 12 miles farther downstream in NE 1/4 sec. 20, tp. 9, rge. 9 is underlain by silts and clays that contain clam shells radiocarbon dated at 10,920 ± 150 years B.P. (GSC-689). Ostracods from the silt indicate it is of estuarine origin (L. D. Delorme, personal communication). This information, along with information from bore-holes (Fig. 4 – line AB) confirms conclusions from earlier studies that the terraces are

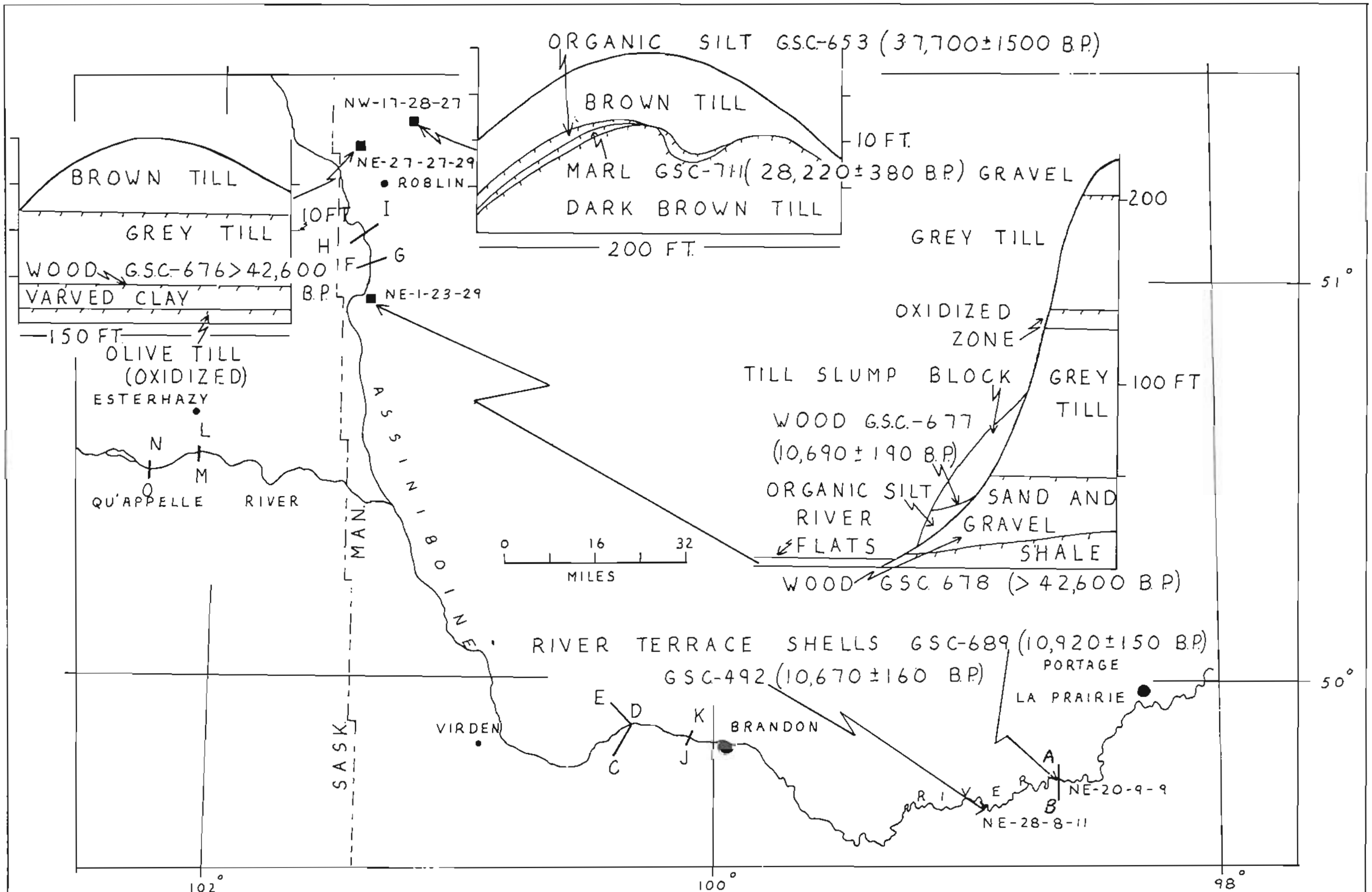


FIGURE I MAP SHOWING BOREHOLE LINE LOCATIONS AND SECTIONS

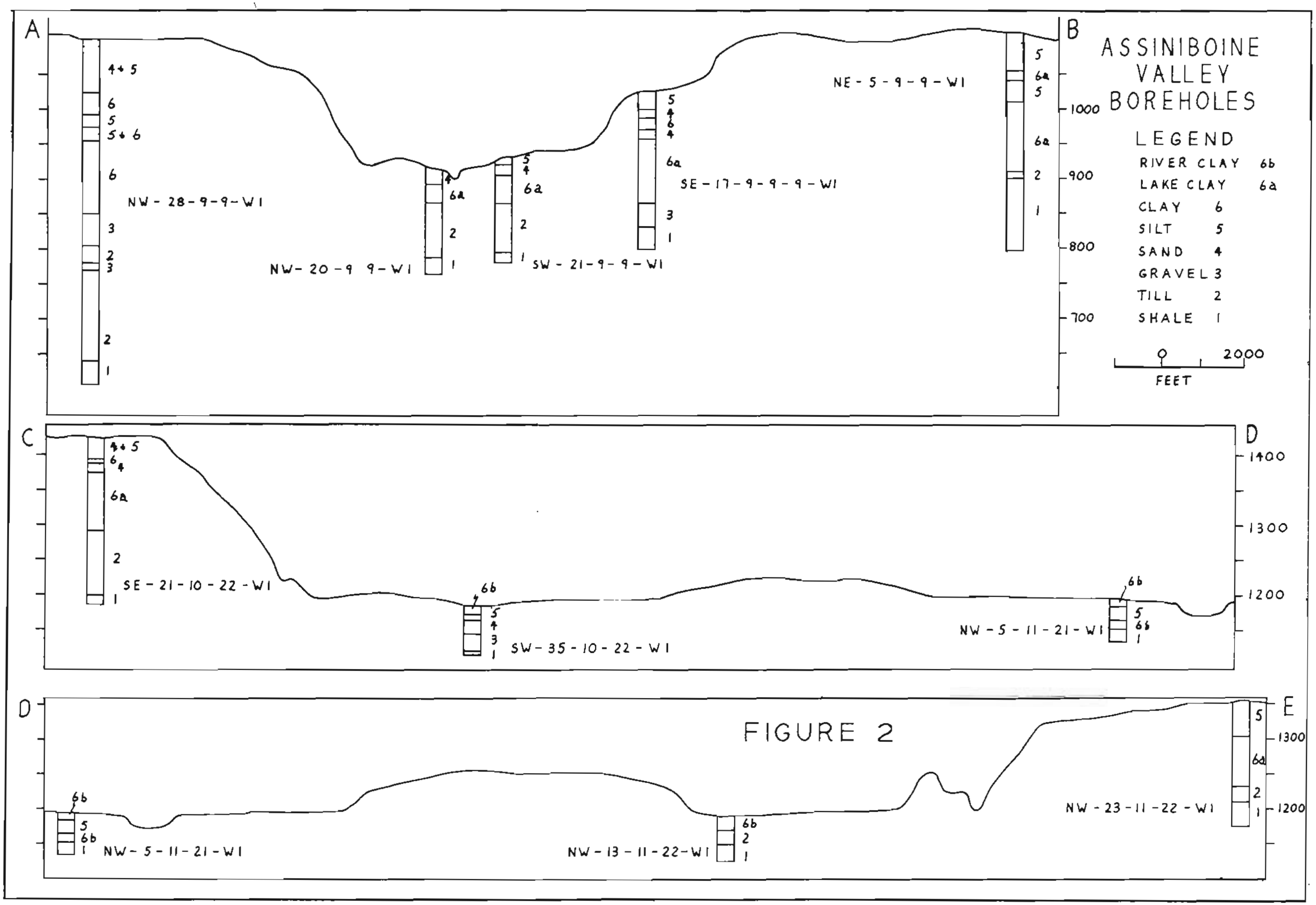

A
B
C
D
D
E
ASSINIBOINE VALLEY BOREHOLES
LEGEND
RIVER CLAY 6b
LAKE CLAY 6a
CLAY 6
SILT 5
SAND 4
GRAVEL 3
TILL 2
SHALE 1
0 2000
FEET
NW - 28 - 9 - 9 - W1
NW - 20 - 9 9 - W1
SW - 21 - 9 - 9 - W1
SE - 17 - 9 - 9 - 9 - W1
NE - 5 - 9 - 9 - W1
1000
900
800
700
SE - 21 - 10 - 22 - W1
SW - 35 - 10 - 22 - W1
NW - 5 - 11 - 21 - W1
1400
1300
1200
NW - 5 - 11 - 21 - W1
NW - 13 - 11 - 22 - W1
NW - 23 - 11 - 22 - W1
1300
1200

FIGURE 2

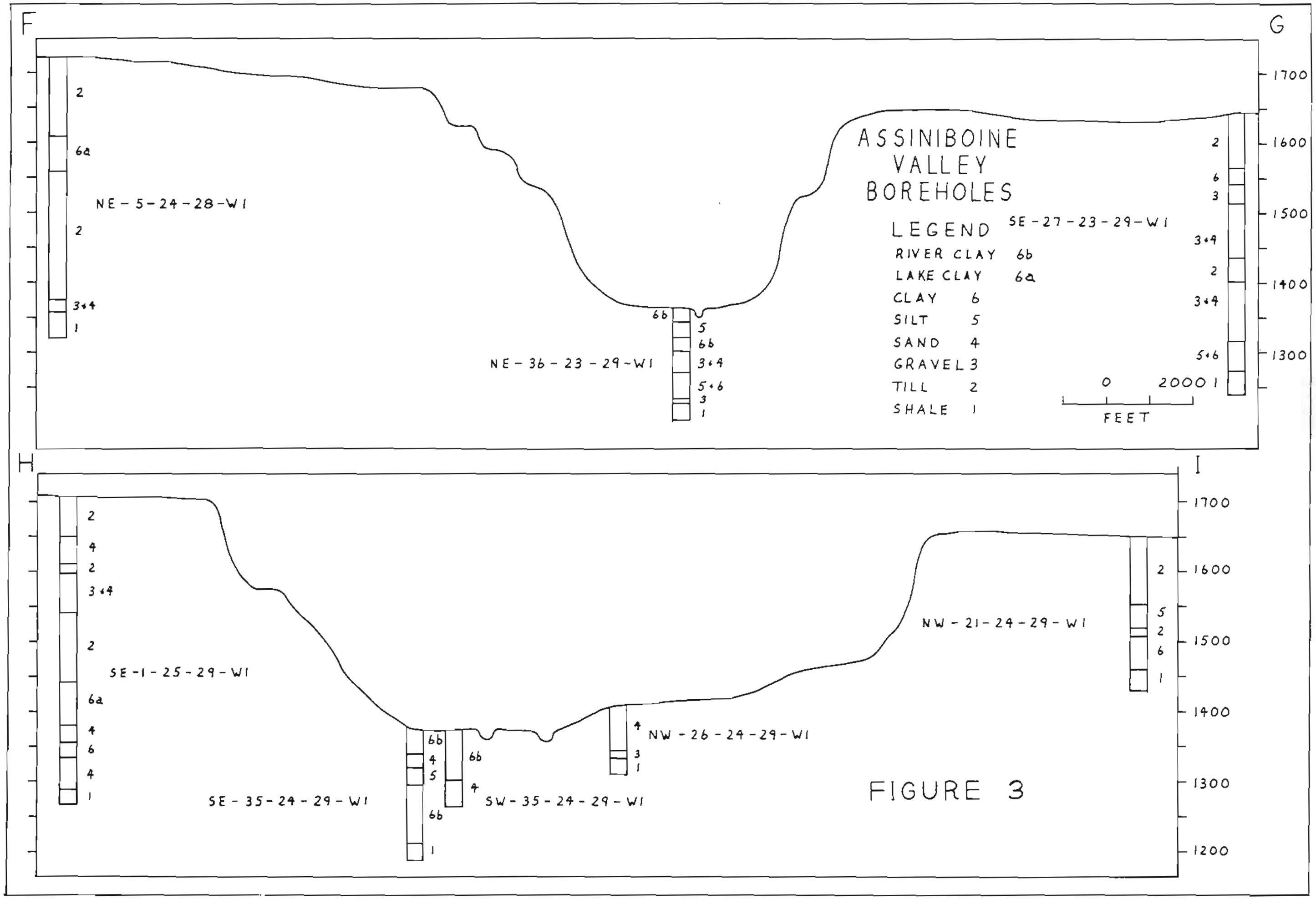
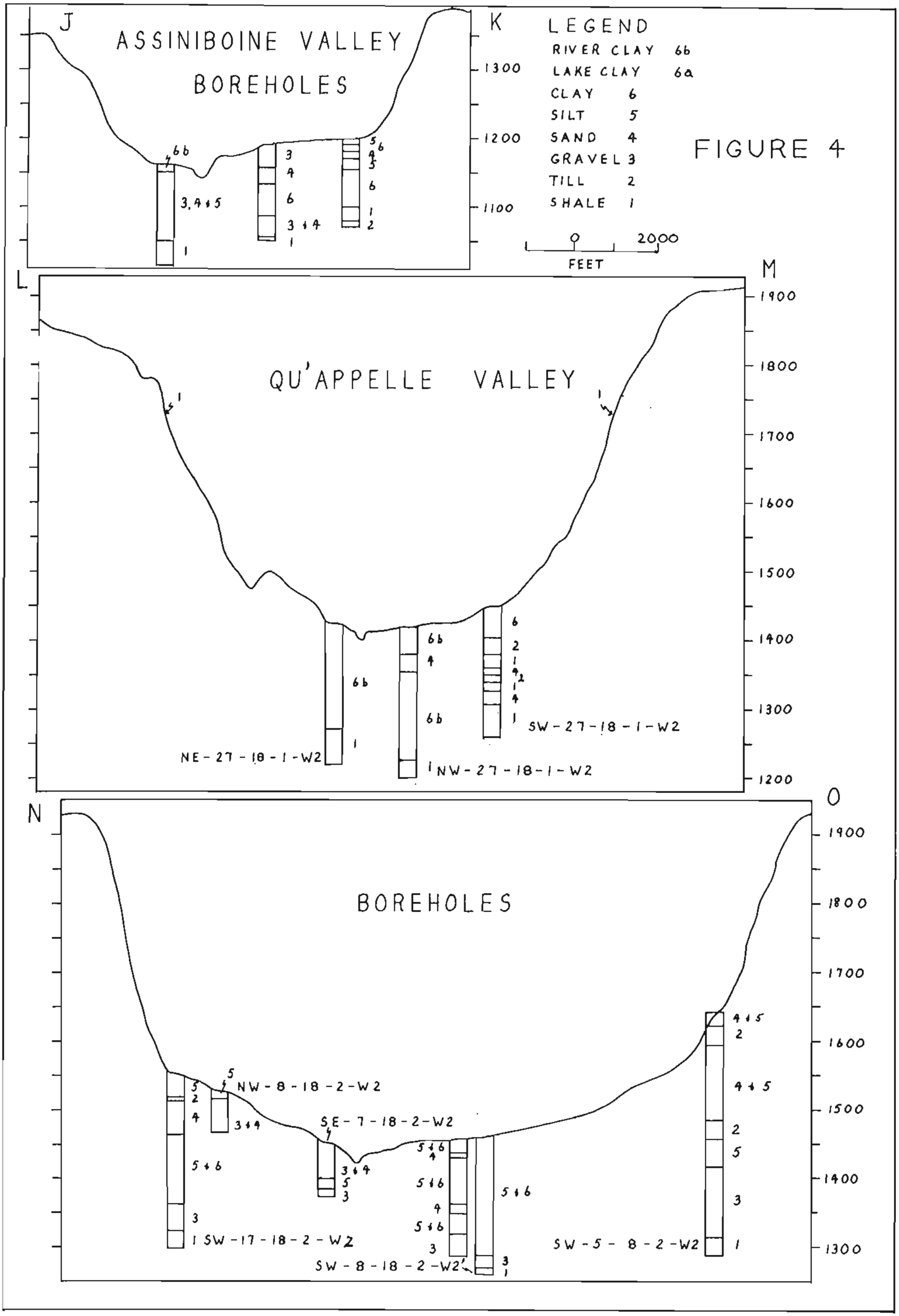

