GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY,
MINES AND RESOURCES

PAPER 72-1
Part B

REPORT OF ACTIVITIES,

Part B: November 1971 to March 1972

Price, $2.00

1972

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CANADA

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REPORT OF ACTIVITIES, NOVEMBER 1971 TO MARCH 1972

INTRODUCTION

The thirty-seven reports that make up this publication present the results of some of the studies carried out by officers of the Geological Survey of Canada between November 1971 and March 1972. The illustrations used are reproduced without change from material submitted by the authors. Manuscripts were accepted for inclusion in this report until May 15, 1972.

The Report of Activities (Parts A and B); the reports on isotopic and radiocarbon dating; the annual index of publications, and the volume of abstracts of papers published by the Survey personnel in non-Survey publications provide an annual accounting of most of the published scientific output of the Branch. Requests for announcement cards, geological reports, maps or information on specific areas or topics should be addressed to: Geological Survey of Canada, Department of Energy, Mines and Resources, 601 Booth Street, Ottawa K1A 0E8, Canada.

ANALYTICAL CHEMISTRY

1. USE OF AN "ATOMIC ABSORPTION SPECTROPHOTOMETER" IN ANALYSIS OF ROCKS AND MINERALS

Project 690090

Sydney Abbey, Naomi J. Lee and J.L. Bouvier

A new design of water-cooled burner head was introduced for use with the acetylene-nitrous oxide flame. The new burner head led to a slight improvement in absorption signal stability but did little to improve silica determination.

Better silica results were obtained by differential colorimetry of the silicomolybdate yellow complex. The determination is done on an aliquot of the lithium-fluoborate master solution of the sample, prepared originally for atomic absorption determination of seven major elements (see GSC Paper 70-23). For spectrophotometric measurements, the absorption-cell housing and holder from an old and dismantled spectrophotometer were adapted to the modular atomic-absorption spectrophotometer. The same apparatus was used for colorimetric determination of phosphorus as molybdenum blue, again using the lithium-fluoborate sample solution.

Incomplete experiments indicate that only two dilutions of the master lithium-fluoborate solutions are required to determine not only the major elements described earlier, but also manganese, chromium and nickel (down to about 0.01 per cent of the respective oxides). Separate aliquots are required for the determination of silica and phosphorus by colorimetry, and titanium, strontium and barium by atomic absorption.

Two major conclusions can be drawn from this and other recent work:

(1) A sample solution derived from the lithium-fluoborate decomposition scheme, using only 200 mg of sample, may be applicable to the determination of as many as 14 major and minor elements in rocks.

(2) By suitable manipulation of components, the modular atomic absorption spectrophotometer can be easily adapted to flame emission and colorimetric ("molecular absorption") spectrophotometry. Components are also available commercially to adapt the instrument to atomic fluorescence work.

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2. THE DETERMINATION OF GOLD, PLATINUM GROUP AND SOME COMMON METALS IN NATIVE SILVER BY ATOMIC ABSORPTION SPECTROSCOPY

Project 690090

J.G. Sen Gupta

Synthetic solutions approximating the compositions of native silver were used to develop analytical procedures for the determination of parts per million ranges of gold and the six platinum group metals in native silver.

Silver interfered in the direct determination of other noble metals by atomic absorption spectroscopy by formation of a precipitate of silver acetylide in air-acetylene flame. Air-propane or air-hydrogen flame did not have sufficient sensitivities for gold and the platinum group metals. Therefore, silver was separated from the associated common and noble metals by double precipitation with hydrochloric acid.

The sample (2-4g) was decomposed by perchloric acid in a distillation apparatus[1] (for osmium and ruthenium) or by nitric acid in a beaker, and any small residue was brought into solution by dry chlorination at 700°C in the presence of sodium chloride. Osmium and ruthenium were determined from the distillate by atomic absorption spectroscopy[1]. After separation of silver as chloride by double precipitation, the filtrate was evaporated to dryness on the steam bath, the residue treated with aqua regia and converted to chloride with hydrochloric acid. The salts were dissolved in dilute hydrochloric acid and the volume made up to 25 ml. From aliquots, atomic absorption spectroscopic methods[1] were used to determine rhodium, palladium, iridium, platinum and gold in the presence of 0.5% Cu-0.5% Cd buffer, and common metals in the presence of 1% lanthanum buffer.

[1] Sen Gupta, J.G.: The determination of noble and base metals in osmiridium, native platinum and sperrylite by atomic absorption spectrophotometry; Anal. Chim. Acta., v. 58, p. 23 (1972).

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3. ATOMIC ABSORPTION SPECTROSCOPIC METHODS FOR THE DETERMINATION OF P.P.M. RANGES OF NOBLE METALS IN IRON METEORITES, SAND, CONCENTRATE AND MATTE AFTER SEPARATION FROM THE MATRIX BY TELLURIUM CO-PRECIPITATION OR CATION-EXCHANGE

Project 690090

J.G. Sen Gupta

Synthetic solutions corresponding to the compositions of iron meteorites were prepared and traces of noble metals were incorporated. The noble metals (except Os and Ir) were quantitatively separated from the major base metals by co-precipitation with tellurium from 2N hydrochloric acid solution. The precipitated tellurium was filtered out through a fritted glass filtering crucible, washed with 2N hydrochloric acid, and dissolved in aqua regia. After evaporation to dryness on the steam bath in the presence of sodium chloride and conversion to chloride with hydrochloric acid, the noble metals (except Os and Ir) were determined by atomic absorption spectroscopy in the presence of 0.5% Cu-0.5% Cd spectroscopic buffer. In the case of a sample containing high copper (e.g. sulphide concentrate and matte), and for determination of iridium, the hydrochloric acid solution of the sample was evaporated to dryness on the steam bath, the salts dissolved in dilute hydrochloric acid (pH 1.4±0.1) and the platinum group metals were separated from the base metals by passing through a column of Dowex 50W-X8 cation exchange resin. From the effluent, the platinum group metals (Ru, Rh, Pd, Ir and Pt) were determined by atomic absorption spectroscopy in the presence of 0.5% Cu-0.5% Cd spectroscopic buffer[1].