F
G
H
I
ASSINIBOINE VALLEY BOREHOLES
LEGEND
RIVER CLAY 6b
LAKE CLAY 6a
CLAY 6
SILT 5
SAND 4
GRAVEL 3
TILL 2
SHALE 1
0 2000
FEET
NE-5-24-28-W1
NE-36-23-29-W1
SE-27-23-29-W1
SE-1-25-29-W1
SE-35-24-29-W1
SW-35-24-29-W1
NW-26-24-29-W1
NW-21-24-29-W1
1700
1600
1500
1400
1300
1200

FIGURE 3


J
K
ASSINIBOINE VALLEY
BOREHOLES
1300
1200
1100
6b
3,4+5
1
3
4
6
3+4
1
5
6
4
5
6
1
2
LEGEND
RIVER CLAY 6b
LAKE CLAY 6a
CLAY 6
SILT 5
SAND 4
GRAVEL 3
TILL 2
SHALE 1
FIGURE 4
0
2000
FEET
L
M
QU'APPELLE VALLEY
1900
1800
1700
1600
1500
1400
1300
1200
6b
1
NE-27-18-1-W2
6b
4
6b
1 NW-27-18-1-W2
6
2
1
4
2
1
4
1
SW-27-18-1-W2
N
O
BOREHOLES
1900
1800
1700
1600
1500
1400
1300
5
2
4
5+6
3
1 SW-17-18-2-W2
5
NW-8-18-2-W2
3+4
SE-7-18-2-W2
4
3+4
5
3
5+6
4
5+6
4
5+6
3
5+6
SW-8-18-2-W2'
3
1
4+5
2
4+5
2
5
3
SW-5-8-2-W2
1

remnants of a fill deposited within Assiniboine River valley when it was in part flooded by Lake Agassiz 11 (Elson, 1962). Lake Agassiz 11 had thus risen to the 1,000-foot level at least 10,770 years B.P.

Drift sections studied near Shellmouth and Roblin, Manitoba provided additional information concerning Quaternary events in this area. Wood-bearing alluvium, containing an anomalous concentration of quartzite pebbles (20 per cent), occurs above bedrock beneath some 200 to 250 feet of drift exposed along Assiniboine River near Shellmouth in NE 1/4 sec. 1, tp. 23, rge. 29 (Fig. 1) and was penetrated in a bore-hole in SE 1/4 sec. 27, tp. 23, rge. 29 (Fig. 3) about 3 1/2 miles to the northwest. Wood from the alluvium exposed near Shellmouth yielded a radiocarbon age of greater than 42,600 years B.P. (GSC-678). This alluvium appears to be within a buried valley that here trends towards the northeast between the Duck and Riding Mountain Uplands. Along the east edge of Big Boggy Creek valley in NE 1/4 sec. 27, tp. 27, rge. 29 (Fig. 1) two tills, oxidized in part, totalling 18 feet in thickness are separated from a highly oxidized lower till by 2 feet of varved clay below a terrace remnant. Wood fragments and organic debris from the upper surface of the clay yielded a radiocarbon age greater than 42,600 years B.P. (GSC-676). Finite radiocarbon dates of 37,700 ± 1,500 years B.P. (GSC-653) and 28,220 ± 380 years B.P. (GSC-711) were obtained from a charcoal-bearing silt bed and underlying marl bed respectively, exposed in the NW 1/4 sec. 17, tp. 28, rge. 27 (Fig. 1) on the Duck Mountain Upland. The silt and marl unit, 1 to 3 feet thick, is a lake deposit that separates the surface till in this area from the underlying till. These finite dates suggest a correlation with deposits of the redefined Port Talbot Interstade in the Lake Erie Region (Dreimanis et al., 1966). It appears that the last glaciation of this part of the Duck Mountain Upland was the Main or Late Wisconsin advance and was preceded by at least two and probably three major intervals of glaciation.

Dreimanis, A., Terasmae, J. and McKenzie, G.D.
1966: The Port Talbot Interstade of the Wisconsin Glaciation; Can. J. Earth Sci., vol. 3, No. 3, pp. 305-325.

Elson, J.A.
1962: History of Glacial Lake Agassiz; in Problems of the Pleistocene and Arctic, vol. 2, No. 2.

PALAEONTOLOGY

37. CLONOGRAPTUS FROM THE ST. GEORGE FORMATION, NEWFOUNDLAND

L. M. Cumming

The rare association, in carbonate rocks, of diagnostic Lower Ordovician graptolites and a shelly fauna containing trilobites, brachiopods and gasteropods has been found in the St. George Formation on Port au Choix Peninsula, latitude 50°43'N., western Newfoundland (Fig. 3). There Clonograptus flexilis (Hall) [see Fig. 2] occurs in beds of Division H of the lower Palaeozoic carbonate platform sequence (Richardson, in Logan 1863, p. 289, 869, 879). This graptolite occurrence dates part of the St. George Formation (see Fig. 1) as an equivalent of Zone 3 of the standard British graptolite succession. Trilobites of Beekmantown age from these same beds (unit 8, p. 289, Geol. of Canada 1863) are:

Bathyurellus abruptus Billings, Bathyurellus marginatus Billings, Petigurus nero (Billings), and Petigurus timon (Billings) [Raymond, p. 71, 72, 164].

Logan, W.E. (and others)
1863: Report on the Geology of Canada; Geol. Surv. Can., Rept. of Progress to 1863, pp. 289, 879.

Raymond, P.E.
1925: Some trilobites of the lower middle Ordovician of eastern North America; Bull. Museum Comp. Zool. Harvard Coll., vol. 67, No. 1, Cambridge, Mass.

Figure 1.
Graptolite locality. Port au Choix Pen. View southwest across mouth of Port au Choix. Black Point in far distance (see Fig. 3) g = graptolite horizon Upright stick is 6 ft. GSC photo 123947.

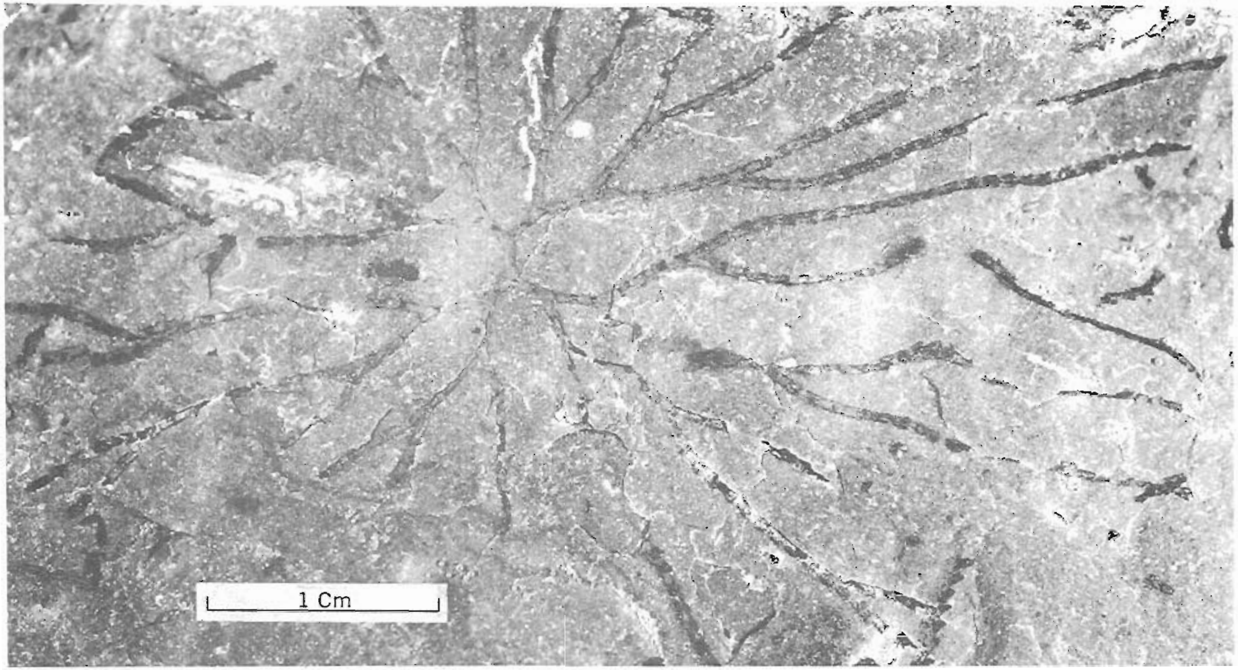


Figure 2. Clonograptus flexilis (Hall) from the St. George Formation, Port au Choix Peninsula, Newfoundland; GSC loc. 77760; 1000 feet south of Barbace Cove (see Figs. 1 and 3). GSC hypotype 22961, GSC photo 200299.

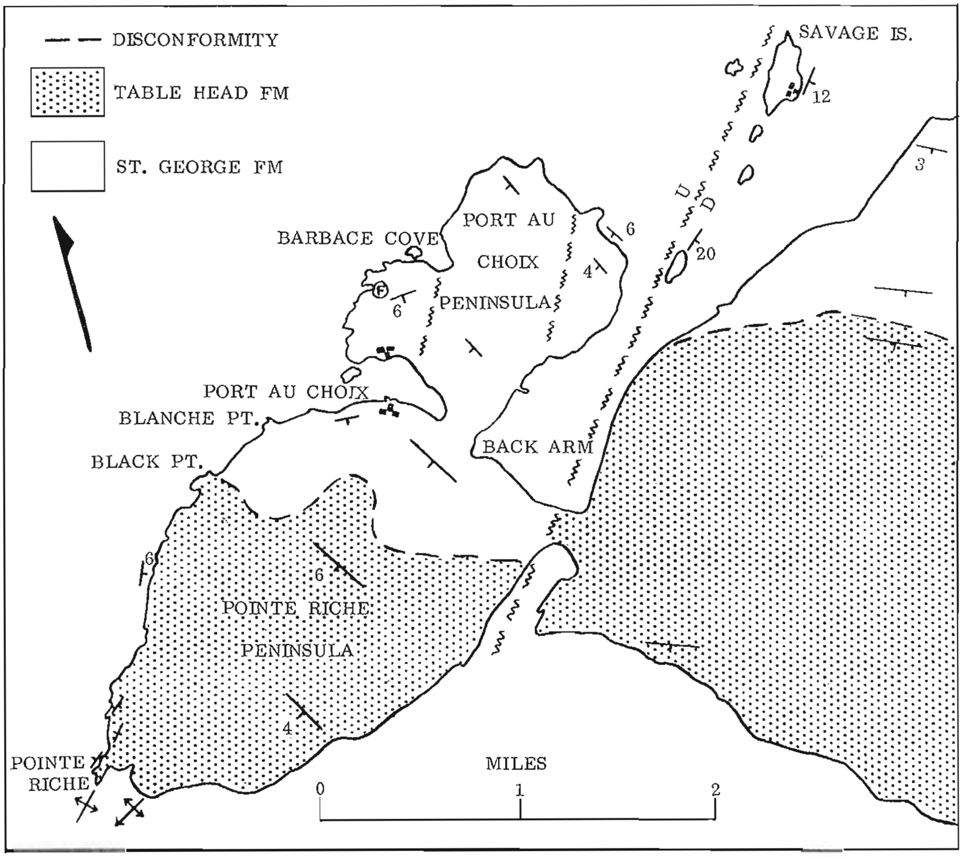


Figure 3. Geological sketch map of the Pointe Riche and Port au Choix Peninsulas, Western Newfoundland - showing fossil locality containing the Lower Ordovician graptolite Clonograptus. The section of the St. George Formation exposed between Port au Choix and Barbace Cove (see Fig. 3) is Division H of the measured section of James Richardson, as reported by Logan [1].