The platinum group metals data on some iron meteorites, as obtained by the application of the two separation methods, agree well with each other.

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[1] Sen Gupta, J.G.: The determination of noble and base metals in osmiridium, native platinum and sperrylite by atomic absorption spectrophotometry; Anal. Chim. Acta., v. 58, p. 23 (1972).

COAL RESEARCH

4. PETROGRAPHY OF KOOTENAY COALS IN THE UPPER ELK RIVER AND CROWSNEST AREAS, BRITISH COLUMBIA AND ALBERTA

82G,5

Project 610269

A. R. Cameron

Thirty-nine whole-seam samples representing Kootenay Formation coals were studied petrographically to determine patterns of component distribution. Coals were obtained from Kootenay sections at Fording River, Line Creek, Natal Ridge and Sparwood Ridge in British Columbia and Grassy Mountain in Alberta. In addition, data were obtained on some of the seams in the Weary Ridge section in British Columbia. In British Columbia, the line of sections extends for about 46 miles from Natal Ridge in the south to Weary Ridge in the north.

Petrographic composition was expressed in terms of maceral content. The most important macerals in these coals are vitrinite, semifusinite and fusinite. The data show a wide variation in the content of these macerals in the seams examined with vitrinite contents ranging from 35 to 94 per cent and combined semifusinite-fusinite varying from 2 to 41 per cent on the mineral-free basis. It is considered significant that these variations are not random but rather show a concentration of low vitrinite and high semifusinite-fusinite in the lower part of the section while the upper part contains seams with increasing vitrinite content as one moves up the section. This is true without exception for the British Columbia sections. The three seams at Grassy Mountain all show relatively low vitrinite content and correspondingly high contents of semifusinite and fusinite.

A grouping of the seams according to petrographic composition suggests a meaningful threshold around 65 per cent vitrinite content. Seams with less than 65 per cent vitrinite occur in the bottom part of the section while those with vitrinite contents higher than 65 per cent are in the upper part of the section. Figure 1 shows the distribution of these two groups of seams in the various sections studied. The seam below which the 65 per cent threshold occurs is indicated in each of the sections.

The petrographic changes in the coals from bottom to top in the sections studied appear to be the effects of the evolution through time of the deltaic system which gave rise to the Kootenay Formation. According to Jansa (ref. 1), the earliest coal-forming swamps were on the lower delta plain while the upper ones were on the upper delta plain. The former may have been areas of open water and characterized by plant communities in which large trees were not dominant elements. With time, the shoreline retreated east and the swamp type also changed into a forested bog with stagnant water where the preservation of relatively unaltered peat was more probable. This would then result eventually in the high vitrinite seams found today at the top of the coal-bearing section.

The data reported on in this study also have a practical application. Vitrinite is considered reactive in the coking process while fusinite along with at least some of the semifusinite is considered inert. An additional

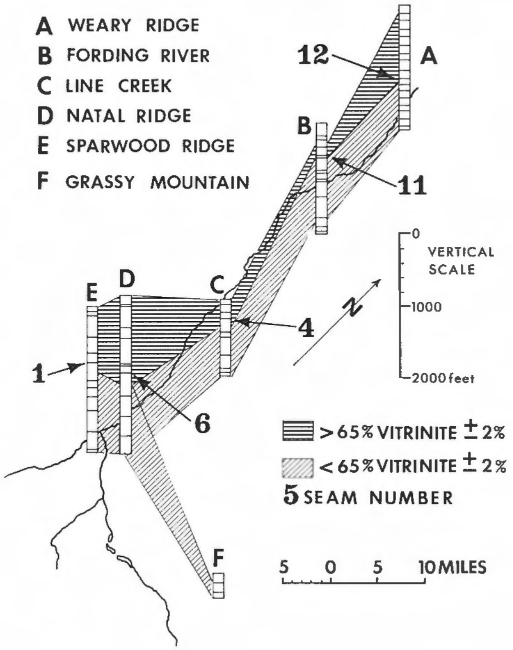

Figure 1.

Panel diagram showing vertical distribution of seams with high and low vitrinite content.

consideration is that the optimum ratio of reactives to inerts for good coke quality varies with rank. The distribution of seams with widely varying ratios of reactives to inerts in most sections of the Kootenay Formation in the area studied presents an almost unique opportunity for the preparation of blends, which theoretically at least should satisfy any compositional specifications required.

[1] Jansa, L. F.: Depositional History of the Coal-bearing Upper Jurassic-Lower Cretaceous Kootenay Formation, Southern Rocky Mountains, Canada. Guidebook, Geol. Soc. Am. Field Trip No. 1, Cascade and Crowsnest Coal Basins, May 1971 (1971).

5. COMPOSITION OF COKING COALS IN TERMS OF PARTICLE TYPES

Project 690022

A. R. Cameron

In studies relating petrography to coking properties, the maceral content has been the compositional parameter most often used along with rank data in terms of reflectance values. The macerals are divided into two broad groups: those which are reactive and those which are inert in the coking process. The former include vitrinite, exinite and some of the semifusinite; the latter include the remainder of the semifusinite along with fusinite, micrinite, macrinite, inertodetrinite and mineral matter. There has also been an awareness that the actual nature of the particles in coals, as charged to the oven, and the particle size distribution may be important in interpreting the coking behaviour of a given coal[1, 2]. Burstlein has shown that coke strength is improved if those particles containing high concentrations of inerts are ground to a size as fine or finer than the associated particles which are high in reactives. In normal crushing operations, inert-rich particles often tend to concentrate in the coarser screen sizes. In this condition they form centres of weakness which lower the strength values of the resulting coke. If such inert-rich particles are crushed to finer sizes, they are more readily assimilated into the coke mass and their effect on strength will be reduced.

In an attempt to discover whether or not differences in particle types do occur in some of the western Canadian coals currently being mined or explored, size fractions of 12 coals as charged to the coke oven were analyzed microscopically not only in terms of overall maceral content but also in terms of total particle composition. Particles were placed in three main groups; namely

A. <33% reactives, > 67% inerts

B. >33%<67% reactives

C. >67% reactives, < 33% inerts.

For each coke charge, three size fractions were considered; namely, plus 1/16 inch, 1/16 inch x 35 mesh and minus 35 mesh.

In Table 1 the summarized maceral compositions of the 12 samples are given in terms of reactives and inerts.

Table 1*

Summarized maceral composition data
for coke oven charges studied
(volume per cent)

Sample	Reactives	Inerts
1	63	37
2	69	31
3	61	39
4	61	39
5	83	17
6	52	48
7	70	30
8	70	30
9	60	40
10	57	43
11	74	26
12	80	20

*All but samples 1, 2 and 5 are coking coals from western Canada.

Table 2
Particle type data on coking coal charges
(volume per cent)

Sample	Size Fractions									Total Coal		
	+ 1/16 inch			1/16 inch x 35 mesh			35 mesh XO					
	A*	B	C	A	B	C	A	B	C	A	B	C
1	8	23	10	3	18	17	4	4	13	15	45	40
2	6	8	12	7	2	32	2	4	27	15	14	71
3	5	7	21	2	12	24	5	6	18	12	25	63
4	9	7	12	5	8	26	5	6	22	19	21	60
5	2	5	28	0	5	36	2	1	21	4	11	85
6	8	7	9	14	14	15	5	9	19	27	30	43
7	4	3	14	8	4	22	5	8	32	17	15	68
8	3	2	10	6	4	21	11	5	38	20	11	69
9	5	12	15	8	10	22	5	4	19	18	26	56
10	11	5	3	15	10	24	10	4	18	36	19	45
11	4	2	18	5	3	34	7	4	23	16	9	75
12	4	5	23	8	5	27	4	0	24	16	10	74

*A, B, C are particle types according to proportions of reactives and inerts.

Table 2 gives the composition of the 12 samples in terms of particle types expressed for both the size fractions and the total coal. For example, sample 1 contains in total 15 per cent by volume of particle type A (<33% reactives), 45 per cent of particle type B and 40 per cent of particle type C. These figures are the sums of the figures given under the size fractions, that is the 15 per cent of particle type A is divided as follows: 8 per cent in the + 1/16 inch fraction, 3 per cent in the 1/16 inch x 35 mesh fraction, and 4 per cent in the minus 35 mesh size.

A comparison of the data in Tables 1 and 2 shows the additional information that may be gained by using the "particle type" or microlithotype approach in conjunction with maceral composition. Table 1 indicates the overall maceral composition but it does not indicate how these materials are associated nor whether certain maceral associations have preferred particle size ranges. As noted earlier, this latter consideration may be important in evaluation of coals for coking. By way of illustration, the following observations may be made relative to the data in Tables 1 and 2.

Samples 1, 3 and 4 are not greatly different in their overall maceral compositions in terms of reactives and inerts. Table 2 shows, however, that these samples exhibit considerable differences in the manner in which reactives and inert are associated. Samples 3 and 4 have 63 and 60 per cent, respectively, of particles with more than 67 per cent reactives; that is Particle Type C. In comparison, sample 1 has only 40 per cent but has a much higher proportion of particles with reactives contents ranging from 33-67 per cent.

Samples 1 and 7 are both high volatile A bituminous coals. On a maceral basis they differ somewhat; 63 versus 70 per cent reactives. These differences are accentuated when the particle type data in both the size fractions and the total coal are compared. The content of particle type B is much lower in sample 7 than in sample 1 (15% versus 45%); sample 7 shows 68 per cent particle type C in comparison to 40 per cent for sample 1. Particle type A on the other hand shows about the same content in both samples. This indicates that the inerts may be concentrated more in discreet bands in the seam from which sample 7 was obtained while, in the parent seam of sample 1, they may be more uniformly distributed thus giving rise to a much larger proportion of the intermediate particle type B in sample 1 as compared to 7. This may have an effect on the preparation properties of these coals.

Samples 10, 6 and 8 show the highest contents of inert-rich particles (Type A) with 36, 27 and 20 per cent respectively on the total-coal basis. In what size fractions do these report? Examination of the data for samples 6 and 10 show that a much higher proportion of the inert-rich particles appear in the two coarser sizes than is the case for sample 8. Improvement in coke strength for samples 6 and 10 might be achieved by screening out the plus 1/16 inch fraction and separately grinding it to a finer size before remixing with the remaining coal. On the other hand, from the size distribution data of sample 8 this procedure might not materially affect the coke strength.