38. PRELIMINARY REPORT ON SOME SIGNIFICANT SPECIES OF ALBIAN FORAMINIFERA FROM WESTERN CANADA

T. Potter Chamney

The microfaunal list shows a few species that have been selected to represent large faunal assemblages. All the specimens have been recovered and identified from samples collected by the author and officers of the Geological Survey on three helicopter-supported operations of the Survey – Operation Liard, Operation Mackenzie and Operation Porcupine.

The species are listed in stratigraphic position in tabular form; the ranges of some are restricted to the time interval indicated, whereas others only show the uppermost limit of the range.

Species of Haplophragmoides are the most common foraminifera recovered from Albian rocks. Because of the many transitional forms and the overlapping ranges of the numerous species of this genus they cannot be readily shown on a simple table and require a graphic chart to demonstrate their true stratigraphic significance; as a consequence they are not included in this preliminary listing.

	Op. Liard NE Brit. Col.	Op. Mackenzie SW Gt. Slave L.	Op. Porcupine Yukon
LATE ALBIAN			
1) Upper Portion:			
Ammobaculites cf. A. fragmentarius Cushman, 1927	X		
Psamminopelta n. sp. 1	X		
Trochammina umiatensis Tappan, 1957	X		
2) Middle or Lower Portion:			
Psamminopelta subcircularis Tappan, 1957	X	X	X
Miliammina ex. gr. manitobensis			

	Op. Liard NE Brit. Col.	Op. Mackenzie SW Gt. Slave L.	Op. Porcupine Yukon
Wickenden, 1932	X	X	X
Verneuilinoides borealis Tappan, 1957		X	X
Miliammina ischnia Tappan, 1957		X	
Arenobulimina cf. *A. torula* Tappan, 1957		X	
Gaudryina cf. *G. subcretacea* Cushman, 1936	X		
3) Lower Portion:			
Siphotextularia cf. *S. rayei* Tappan, 1957	X		
Gaudryina n. sp. 1 (tricarinate)	X		X
Hippocrepina barksdalei Tappan, 1957	X		
MIDDLE ALBIAN			
4) Upper Portion:			
Globorotalites alaskensis Tappan, 1957	X		X
Gaudryina canadensis Cushman, 1943	X	X	X
Valvulineria loetterlei Tappan, 1940			X
Gaudryina subcretacea Cushman, 1936		X	X
Ammobaculites fragmentarius Cushman, 1927	X	X	X
5) Middle Portion:			
Marsonella spp.	?	X	X
Globulina lacrima Reuss subsp. *canadensis* Mellon & Wall, 1956			X
Saccammina n. sp. 1	?		X
Trochammina rainwateri Cushman & Aplin, 1946	?	X	X
Gaudryina nanushukensis Tappan, 1957		X	X

	Op. Liard NE Brit. Col.	Op. Mackenzie SW Gt. Slave L.	Op. Porcupine Yukon
6) Lower Portion:			
Ammodiscus mangusi (Tappan), 1957	?	X	X
Ammodiscus n. sp. 1		X	X
Glomospirella sp.	?	X	X
Bathysiphon brosgei Tappan, 1957 (coarse)	X	X	X
Miliammina cf. M. sproulei Nauss, 1947	?	X	X
Gaudryina barrowensis Tappan, 1957		?	X
Haplophragmoides gigas minor Nauss, 1947	?	X	
EARLY ALBIAN			
7) Upper Portion:			
Saracenaria trollopei Mellon and Wall, 1956	X	X	X
Marginulinopsis collinsi Mellon and Wall, 1956	X	?	X
Lenticulina spp.	X	X	X
radiolaria - Dictyometra sp. & Lithocampe sp.		X	X
Glomospira sp. - Glomospirella sp.	X	X	X
8) Lower Portion:			
Lenticulina erecta (Perner), 1892		X	X
Globulina prisca Reuss, 1863			X
Gaudryina n. sp. 2 (tricarinate)		?	X
TRANSITIONAL Albian/Aptian			
9) Textularia topagorukensis Tappan, 1957	?	X	X
Bathysiphon cf. B. brosgei Tappan, 1957		X	X
Gaudryina cf. G. tailleuri Tappan, 1957			X
Trochammina eilete Tappan, 1957			X

STRATIGRAPHY

39. UPPER PALAEOZOIC ROCKS OF NORTHEAST BRITISH COLUMBIA

E.W. Bamber, G.C. Taylor, and R.M. Procter

A belt of Carboniferous and Permian rocks extends from the southern District of Mackenzie, through northeastern British Columbia into western Alberta. The stratigraphic succession has been established in the southern District of Mackenzie from studies of the surface exposures, and in the Peace River area from surface and subsurface studies (see Fig. 1). Significant facies changes which occur between the two areas, have obscured the relationships of the two local stratigraphic successions. Recent study of the intervening area in northeastern British Columbia has clarified the relationships between the two stratigraphic successions.

	District of Mackenzie		Northeastern British Columbia	Peace River
Permian	Fantasque		Fantasque	Belloy
	Upper Mattson		Kindle	
*				
Mississippian	Lower and Middle Mattson		Stoddart-Mattson	Stoddart
	Etanda	Flett	Prophet	Debolt
		Clausen	Besa River	Shunda-Pekisko
				Banff

Figure 1. Correlation chart of Upper Palaeozoic Formations
*Lower Pennsylvanian may be present locally.

Rocks of late Palaeozoic age are exposed in a long, narrow, sinuous belt in northeastern British Columbia, subparallel with the front of the Rocky Mountains south of Liard River, and extending north along both flanks of the Caribou Range (Fig. 2). East of the exposure belt, numerous wells have penetrated the succession. A disconformity separates Mississippian rocks from overlying beds and a disconformity also exists within the Permian sequence. Lower Pennsylvanian rocks may be locally present beneath the pre-Permian disconformity. The exposed belt provides an oblique cross-section through a major east-west facies change in Mississippian strata. Subsurface formations are related to a framework of five formations recognized in the exposure belt.

The Besa River Formation, at its type section (Locality 6), is mainly medium to dark grey, calcareous shale, with thin beds of argillaceous, silty limestone which are most abundant in the upper 600 feet of the formation. A unit in the lower part of the section, consisting of dark grey to black, siliceous shale and mudstone, has been correlated with the Exshaw Formation by Pelzer (1966, p. 302). In almost all other stratigraphic sections to the west, the formation is dominated by siliceous, partly pyritic shale and mudstone with some siliceous nodules. At Mount Dopp (Locality 4), which is the most southerly of the western sections, much of the shale is calcareous or dolomitic, and there are intervals of calcareous siltstone, and argillaceous, silty dolomite. The upper contact of the Besa River Formation becomes younger, and the lower contact becomes older, from east to west. This diachronism is caused by a lateral change from carbonate in the east, to shale and mudstone in the west, in units of Late Devonian and Mississippian age. Despite its westward increase in stratigraphic range, the Besa River Formation decreases in thickness from more than 2,700 feet in its type section, to 1,000-1,300 feet in the northwest.

The Besa River Formation extends eastward under the plains to about longitude 123°30'W., and is present in the most westerly wells south of latitude 59°N. In the SOBC HB Trimble c-98-L, HB Pan Am Muskwa a-6-G, Pacific -SR-Del Rio Kledo c-14-G, and Pan Am Sheep Creek #1 wells (Localities 43, 39, 34, and 35 respectively), the formation is overlain by Mississippian carbonates and is transitional with the Banff Formation of the plains. Here, the dark grey to black shale of the Besa River Formation is interbedded with medium-grey calcareous shale and argillaceous limestone of the Banff. In this area the basal Mississippian black shale of the Exshaw Formation is easily recognized on gamma ray logs by its relatively high radioactivity. In wells farther west, where the Exshaw Formation is less radioactive, it is indistinguishable from the Besa River Formation. Combined evidence from surface and subsurface observations shows that the facies change from Lower Mississippian units of the plains to the Besa River shale in the west takes place along a line which trends almost exactly north.

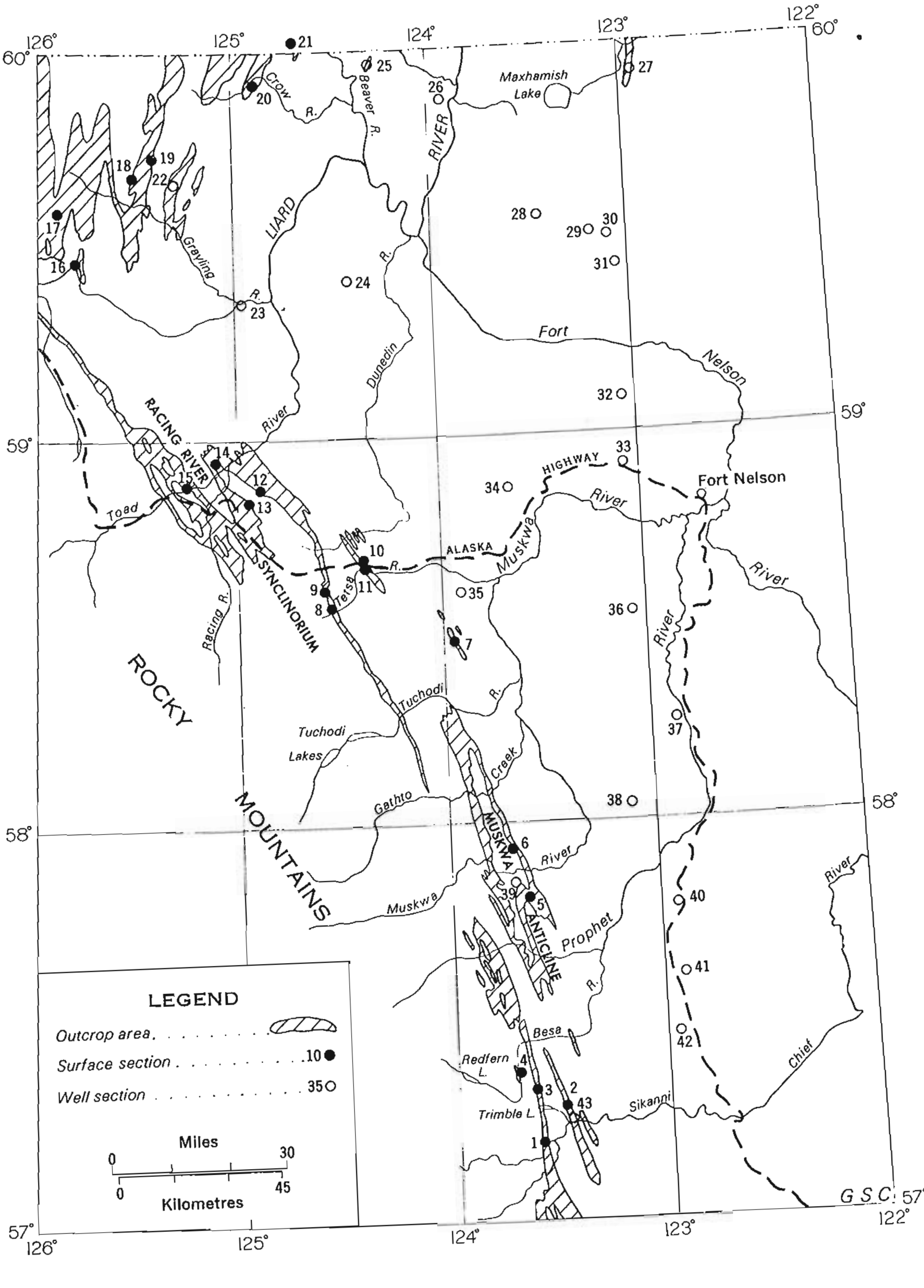
The Prophet Formation is a sequence of limestone, chert and dolomite of Mississippian age, named by Sutherland (1958), who divided it into Members A, B, and C, from base to top. The thickness decreases northwestward, from a maximum of 1,380 feet on Halfway River, to 11 feet at a point 3 miles north of the Alaska Highway near the headwaters of Dunedin River. The carbonate and chert of the Prophet Formation pass westward into Besa River shale and mudstone. In eastern exposures of the Prophet Formation (including the type section), Member A consists of approximately 500 feet of banded orange-brown and dark grey, slightly recessive siltstone, mudstone, chert, and silty limestone. Member B consists of 500-600 feet of irregular lenses and beds of chert, limestone, and dolomite, with chert making up 60-70 per cent of the member. This member forms the resistant, dark grey-banded cliffs that characterize the Prophet Formation in outcrop. Member C consists of 150-200 feet of limestone and chert. To the west, the Prophet

Formation is thinner and has a greater chert content. North of Trimble Lake (Locality 3), Member A consists mainly of siliceous mudstone. Member B, which is reduced in thickness to 425 feet, is 85-90 per cent chert, with minor limestone and dolomite lenses, and contains several shale and siltstone beds. Shale and siltstone also occur in Member C, which is 175 feet thick. Thinning of the Prophet Formation continues in a westerly direction. At the western edge of the foothills the formation is reduced to thin chert units which contain minor lenses of limestone and dolomite, and are separated by shale tongues of the Besa River Formation.