[1] Burstlein, E.: Selective and petrographic preparation of coals for coking; Chaleur et Industrie, v. 35, p. 351-370 (1954).

[2] MacKowsky, M. T. and Simonis, W.: Die Kennzeichnung von Kokskohlen fur die Mathematische Beschreibung der Hochtempevatur ver kokung im HorizontalKammerofen bei Schuttbetrieb durch Ergebnisse mikroskopischer Analysen; Gluckauf-Forschungsheffe 30, 1, p. 25-37 (1969).

6. RANK STUDIES OF COALS IN THE ROCKY MOUNTAINS AND INNER FOOTHILLS BELT, CANADA

82 G,J

Project 680102

P. A. Hacquebard and J. R. Donaldson

In this study, the rank of coal has been determined by means of vitrinite reflectance measurements. For the regional changes the Kootenay coals of the Crowsnest Pass area have been examined; they show a progressive westward increase in rank. The changes in rank with stratigraphic position are illustrated in Figure 1 with rank-depth curves of ten coal-bearing sections of Jurassic-Cretaceous age that are situated between the Crowsnest field in the south and the Peace River canyon in the north. Both studies indicate pre-orogenic coalification, because the rank increases regularly with stratigraphic depth, but not with geologic age, depth of mining or degree of tectonic disturbance.

For each of the ten curves plotted, the coalification gradient is calculated in terms of per cent reflectance (Ro)-change per 100 m increase in depth.

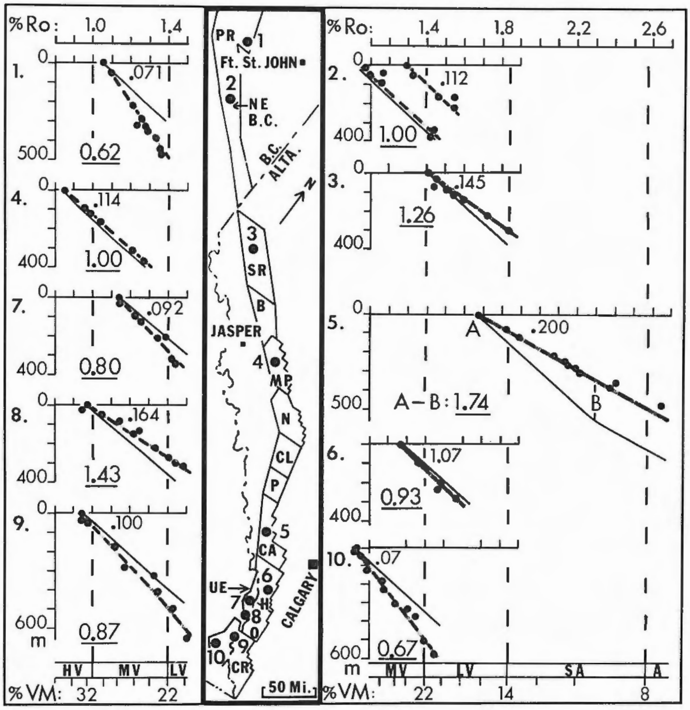

Figure 1. Coal rank changes in 10 stratigraphic sections of the Rocky Mountains and Inner Foothills Belt (solid curve represents Peel reference curve, 0.62 indicates the Peel rank ratio, 0.71 is coalification gradient in terms of % Ro change per 100 m; locations of sections are as follows:

1. Peace River Canyon.
2. Sukunka River, two boreholes.
3. Smoky River, 1 and 2 Mine areas.
4. Mountain Park.
5. Canmore Coalfield.
6. Highwood River, Ford Collieries.
7. Fording River, Eagle Mountain.
8. Line Creek Ridge.
9. Natal Ridge.
10. Sparwood Ridge.

By relating this gradient to that of a known curve (the Peel curve of the Netherlands), a reference for comparison is obtained, which is expressed as the Peel rank ratio. Different ratios were obtained, which probably are related to variations in the temperature gradients. The lowest ratio was found in the Peace River canyon area, and the highest occurs in the Canmore coalfield.

The coalification gradient affects the availability of coking coals of most favourable rank, i.e. the medium volatile coals. With a low gradient (and corresponding steep curve), medium volatile coals occur over a greater stratigraphic interval, with the possibility of a larger number of seams, than with a high gradient. Within limited areas of the same coalfield, the rank as determined from vitrinite reflectance can be used for correlating coal seams provided a high coalification gradient is present. This method has been employed successfully in the Canmore coalfield on seams that lie not less than 120 feet apart stratigraphically.

7. LES TONSTEINS DE LA VEINE DE CHARBON N° 10 (BALMER) A SPARWOOD RIDGE DANS LE BASSIN DE FERNIE (COLOMBIE BRITANNIQUE).

E. Mériaux*

Introduction

Le Bassin de Fernie est situé au SE de la Colombie britannique dans les Montagnes Rocheuses. A. R. Cameron et S. K. Babu[1] ont rappelé les grands traits de la géologie régionale (stratigraphique et structure) de ce bassin charbonnier appartenant à la formation de Kootenay. Il contient des veines de houille parfois de grande épaisseur. Ces veines renferment généralement des lits argileux. En Europe, ces horizons particuliers ont fait l'objet de nombreuses recherches très importantes. Les résultats obtenus ont permis d'établir des corrélations à longue distance entre les bassins houillers[2, 3, 4, 5, 6].

L'étude pétrographique des niveaux argileux contenus dans les veines de charbon a pour but essentiel de définir la nature et l'origine de ces lits particuliers d'une part et de tenter de découvrir des niveaux repères pour établir des corrélations entre ces différents horizons, et par la suite entre les divers bassins.