To the east, the Prophet Formation can be recognized in two foothills wells, SOBC HB Trimble c-98-L and Pan Am Sheep Cr. #1 (Localities 43, and 35). In wells farther east, the equivalent stratigraphic interval is assigned to the Debolt, Shunda and Pekisko Formations. The Shunda and Pekisko Formations consist of fossiliferous, argillaceous limestone, calcareous shale, and calcarenite, that pass laterally into Member A of the Prophet Formation and the uppermost Besa River Formation. The Debolt Formation consists of thick bioclastic limestone interbedded with thin shale. The lower and upper members of the Debolt Formation are equivalent to Members B and C of the Prophet Formation. The chert content of the lower member of the Debolt Formation, which is relatively low in eastern wells, becomes progressively higher toward the west, and chert is dominant in Member B of the Prophet Formation.

The Stoddart Formation is a sandstone, shale, and limestone succession between the Debolt Formation and the Permian beds in the subsurface. The subdivisions used in outcrop sections by Irish (1963) are recognizable locally in a narrow belt from the east end of Trimble Lake to the confluence of Keily Creek and Besa River. The lithology of the Stoddart Formation throughout the remainder of the area is transitional with that of either the Besa River Formation to the west, or the Mattson Formation to the north. The Stoddart Formation is absent from the easternmost Palaeozoic outcrops between Chlotopecta Creek and Halfway River. In this belt, the Prophet Formation is directly overlain by rocks of either Permian or Triassic age. East of this belt the Stoddart Formation is preserved in a south-plunging structural depression along the western margin of the plains (Localities 40, 41, and 42). The Stoddart Formation has been removed by pre-Permian erosion over the remainder of the subsurface area. Rocks equivalent to the Stoddart Formation are present beneath the Liard Syncline, but there the sequence has a greater affinity to the Mattson succession of the Northwest Territories. On the east flank of the Caribou Range, the upper half of the Besa River Formation contains numerous thin, lensing sandstone beds. These are probably tongues of the Mattson Formation, which is well developed in La Biche Range to the northwest.

The Kindle Formation was named by Laudon and Chronic (1949) for the siltstone, shale, siliceous limestone, and chert between the Besa River Formation and Triassic rocks exposed along the Alaska Highway between mile



126°
125°
124°
123°
122°
60°
59°
58°
57°
Maxhamish Lake
Crow R.
Beaver R.
LIARD RIVER
Grayling R.
Dunedin R.
Fort Nelson River
Fort Nelson
ALASKA HIGHWAY
Muskwa River
Toad
Tetsa R.
Racing R.
RACING RIVER SYNCLINORIUM
ROCKY MOUNTAINS
Tuchodi R.
Tuchodi Lakes
Gathto Creek
MUSKWA ANTICLINE
Muskwa River
Prophet R.
Besa
Redfern L.
Trimble L.
Sikanni Chief River
LEGEND
Outcrop area
Surface section . . . 10
Well section . . . 35
Miles
0
30
0
45
Kilometres
GSC

380 and mile 430. The Kindle Formation is well developed in the Racing River synclinorium and in a broad area surrounding the south end of Caribou Range. Its thickness increases from 291 feet at the type section in the Racing River synclinorium to 673 feet between Liard River and Caribou Range (Locality 17). Three units are recognizable within the Kindle Formation. The lower unit consists of dark grey-weathering siltstone with thin shale beds and some lensing beds of calcareous siltstone. The middle unit has a banded appearance produced by alternation of dark grey-weathering, argillaceous siltstone, and orange-weathering calcareous and dolomitic siltstone. This unit is recognizable as far north as Caribou Range and is present on the east flank of the Dunedin anticline. The upper unit consists of dark grey-weathering siliceous mudstone, shale, and minor chert. The upper part of the Kindle Formation is Permian in age, but the lower age limit of the formation is not precisely known. The lower and middle units of the Kindle Formation are tentatively correlated with the upper part of the Mattson Formation in southern La Biche Range. There, the uppermost Mattson Formation contains the Permian brachiopods Pterospirifer sp., Waagenoconcha sp., and ? Muirwoodia sp. (GSC Locs. 68830 and 68831). The sandstone beds within the lower unit of the Kindle Formation between Liard River and Caribou Range appear to be tongues of the upper Mattson Formation. The relationship between the upper unit of the Kindle Formation and the Fantasque Formation to the east has been definitely established. The Fantasque Formation is underlain by a sequence of siltstone, sandstone, shale, and limestone in the foothills between Toad and Halfway Rivers. This sequence is of Permian age in part, but its lower age limit is in doubt, and its exact stratigraphic relationship to the Kindle Formation has yet to be established. The succession in the foothills appears to correlate with the lower part of the Belloy Formation of the adjacent plains, and with Permian beds in the foothills between Halfway and Peace Rivers, which Irish (1963) included in the uppermost Stoddart Group.

The Fantasque chert is present in British Columbia at the south end of La Biche Range, and has a distribution similar to that of the older Permian rocks in the foothills between Halfway and Dunedin Rivers. The thickness of the formation decreases from 150 feet in the north to approximately 40 feet in the south, near Halfway River. In southern La Biche Range, and in the eastern and central foothills between Toad and Halfway Rivers, the Fantasque Formation is composed of irregularly bedded, medium to dark grey chert, which is pyritic in part and contains abundant sponge spicules. North of Tuchodi River the chert beds in the lower 10-15 feet of the unit are separated by laminae and thin beds of dark grey shale, as in the lower 22 feet of the type section. At the western edge of the foothills, near South Tetsa River, there are laminae and beds of shale throughout the formation, and the chert is interbedded with siliceous mudstone and siltstone. The Fantasque Formation is Permian in age. Helicoprion sp. and rare productoid brachiopods have been collected 81 feet below the top of the formation (GSC Loc. 66707). The Fantasque Formation has been recognized in the Halfway map-area by Irish (1963), and is probably equivalent to the upper chert of the Belloy Formation of the subsurface.

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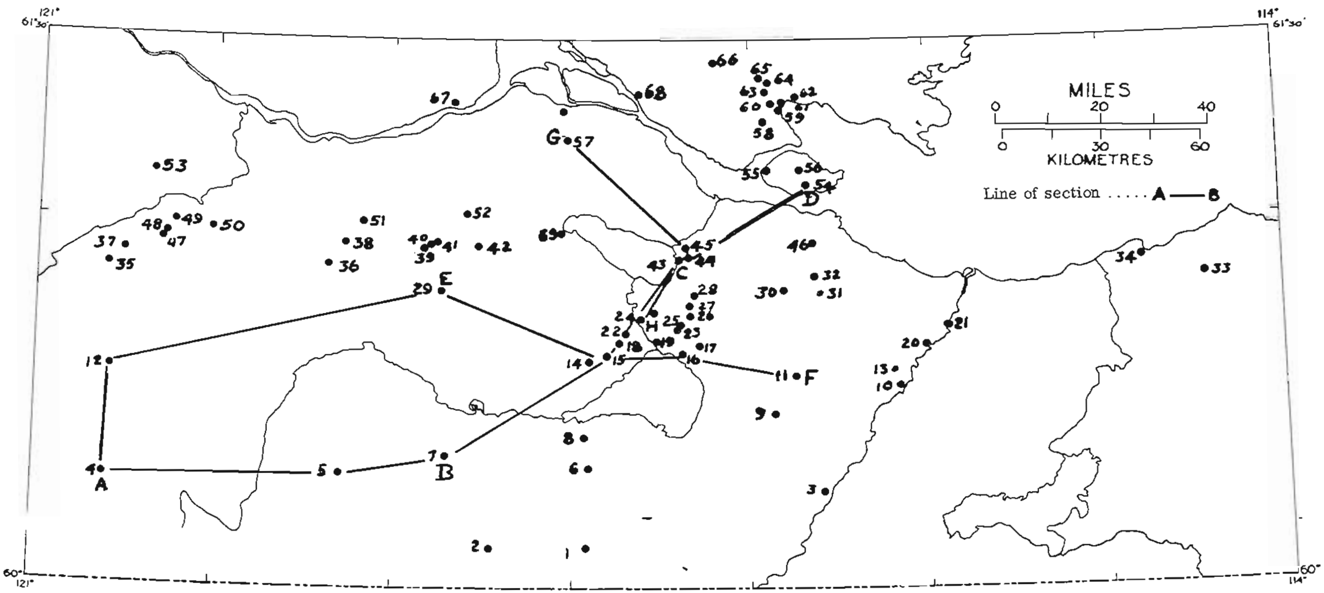
40. MIDDLE DEVONIAN DEPOSITION AND FACIES CHANGES, TATHLINA ARCH, NORTHWEST TERRITORIES

Helen R. Belyea

The Late Middle Devonian marine transgression over the Tathlina arch is not a simple progressive onlap. This is attested by the distribution of rock units, the presence of disconformities and the occurrence of the same fauna in the Rabbit Lake, Foetus Lake, and Deep Bay wells as is present high in the bituminous limestone and shale member of the Pine Point (Norris, 1965 and personal communication). Deposition began with the arkoses, sandstones and shales of the Lotsberg followed by the Ernestina Lake of the lower Elk Point Group. These flank the arch both to the southwest and northeast (Fig. 2). The Cold Lake is represented by a breccia in the Cominco Tests G1 and G4 at Pine Point; elsewhere, it is absent or is represented by sandstone, bright green, waxy non-calcareous shales and anhydrite. The upper Chinchaga, predominantly anhydrite, although thicker on the flanks, almost completely covers the arch (Fig. 3). The lower part of the succeeding basal dolomite member of the Pine Point covers the arch whereas higher dolomite beds present on the flanks, are missing over the top (Fig. 4). A platform carbonate (Fig. 5), mostly brown limestone with bituminous shale laminae forms a unit of almost constant thickness over the basal dolomite. The lower part of this member and the basal dolomite form the Lower Keg River of Hriskevitch (1966). The upper part, limestone changing in certain areas to crystalline vuggy dolomite (Fig. 7), is the lowest member of the Upper Keg River of Hriskevitch, and forms the foundation on which the Keg River reefs developed. Interbedded bituminous limestones and shales on the flanks of the arch disappear either by condensation or disconformity into a thin black shale over the arch. The relationship of these units is shown on Figure 6.

The succeeding black bituminous shales with distinctive gamma ray characteristics are taken as the base of the upper part of the Pine Point. They grade up to a sequence of interbedded dark brown bituminous limestones and shales that contain stromatoporoid debris in the vicinity of the reefs. This unit condenses as it encroaches on the arch and is probably equivalent to the vuggy dolomites of the Upper Keg River (Fig. 8).

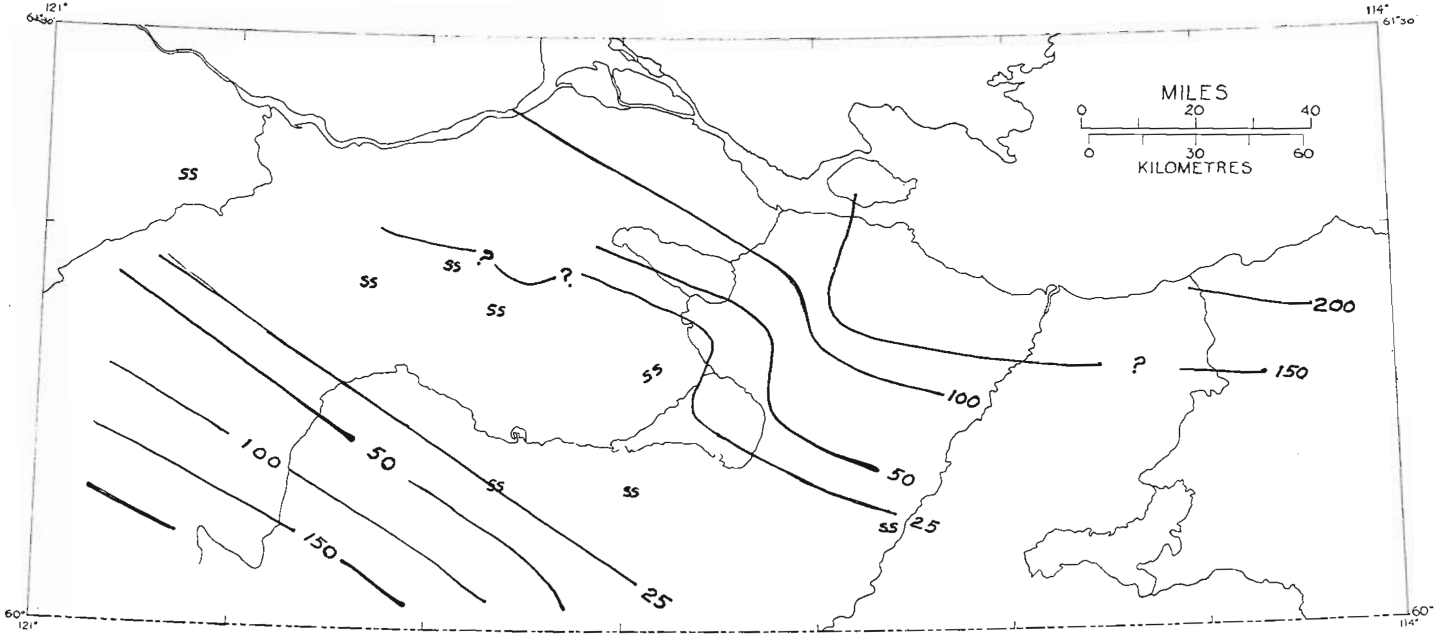
The overlying upper Pine Point shows a facies distribution of greenish grey or brown shales in lateral juxtaposition with stromatoporoid-rich limestone or vuggy dolomite grading to anhydrite (Fig. 9). These beds are not present on the upper part of the arch as a result of pre-Sulphur Point erosion or non-deposition. Figure 10 shows the unconformable relationship of these formations.