Echantillonnage

Afin de tester la méthode, les présentes recherches ont été volontairement limitées à la partie sud de Natal Creek, c'est-à-dire Sparwood Ridge. De plus, seule la veine Balmer (veine numéro 10) située, rappelons-le, à la partie basale de la formation de Kootenay, fait l'objet de cette étude. Cette veine en partie exploitée est donc particulièrement bien repérée et permet de ce fait une étude précise.

Quatre prélèvements ont été réalisés dans cette région. Ce sont les prélèvements CQ 181, CQ 182, CQ 161 et CQ 8. Les trois premiers sont respectivement situés du SSW au NNE en:

CQ 181 = W 2250; S 3802, 5; 5140 (Adit 14)
CQ 182 = W 3125; S 0250; 3220 (près d'Adit 15; N 300 pieds)
CQ 161 - W 5125; N 8250; 4840 (Hydraulic Test Mine).

Les charbons du prélèvement CQ 8 réalisé en 1967 ont fait l'objet d'une étude pétrographique complète[1].

CQ 8 = W 4500; N 10500; 3800 (Balmer South Mine).

Les distances approximatives entre ces points sont les suivantes:

CQ 181 - CQ 182 = 3500 pieds
CQ 182 - CQ 161 = 8750 pieds
CQ 161 - CQ 8 = 2150 pieds

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*Université des Sciences et Techniques de Lille, France.

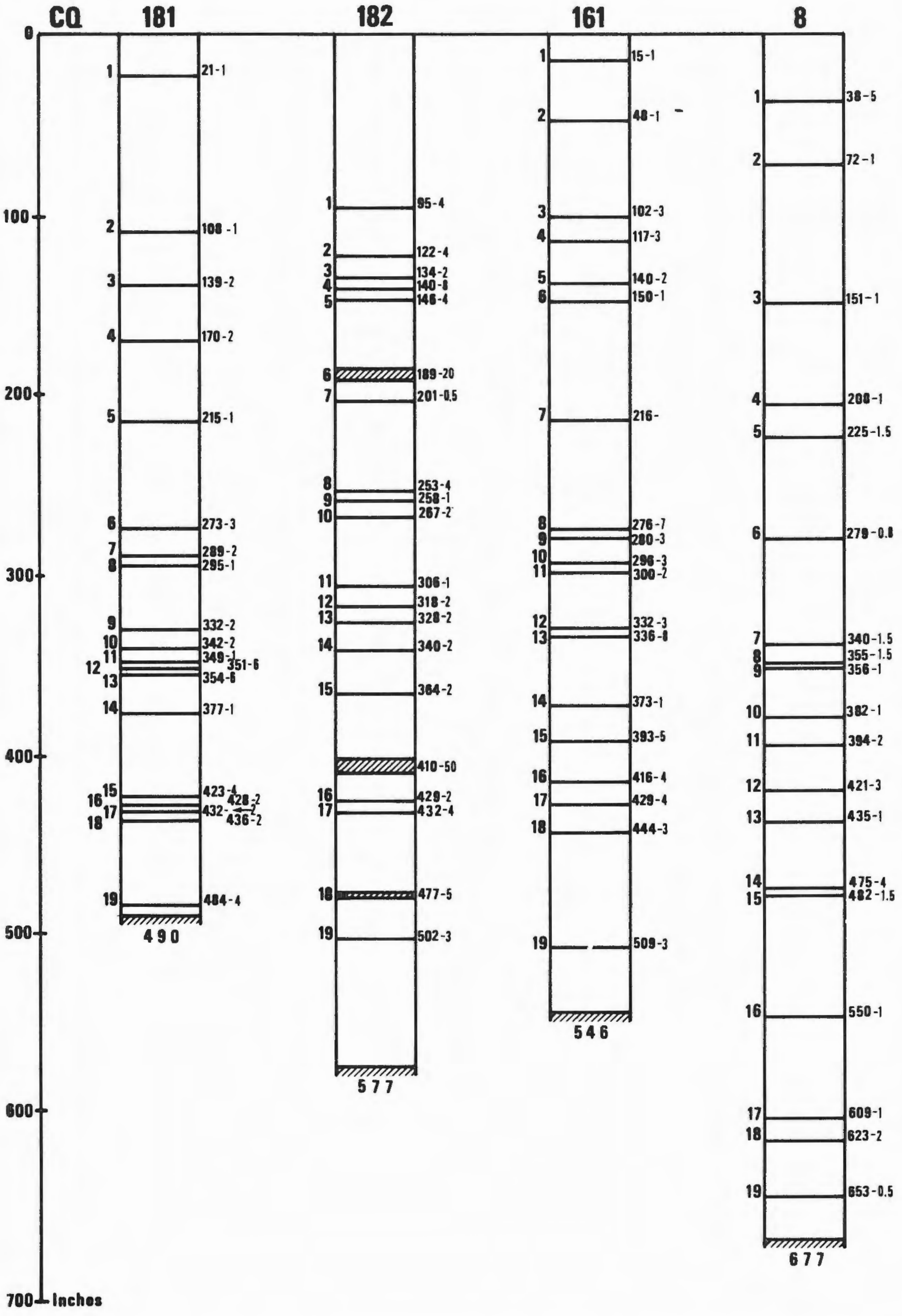


Figure 1. Position des niveaux argileux dans la veine Balmer.

Analyse macroscopique

En ces quatre points de prélèvements, tous les niveaux stériles observables ont été échantillonnés. Lors des prélèvements, la teinte claire ou plus souvent brunâtre des lits a tout d'abord retenu notre attention. Une saignée continue du toit au mur de la veine est ensuite effectuée. Tous les niveaux dont la consistance ou/et la poussière sont différentes de celles du charbon environnant ont été systématiquement prélevés. Il est possible que certains niveaux ont dû nous échapper. La figure 1 montre la position des différents lits observés. Les indications CQ 181, 4-170-2 correspondent respectivement au numéro du prélèvement (CQ 181), au numéro du lit argileux (4), à sa position comptée en pouces à partir du toit de la veine (170) et à son épaisseur approximative comptée en centimètres et observée au point de prélèvement (2).

On constate une diminution de l'épaisseur de la veine Balmer du nord vers le sud.

Aux 4 points étudiés, 19 niveaux stériles ont été repérés. Cependant, il apparaît immédiatement (cf. fig. 1) que leur répartition verticale est variable en chacun de ces points. De ce fait, aucune corrélation a priori n'est possible même en essayant de regrouper certains niveaux très rapprochés.

L'épaisseur de chacun des niveaux argileux est elle aussi variable. Par exemple, les épaisseurs des horizons CQ 161-12 et 13 oscillent entre 4 et 8 centimètres. L'épaisseur ne doit donc pas constituer non plus un critère de corrélation.

Analyse microscopique

La cohésion des niveaux est extrêmement variable aussi bien d'un horizon à l'autre qu'à l'intérieur d'un même niveau. Les échantillons friables ont été enrobés dans le plastique et étudiés en surfaces polies à immersion d'huile. Des lames minces ont été confectionnées dans les niveaux les plus cohérants. L'utilisation de ces deux techniques pose des problèmes et par ailleurs, l'interprétation des surfaces polies reste difficile.

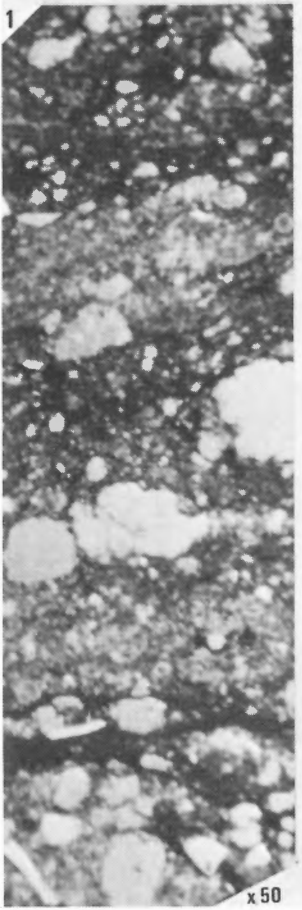
Toutefois, il a été possible d'obtenir une série complète de lames minces pour les prélèvements CQ 181 et CQ 161. CQ 8 n'a pu être étudié qu'en surface polie et CQ 182 en surface polie pour certains niveaux et en lame mince pour d'autres.

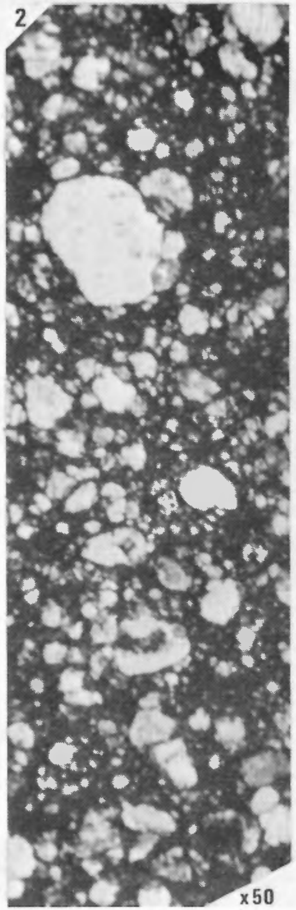
Etude qualitative (planches 1 et 2 et fig. 2)

Les planches 1 et 2 représentent quelques aspects des tonstein observés dans la veine Balmer.

Les éléments les plus importants de ces niveaux argileux sont les quartz, les graupen et les vermicules. La figure 2 montre la répartition de ces éléments observés en lames minces aux points CQ 181 et CQ 161. Il apparaît que la veine Balmer contient des niveaux argileux extrêmement homogènes. Le quartz est présent partout. Quelques horizons sont dépourvus de graupen ou en montrent très peu. Les vermicules sont surtout abondants