1. Shell Kakisa River 1
2. Shell Kakisa River 2
3. Murphy Canada Alexandra Falls 2
4. Trainor Lake C-39
5. Shell Mobil Alexandra 6
6. Shell Alexandra 4
7. Shell Alexandra 7
8. Shell Alexandra 2
9. Murphy Canada Alexandra Falls 1
10. *Union Alexandra Falls Test 6
11. Shell Alexandra 5
12. *Briggs Tetcho Lake 1
13. *N.W.T. Escarpment Lake 1
14. Briggs West Tathlina Lake 1
15. Briggs West Tathlina Lake 2
16. Calstan Tathlina D-39
17. *Calstan Tathlina K-10
18. Briggs West Tathlina Lake 3
19. Briggs Tathlina Lake
20. *Cominco Hay River Test G-2
21. *Frobisher Hay River Test 8
22. Wilkinson West Tathlina Lake 4
23. *Briggs Tathlina Lake 7
24. Wilkinson Kakisa River 1
25. Briggs N.E. Tathlina Lake 9
26. *Briggs Tathlina Lake 8
27. *Briggs N.E. Tathlina Lake 1
28. *Briggs N.E. Tathlina Lake 2
29. Calstan Imperial Bouvier
30. N.W.T. Desmarais Lake 1
31. *N.W.T. Heart Lake 1
32. *N.W.T. Heart Lake 2
33. Cominco Pine Point Test G-1
34. Cominco Sulphur Pt. Test G-4
35. Briggs Trout River 1
36. Wilkinson Redknife River 2
37. *Briggs Trout River 5
38. Imperial Redknife N-6
39. Briggs Rabbit Lake 2
40. Briggs Rabbit Lake 1
41. *Briggs Rabbit Lake 3
42. Briggs Foetus Lake 1
43. Pan Am-Shell Kakisa I-44
44. Pan Am-Shell Kakisa H-36
45. Pan Am-Shell Kakisa F-35
46. Briggs Great Slave Lake 1
47. Briggs Trout River 2
48. Briggs Trout River 6
49. Briggs Trout River 4
50. Briggs Trout River 3
51. *Wilkinson Redknife River 1
52. Briggs N.E. Rabbit Lake 1
53. Briggs Turkey Lake 1
54. Calstan Big Island G-56
55. N.W.T. Big Island 1
56. N.W.T. Big Island 2
57. Calstan Mills Lake C-3
58. *N.W.T. Deep Bay 1
59. *N.W.T. Deep Bay 2
60. Punch Deep Bay 4
61. *N.W.T. Deep Bay 4
62. N.W.T. Deep Bay 3
63. Punch Deep Bay 2
64. *Punch Deep Bay 3, 6
65. *Punch Deep Bay 7
66. *Punch Deep Bay 5
67. *N.W.T. 2
68. N.W.T. 1
69. Pan-Am Shell Kakisa L-19

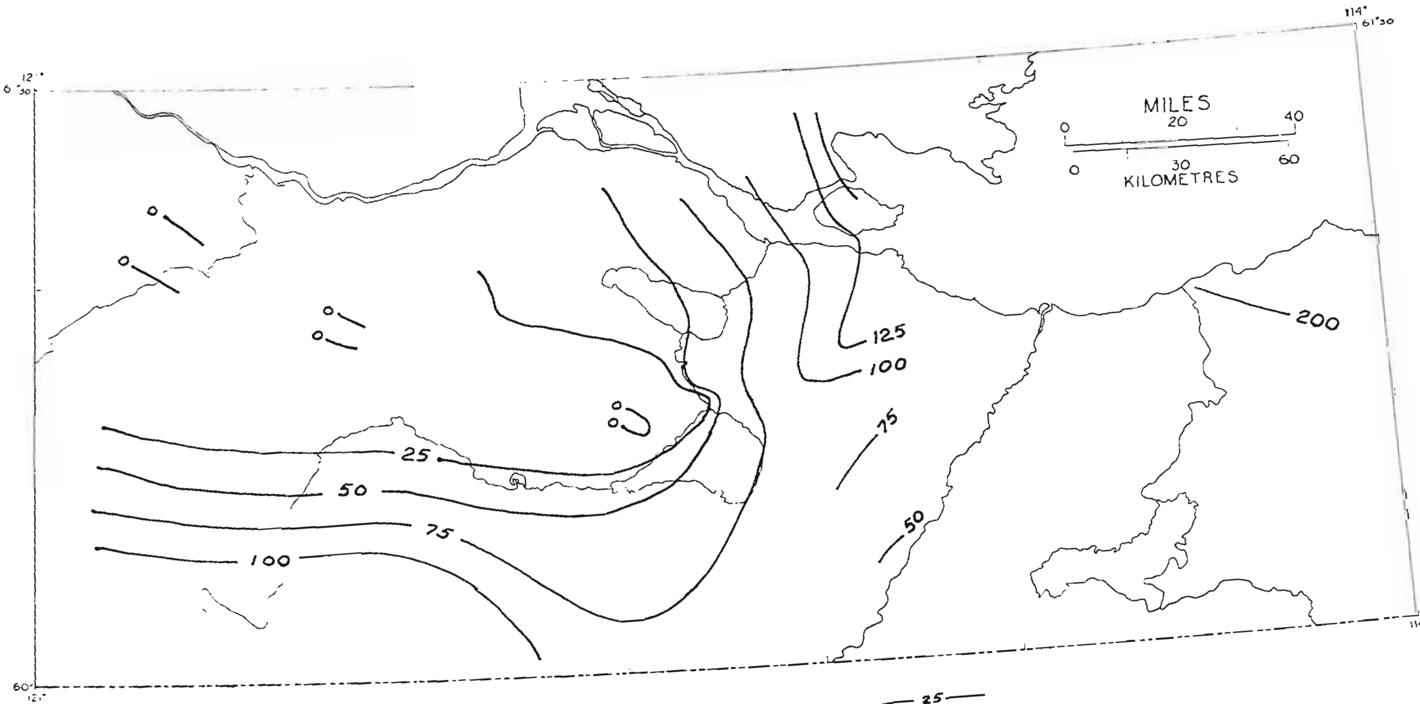
*Well not drilled to basement

Figure I. Index Map.



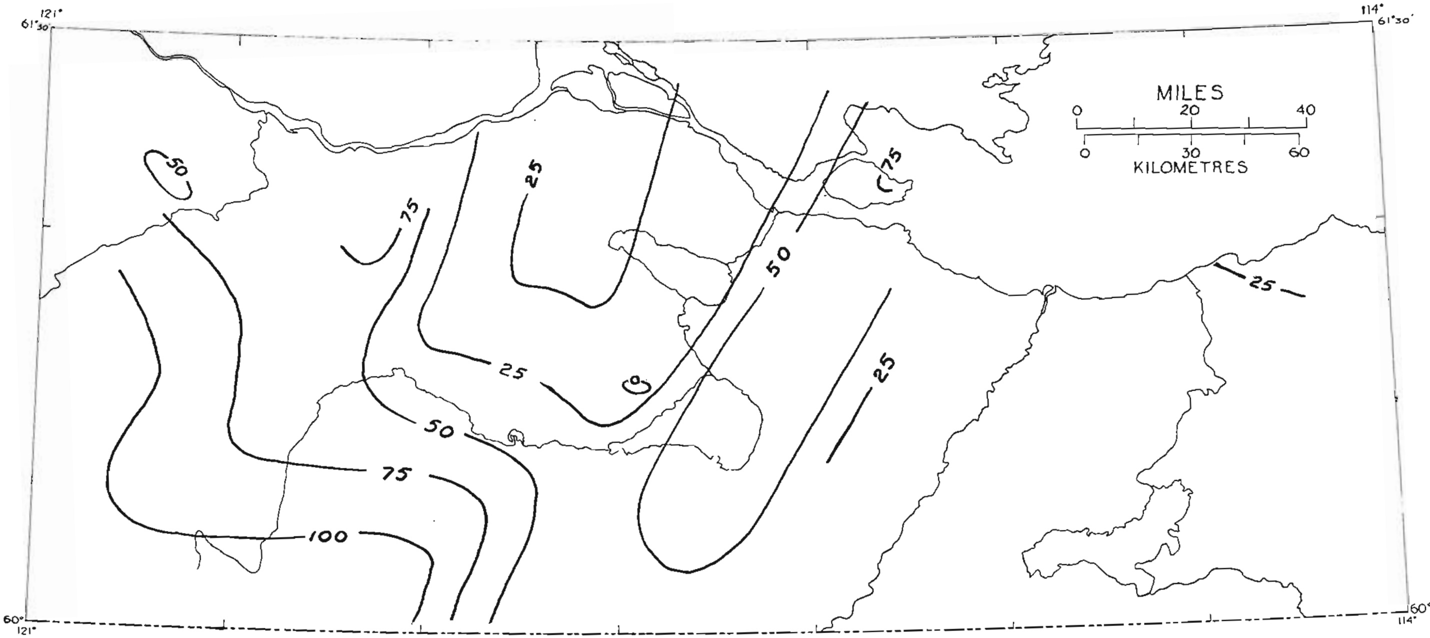
SS, Basal sandstone (in part probably equivalent of Lower Elk Point)
Isopachs (interval 50 feet) .... ——50——
Facies boundary — — —

Figure 2. Lower Elk Point Isopach Map. Top is a regional unconformity.



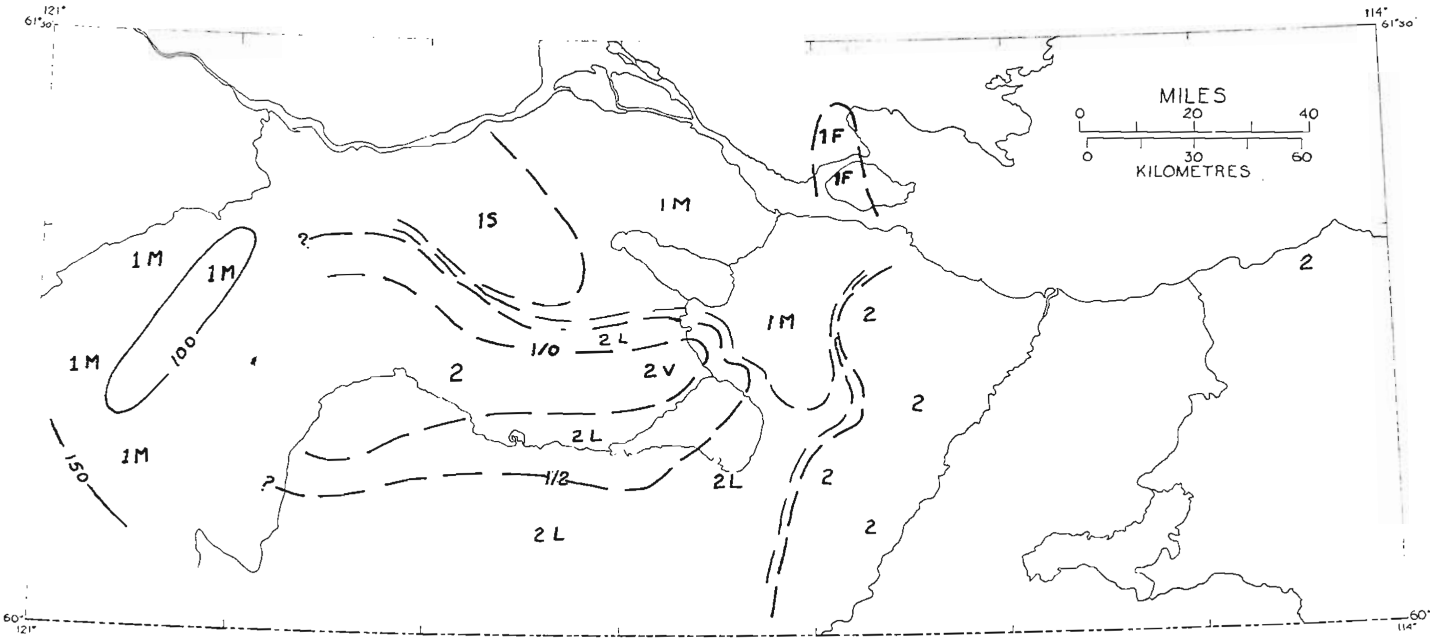
Isopachs (interval 25 feet) 25

Figure 3. Upper Chinchaga Isopach Map.



Isopachs (interval 25 feet)................ 25

Figure 4. Basal dolomite member. The top of this member is a disconformity.



1, Limestone; 1M, Lime mudstone; 1F, bioclastic grainstone, frame-building organisms, reefs; 1S, limestone with black shale over 25%. 2, Dolomite, crystalline, mosaic texture; 2V, Dolomite with vugs. 2L, dolomite and Limestone

Isopach (interval 50 feet) .... —— 50 ——

Facies boundary .... — — —

Dolomite-Limestone ratio 1/2

Figure 5. Platform carbonate, includes Lower Keg River above the basal dolomite and lowest member of Upper Keg River Formation. This unit thins slightly by condensation over the top of the arch but is only locally less than 130 feet thick.

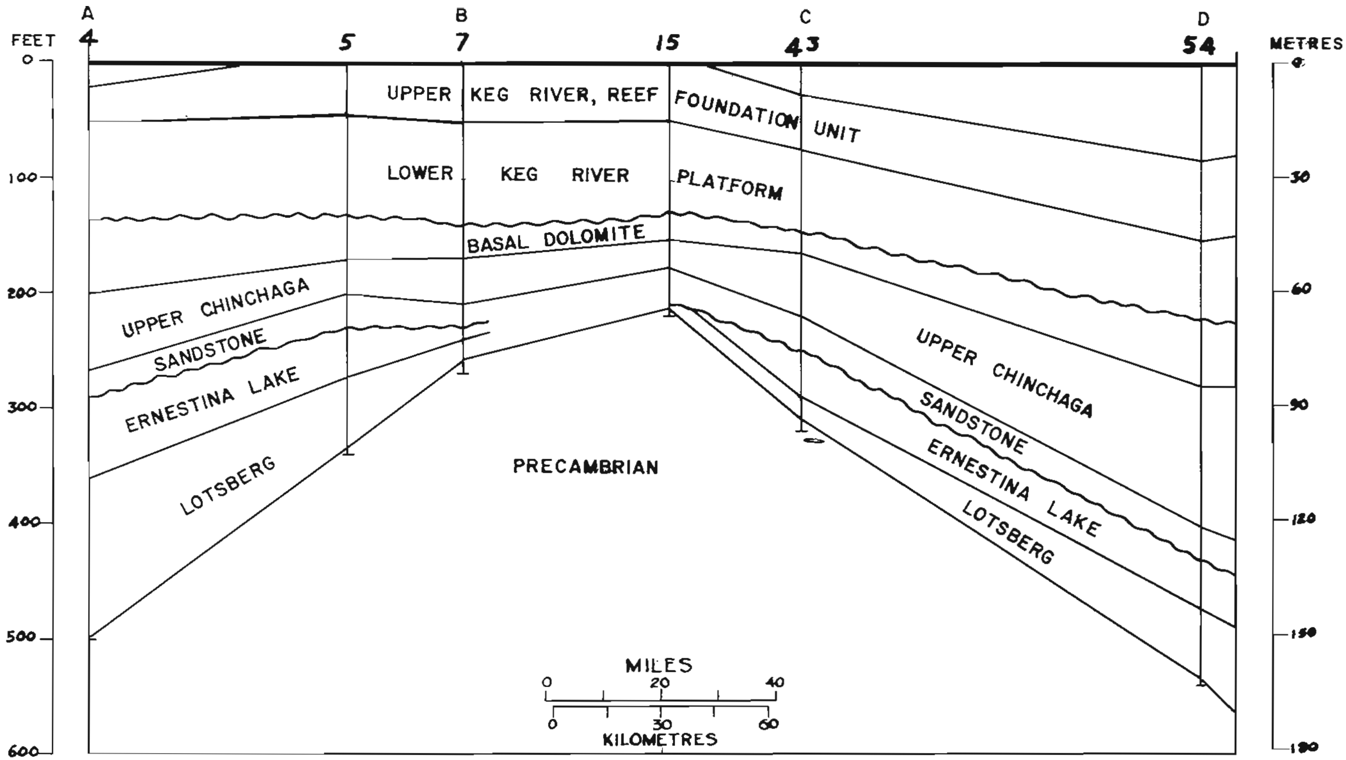
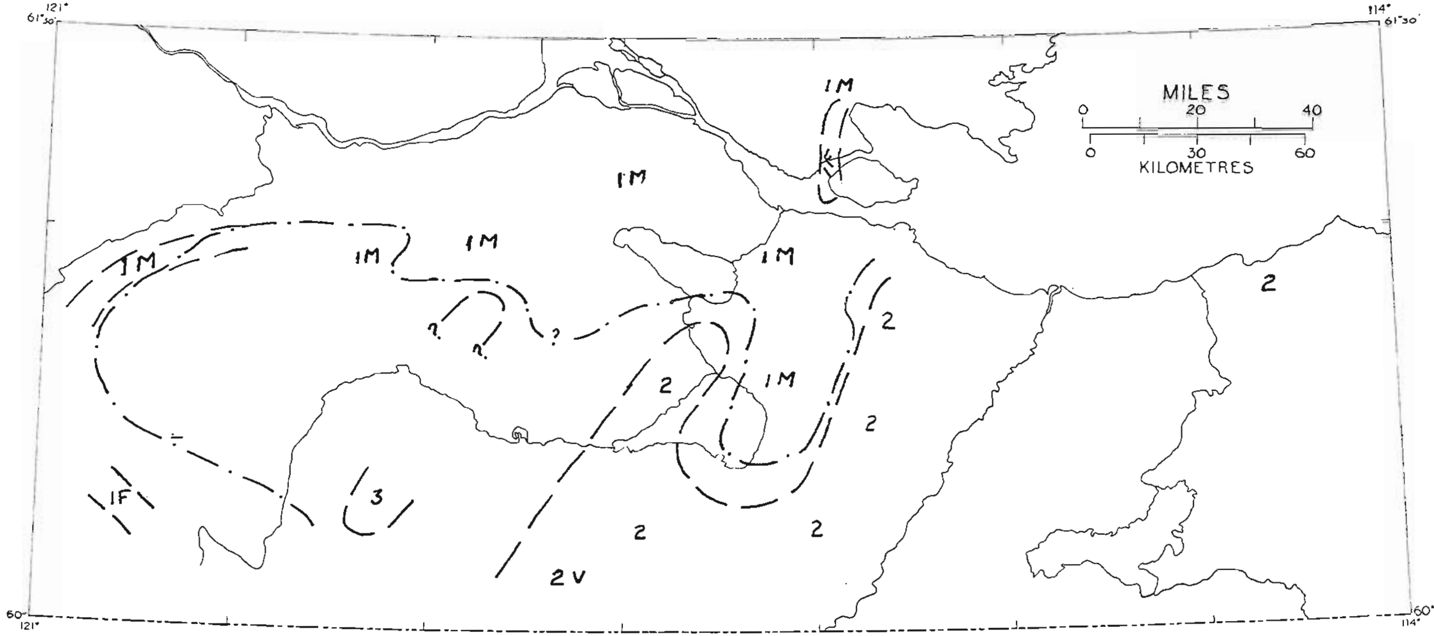


Figure 6. Section A-B-C-D. Shows relationship of Lower Elk Point, Chinchaga and lower Pine Point platform to the arch. Unconformities occur at the top of Lower Elk Point and basal dolomite member of Pine Point. Datum is the base of the maximum transgression of the black shale member (Horn River tongue).

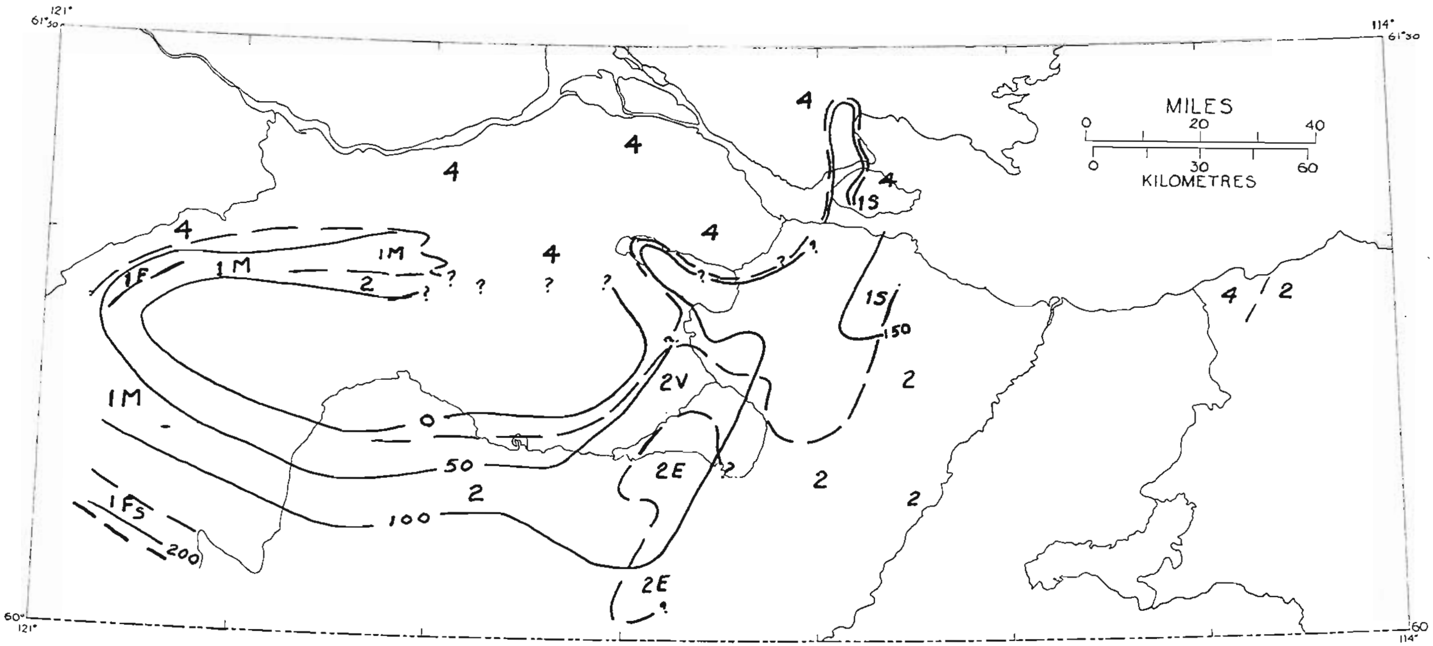


1, Limestone: 1M, lime mudstone with crinoid, brachiopod, ostracod fauna; 1F, Frame-building organisms present. 2, Dolomite, fine to medium crystalline; 2V, vugs. 3, Dolomite, white, coarse, recrystallized.

Facies boundary.......................... — — —

Limit of black bituminous limestone and shale, except for thin black shale layer present over most of arch . . . . —·—·—

Figure 7. Lower carbonate member of Upper Keg River, the foundation unit of the Keg River reefs. It is 35 to 50 feet thick. The top builds up to a bituminous limestone and shale on periphery of arch, condenses into black shales over most of arch or is truncated below black shale (Horn River tongue).

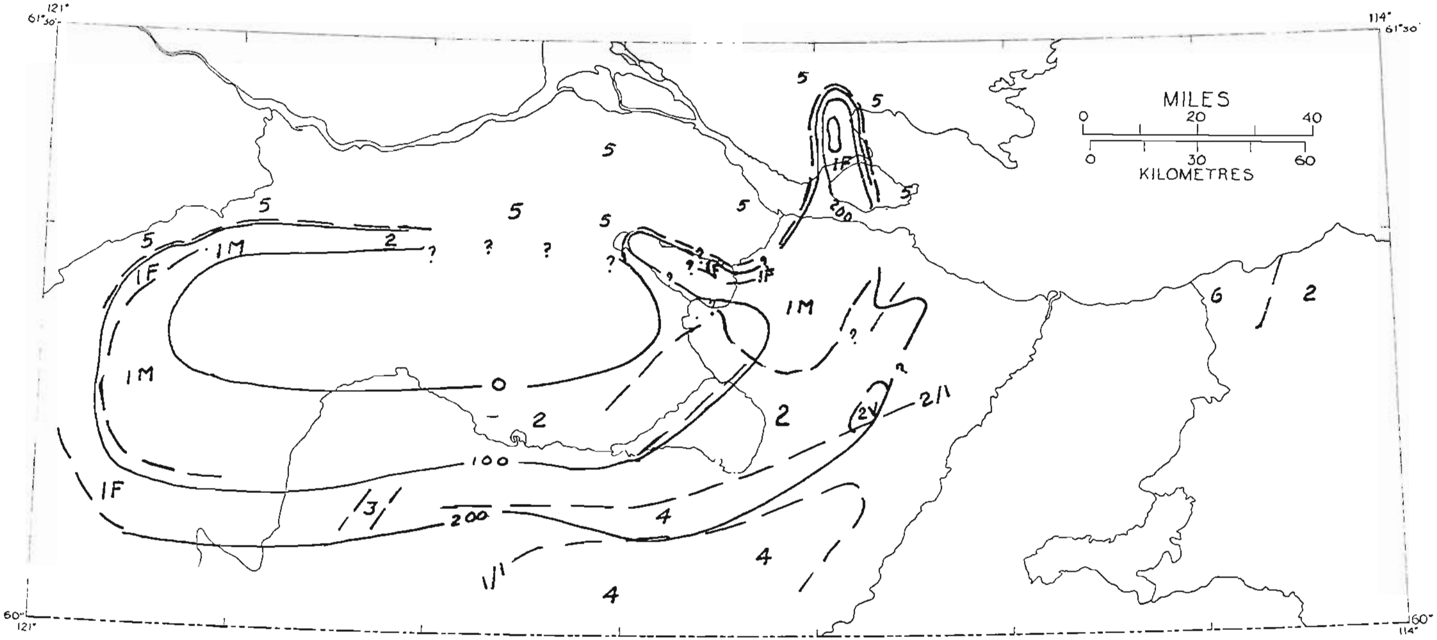


1, Limestone; 1M, lime mudstone; black shale laminae, brachiopods, crinoids; 1F, bioclastic grainstone, frame-building organisms, reefs; 1S, limestone and black shale interbedded. 2, Dolomite, yellow brown, fine, medium crystalline; 2V, dolomite with vugs; 2E dolomite, euhedral, evaporitic, in places anhydritic. 3, Dolomite and anhydrite. 4, Shales, Middle Devonian

Isopach (interval 50 feet).................. —— 50 ——

Facies boundary.......................... — — —

Figure 8. Upper Keg River bituminous limestone and shale and stratigraphically equivalent dolomites.