Pl.I





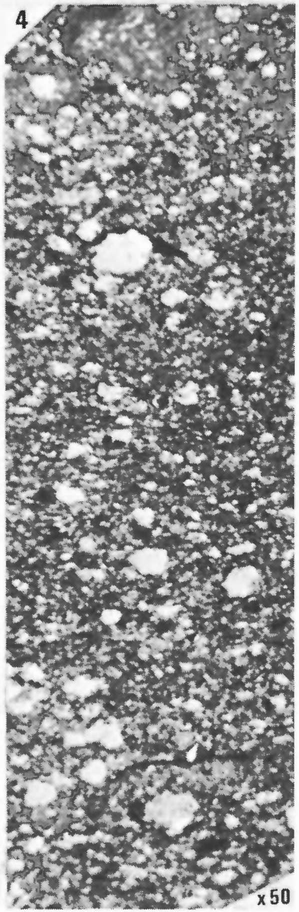
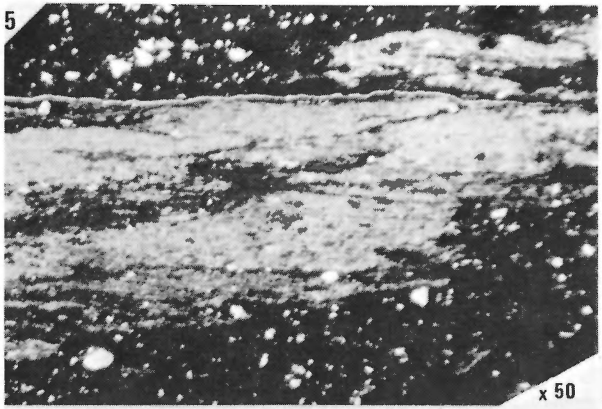
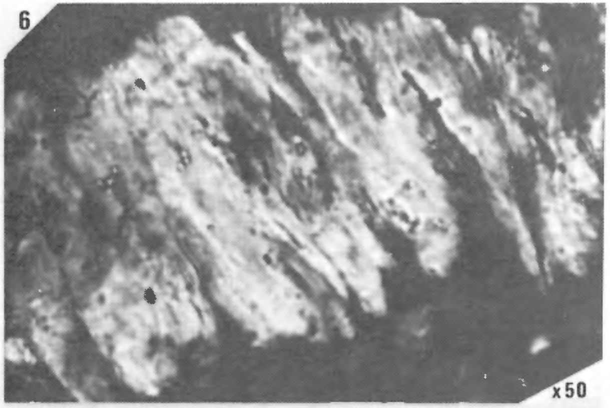


Fig. 1. - CQ 161-1 Graupen-tonstein. Quartz en aiguille. G = X 50 Lumière naturelle (LN).
Fig. 2. - CQ 161-2 Graupen-tonstein. Graupen dispersés. G = X 50 LN.
Fig. 3. - CQ 161-3 Graupen-tonstein. Graupen ovoides. G = X 50 LN.
Fig. 4. - CQ 161-4 Graupen-tonstein. Graupen de petite taille. G = X 50 LN.





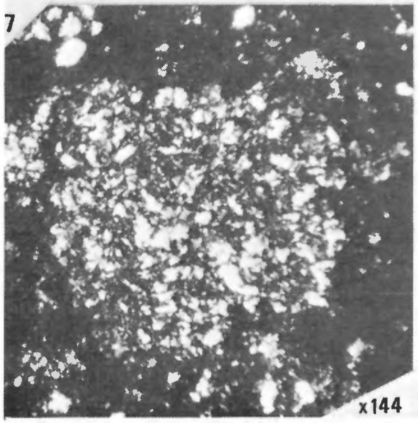


Fig. 5. - CQ 161-19 Niveau argileux banal à quartz en aiguille et à poussière de quartz. G = X 50 LN.
Fig. 6. - CQ 161-15 Pseudomorphose de mica. G = X 50 LN.
Fig. 7. - CQ 161-1 Boule de kaolin. G = X 144 Lumière polarisée.
Fig. 8. - CQ 181-7 Vermicule de kaolinite. G = X 300 Lumière réfléchie.