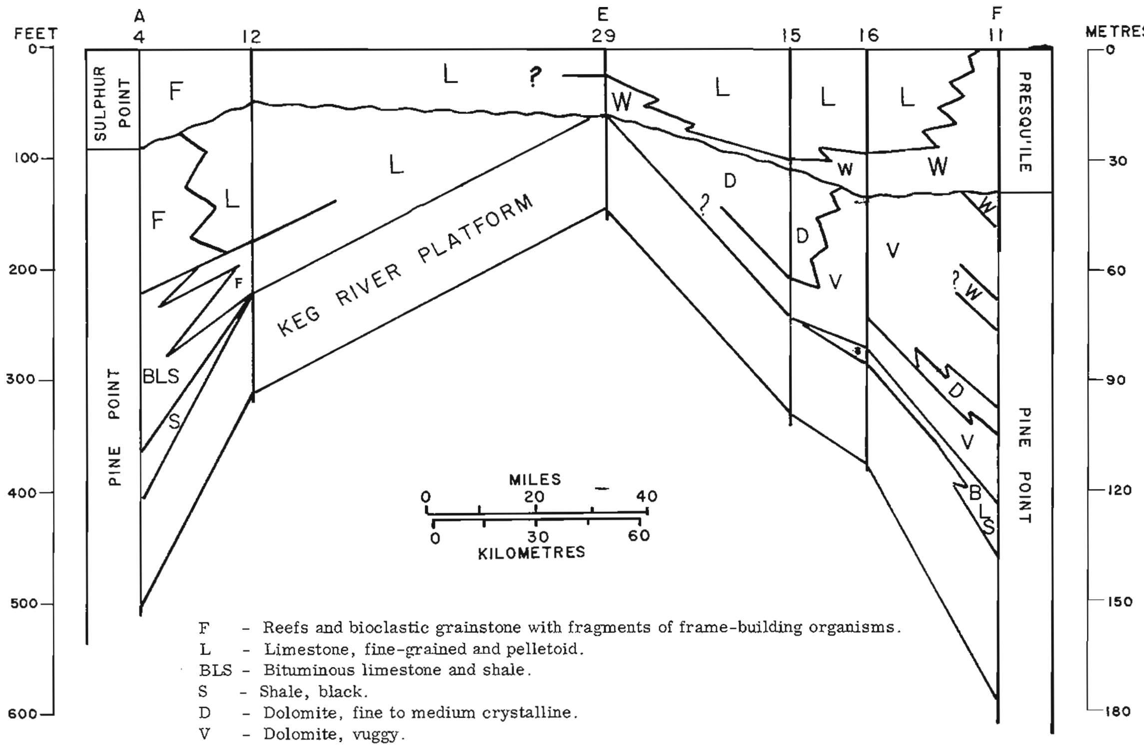
1, Limestone; 1M, lime mudstone; 1F, bioclastic grainstone, local reefs, contains stromatoporoids, corals; 1S, limestone and black shale, interbedded. 2, Dolomite. 2V, vuggy dolomite. 3, Dolomite, white,coarse, recrystallized. 4, Dolomite and anhydrite. 5, Middle and Upper Devonian shales. 6, Middle Devonian shale

Isopach (interval 100 feet)................ ——— 100 ———

Facies boundary .... ——— ——— ———

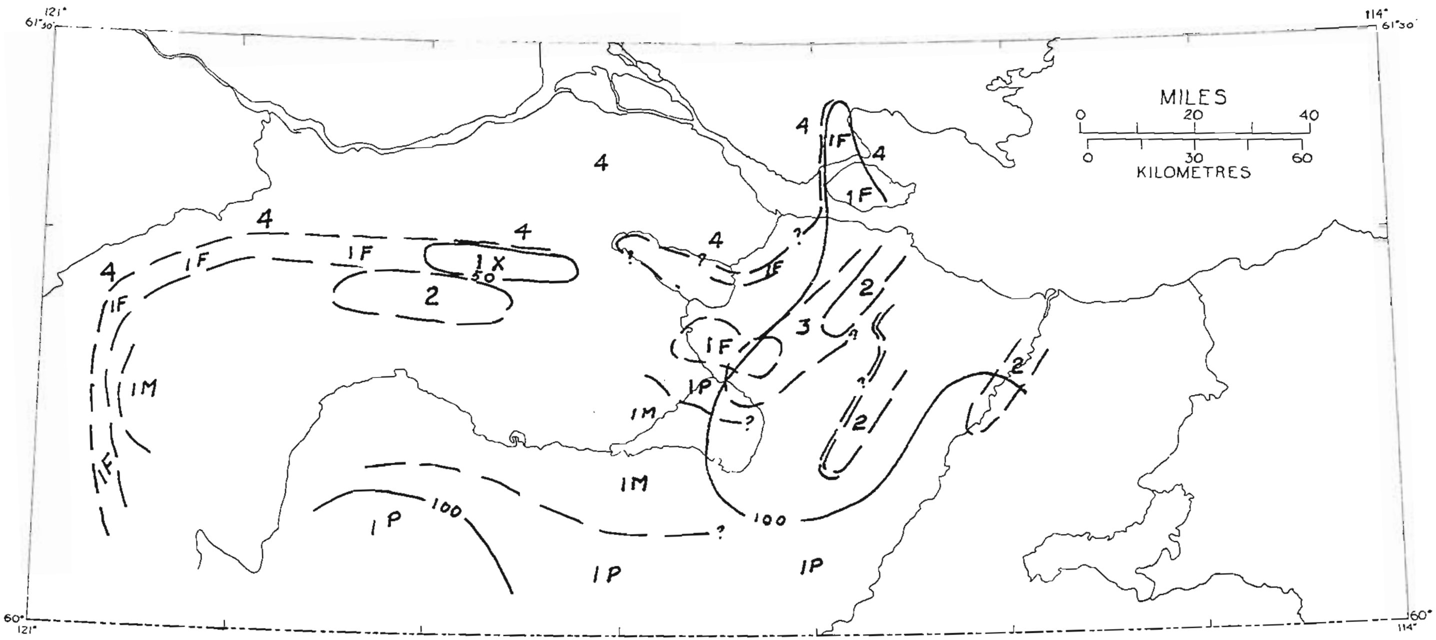
Dolomite-anhydrite ratio 2/1

Figure 9. Upper Pine Point Isopach and Lithofacies Map. Area of erosion or non-deposition on top of arch.



F - Reefs and bioclastic grainstone with fragments of frame-building organisms.
L - Limestone, fine-grained and pelletoid.
BLS - Bituminous limestone and shale.
S - Shale, black.
D - Dolomite, fine to medium crystalline.
V - Dolomite, vuggy.
W - Dolomite, white, coarse, recrystallized.

Figure 10. A-E-F. This section shows (1) Thinning of the bituminous limestone and shale on the flanks of the arch by condensation or disconformity to a thin black shale over the arch; (2) Truncation of the Pine Point by unconformity below the Sulphur Point; (3) Relationship of carbonate facies to the flanks of the arch. Note that Presqu'ile type dolomitization seems to follow the unconformity and possibly to follow porous beds into the Pine Point.

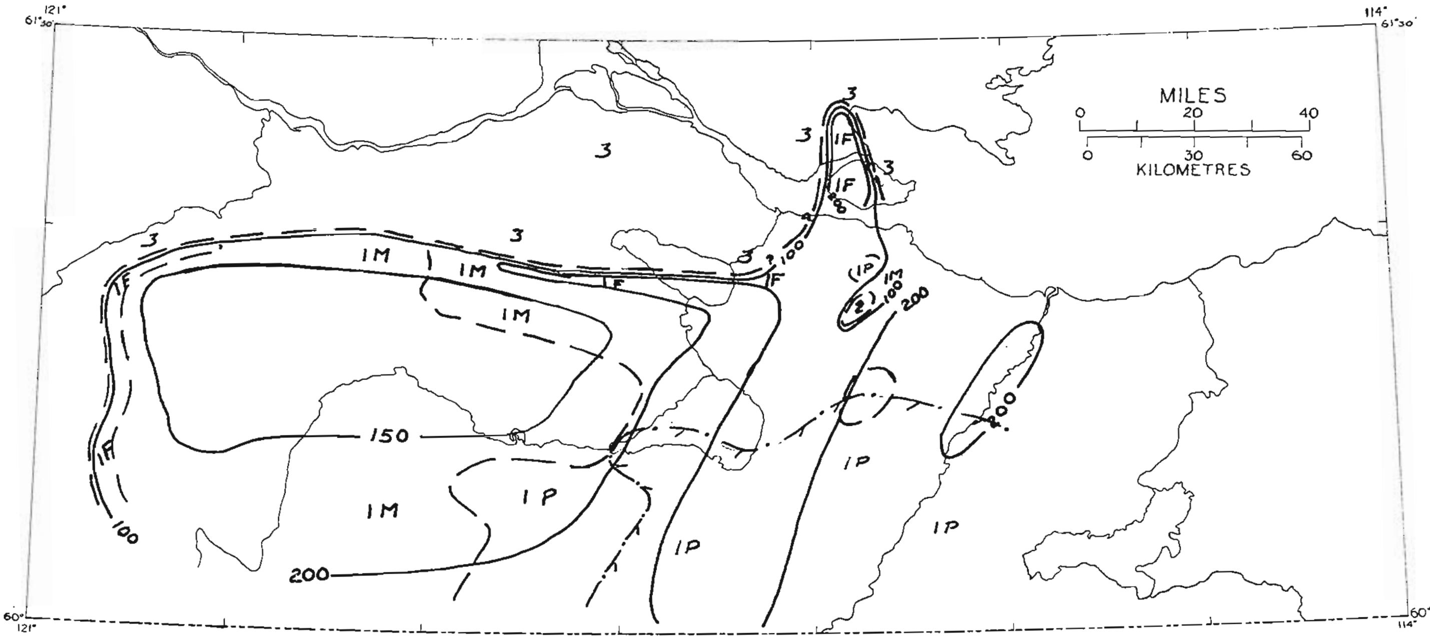


1, Limestone; 1M, lime mudstone, in places clotted, 1F, bioclastic grainstone, reefs, stromatoporoids, corals; 1X, limestone breccia with green shale; 1P, non-skeletal grainstone. 2, Dolomite; white coarse crystalline (Presquile Formation). 3, Limestone, underlain by coarse white crystalline dolomite.

Isopach (interval 50 feet) .... —— 50 ——

Facies boundary .... —— —— ——

Figure 11. Sulphur Point-Presquile Isopach and Lithofacies Map.



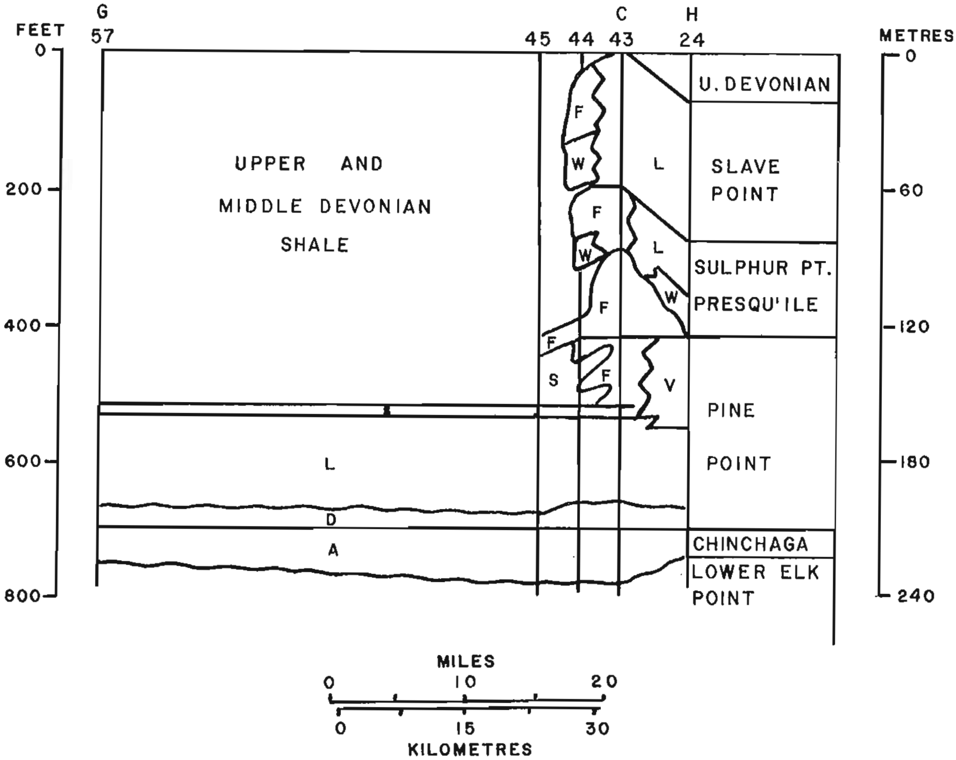
1, Limestone; 1M, lime mudstone; patches of pellets, some zones with stromatoporoid fragments. 1F, bioclastic grainstone, frame building organisms, reefs; stromatoporoids. 1P, stromatoporoid and pelletoid limestone zones common. 2, Dolomite, coarse white recrystallized. 3, Middle and Upper Devonian shales.

Isopach (interval 50 feet) .... —— 50 ——

Facies boundary .... — — —

Limit of Fort Vermilion Member-anhydrite and dolomite

Figure 12. Slave Point Formation, Isopach and Lithofacies Map. Upper surface is locally channelled.



F - Frame-building organisms, reefs, bioclastic grainstone.
L - Limestone, fine-grained and pelletoid.
V - Dolomite, fine to medium crystalline, vuggy.
D - Dolomite, finely crystalline, euhedral, evaporitic.
W - Dolomite, white, coarse, recrystallized.
S - Shale, black, bituminous.

Figure 13. Section G-C-H illustrates the facies at the carbonate "front" on the northeast flank of the arch. The Horn River bituminous limestones and shales transgress the platform in juxtaposition with the upper Keg River dolomite. The upper Pine Point carbonate with frame-building organisms extends outward over the limestone shale unit. It is trucated high on the arch and is overlain by the Sulphur Point and succeeding Slave Point. Both these formations contain abundant frame-building organisms at the front and are there partly replaced by coarse recrystallized white dolomite.

The Sulphur Point, white to light grey limestone, covers the arch. The facies distribution is shown in Figure 11. It is locally altered entirely to white, coarse crystalline dolomite; elsewhere it is underlain by a thin recrystallized dolomite layer, the distribution suggesting that recrystallization followed the unconformity between the Sulphur Point and Pine Point, in places affecting the underlying Pine Point as well as the Sulphur Point.

The Slave Point similarly forms a blanket deposit of fine-grained limestone over the arch with a stromatoporoid-rich zone at the top. Along the margins of the arch the whole formation becomes richly stromatoporoidal (Fig. 12). The top has been channelled and the formation locally removed before deposition of Upper Devonian shales.

The distribution of the units figured in the diagrams and the presence of unconformities suggest pulsating uplift of the Tathlina arch. The linear pattern of the distribution of stromatoporoid-rich and vuggy dolomite facies suggest that the uplift may have been at least in part the result of periodic reactivation of the arch along fault zones.

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Hriskevich, M. E.
1966: Stratigraphy of Middle Devonian and older rocks of Banff Aquitaine Rainbow West 7-32 Discovery well, Alberta; Bull. Can. Petrol. Geol., vol. 14, pp. 241-265.

41. GOLDEN, EAST HALF, MAP-AREA (82 N E 1/2), BRITISH COLUMBIA AND ALBERTA

R. A. Price

The bedrock geology of Golden, East Half, map-area was investigated as part of Operation Bow-Athabasca, a reconnaissance study of about 12,000 square miles of the Rocky Mountains between Mount Assiniboine and Mount Robson. The geologic structure and other aspects of the regional geology of the map-area have been discussed in previous reports on Operation Bow-Athabasca, which included sketch maps of adjoining areas (Price and Mountjoy, 1966, Price 1967). The following is supplementary to these and should be read in conjunction with them.

The geology of the area is outlined in the map of Figure 1. This map incorporates the results of regional reconnaissance studies by R.A. Price and E.W. Mountjoy, as well as those of more detailed studies of the structural relationships between the 'carbonate' and 'slate facies' of the lower Palaeozoic sequence near Field, B.C. by D.G. Cook, of the structure of the Western Ranges of the Rocky Mountains northwest of Highway No. 1 by H.R. Balkwill, and of the pre-Devonian stratigraphy of the region by J.D. Aitken.

Structural features associated with the abrupt and pronounced southwesterly change from a 'carbonate facies' to a 'slate facies' in the Middle and Upper Cambrian and the Ordovician that have been discussed by Price (1967), are illustrated in Figure 1. The position of the facies boundary for the Middle Cambrian, where not obscured by faulting, is shown by a 'saw-tooth' line that marks an arbitrary cut-off between the Cathedral, Stephen, Eldon, Pika, Arctomys, and Waterfowl Formations on the northeast and the lower and middle units of the Chancellor Group on the southwest. The overlying beds comprise the Sullivan and Lyell Formations in the northeast and the upper unit of the Chancellor Group and the Ottertail Formation in the southwest. Studies by Aitken (1967) have confirmed the correspondence of the Ottertail and Lyell Formations and the correlation of the upper slate unit of the Chancellor with the Sullivan Formation.

The broad, asymmetric, fan-shaped anticlinorium that dominates the structure of the western part of the Main Ranges of the Rocky Mountains extends southeast of Highway No. 1 with a more subdued form. There, the alkaline Ice River igneous complex has been emplaced along the comparatively flat top of the structure. Calc-silicate skarn, marble, and other contact metamorphic phenomena observed along both the hanging-wall and foot-wall confirm Allan's (1914) conclusions regarding the intrusive contacts of the complex.

Tight southwesterly overfolds and a complex pattern of longitudinal and transverse faults characterize the Western Ranges subprovince of the

Rocky Mountains immediately northeast of Highway No. 95 and the Rocky Mountain Trench. These mark the core of a synclinorium that shares a common, and apparently unbroken, limb with the anticlinorium of the western Main Ranges. The youngest rocks observed with the synclinorium comprise gypsum that occurs above the Harrogate Formation along the crest of Beaverfoot Range.

The Canyon Creek Formation occurs in the west limb of the synclinorium along the west wall of the Rocky Mountain Trench, and has yielded trilobite fragments of late Upper Cambrian age (W.H. Fritz, personal communication 1966). It is in stratigraphic contact with the McKay Group, but is separated from the Donald Formation and older rocks by faults. Accordingly, the stratigraphic relationships between the Canyon Creek and Donald Formations have not been established and a substantial part of the Cambrian sequence between them may be missing in this region as a result of faulting.

Northeasterly overfolds and southwest-dipping faults in the Lower Cambrian and Windermere rocks of Dogtooth Range provide a marked contrast with the structure across the Rocky Mountain Trench in the Western Ranges of the Rocky Mountains. The Trench in this area is an erosional feature whose locus appears to have been controlled exclusively by the weak slates of the McKay Group.

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1967: Pre-Devonian Stratigraphy, Southern Rocky Mountains; in Report of Activities, Part A: May to October, 1966; Geol. Surv. Can., Paper 67-1, Part A, pp. 96-97.

Allan, J.A.
1914: Geology of Field map-area, British Columbia and Alberta; Geol. Surv. Can., Mem. 55.

Price, R.A. and Mountjoy, E.W.
1966: Operation Bow-Athabasca, Alberta and British Columbia; in Report of Activities, May to October, 1965; Geol. Surv. Can., Paper 66-1, pp. 116-121.

Price, R.A.
1967: Operation Bow-Athabasca, Alberta and British Columbia; in Report of Activities, Part A: May to October, 1966; Geol. Surv. Can., Paper 67-1, Part A, pp. 106-112 (1967).

TRIASSIC, JURASSIC, AND CRETACEOUS

13 Spray River, Fernie, and Blairmore Groups and Kootenay Formation

DEVONIAN, MISSISSIPPIAN, PENNSYLVANIAN, AND PERMIAN

12 Fairholme Group, Alexo, Palliser, Exshaw, and Banff Formations, Rundle and Rocky Mountain Groups (comprises basal Devonian unit, Harrogate Formation and unnamed gypsum unit in the southwest)

DEVONIAN (?)

11 Ice River complex

UPPER CAMBRIAN AND ORDOVICIAN

10 (Eastern 'carbonate facies') Sullivan, Lyell, Bison Creek, Mistaya, Mons, Sarbach, unnamed carbonate, Skoki, Mount Wilson, and Beaverfoot Formations

ORDOVICIAN

9 (Western facies) Beaverfoot, Mount Wilson, and Glenogle Formations

UPPER CAMBRIAN AND ORDOVICIAN

8 (Western 'shaly facies') McKay and Goodsir Groups

UPPER CAMBRIAN

7 (Western 'shaly facies') Ottertail Formation

6 (Western 'shaly facies') upper unit of Chancellor Group

MIDDLE (?) AND UPPER CAMBRIAN

5 (Western 'shaly facies') Canyon Creek Formation

MIDDLE CAMBRIAN

4 (Western 'shaly facies') lower and middle units of Chancellor Group

3 (Eastern 'carbonate facies') Mount Whyte, Cathedral, Stephen, Eldon, Pika, Arctomys, and Waterfowl Formations

LOWER CAMBRIAN

2 Gog Group and equivalent strata

WINDERMERE

1 Miette Group and equivalent strata

Geological contact . . . .

Thrust fault . . . .

Gravity fault . . . .

Fault (undifferentiated) . . . .

Anticline . . . .

Syncline . . . .

Geology by R. A. Price, E. W. Mountjoy, J. D. Aitken, and D. G. Cook, 1965, R. A. Price, E. W. Mountjoy, D. G. Cook, H. R. Balkwill, and J. D. Aitken, 1966

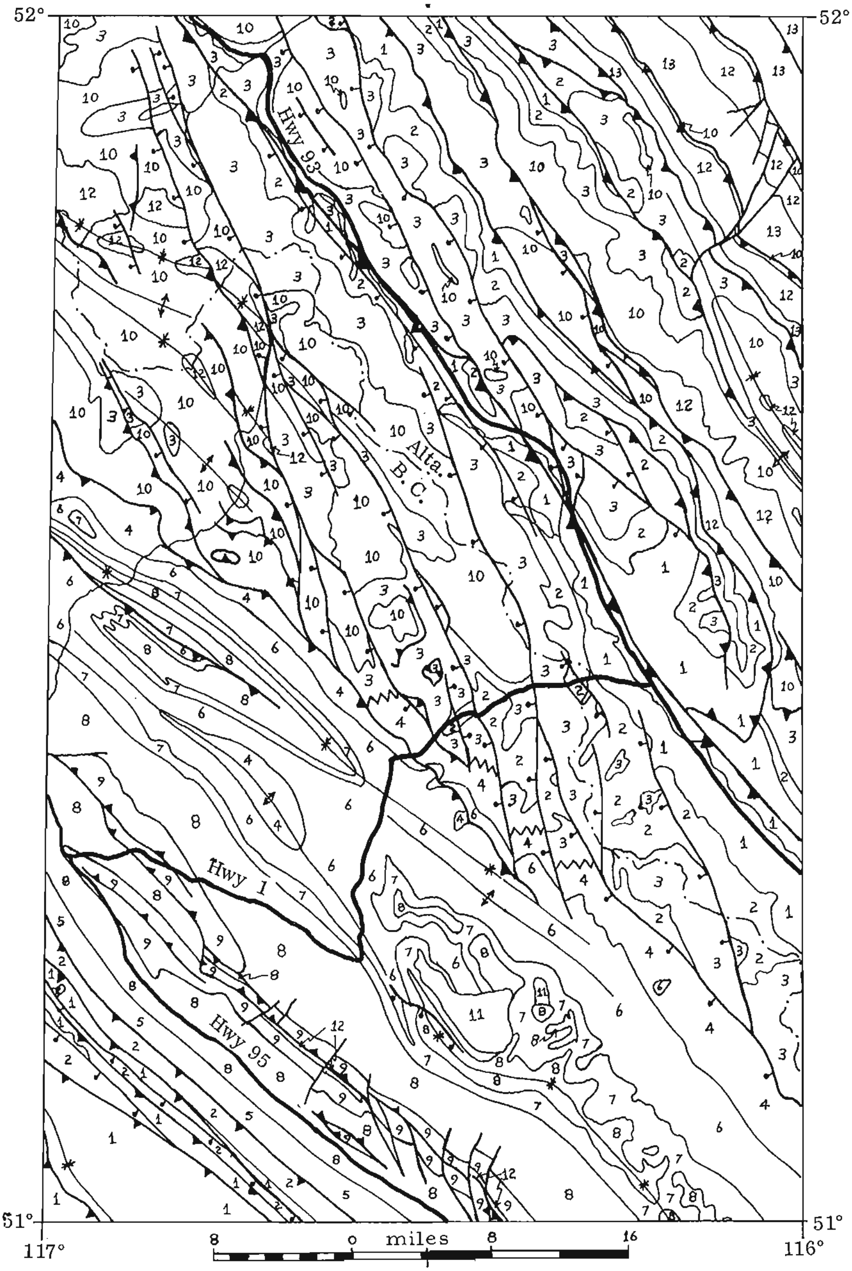

Figure 1. Sketch map of Golden, east half, British Columbia and Alberta, 82 N E 1/2.

AUTHOR INDEX