Pl.II

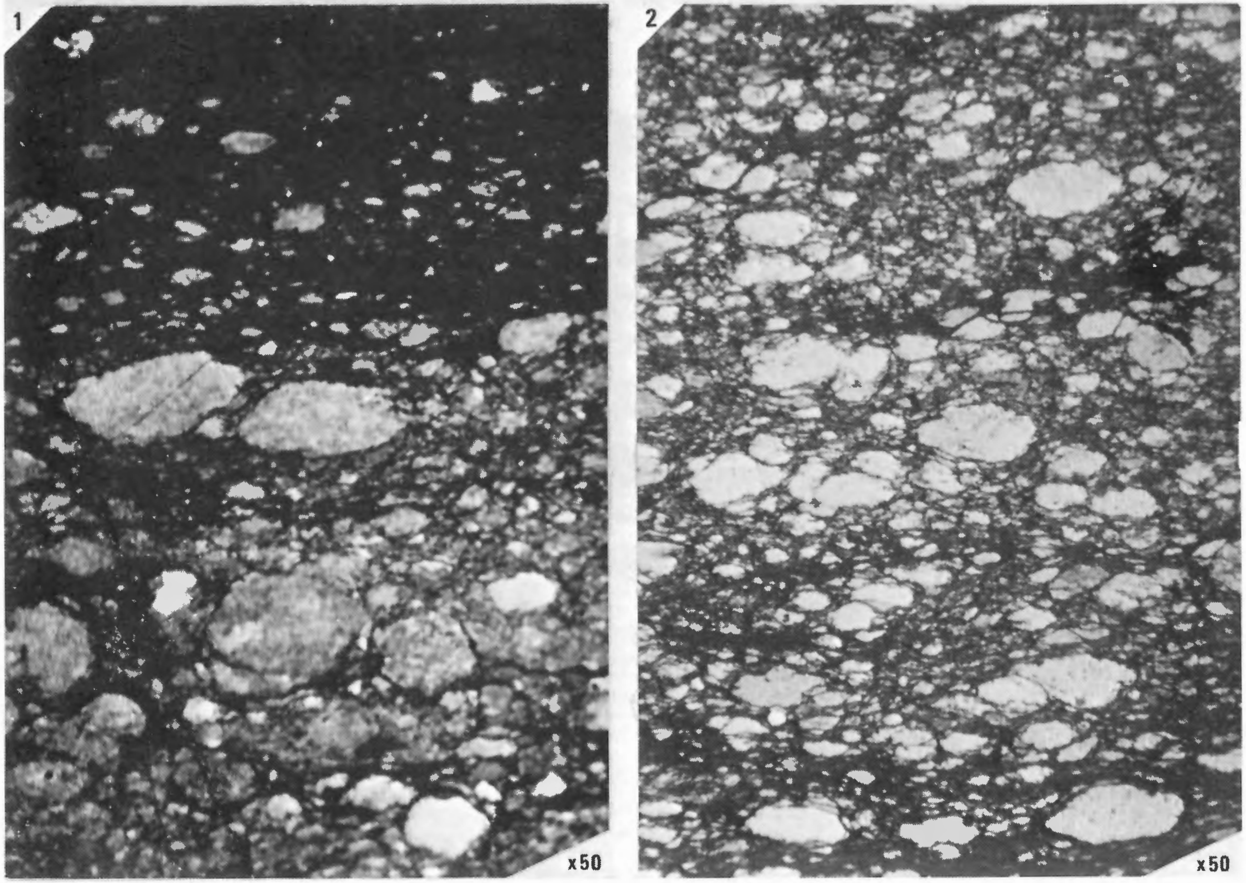
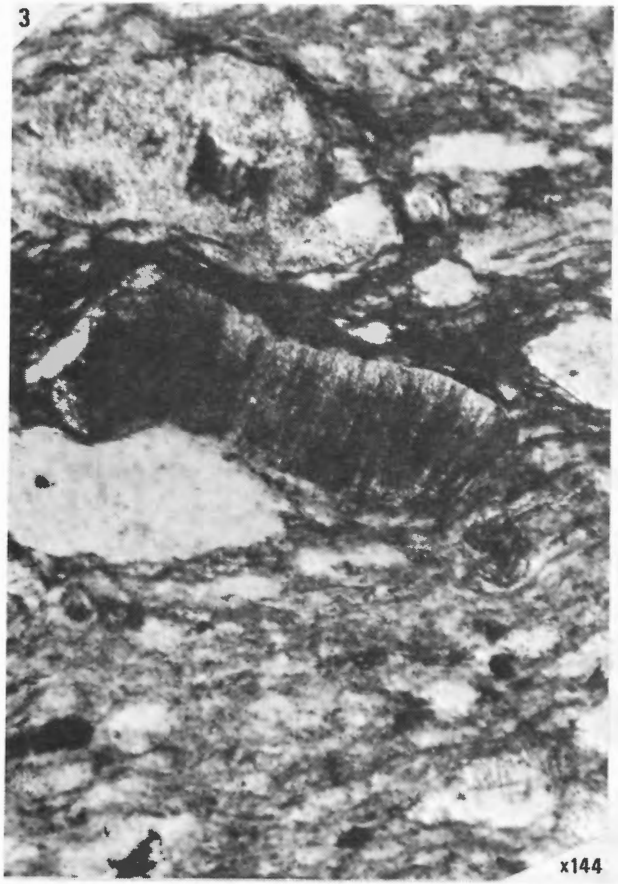


Fig. 1. - <u>CQ 181-9</u> Graupen-tonstein et Fig. 2. - <u>CQ 181-12</u> Graupen-tonstein. Nombreux et minuscules graupen de kaolinite isotrope et petits cristaux de kaolinite claire dans une pâte charbonneuse. G = X 50 LN.



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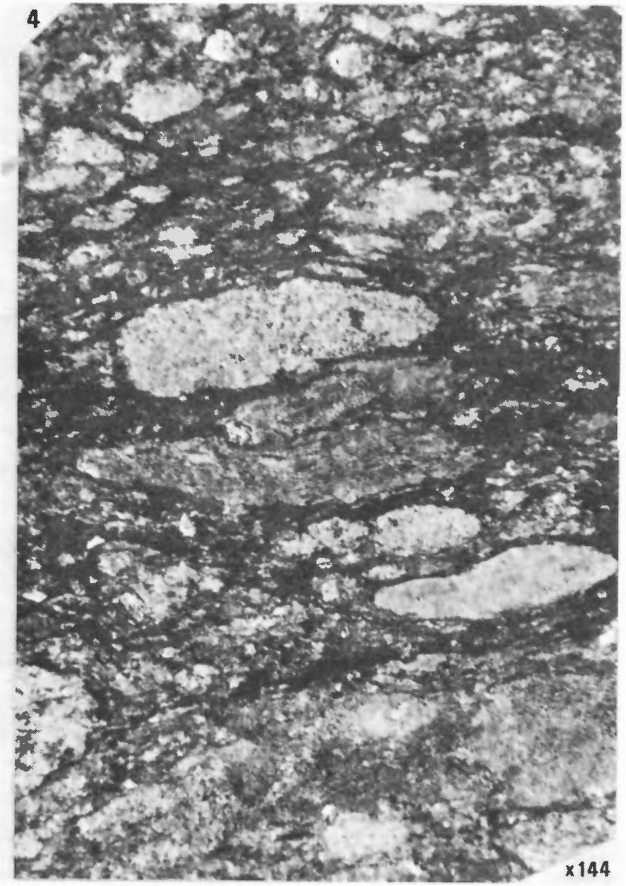

4

Fig. 3. - CQ 181-17 Graupen-tonstein. Nombreuses boules de kaolinite. Vermicule strié transversalement au centre. Poussière de quartz anguleux et quartz aciculaire. G = X 144 LN.

Fig. 4. - CQ 181-18 Graupen-tonstein. Boules extrêmement aplaties de kaolinite isotrope et cryptocristalline. G = X 144 LN.

Table 1

Résultats des analyses en spectrométrie optique d'émission.

Numéros / Eléments	161-4	161-13	181-6	186-27
Be	< 3	< 3	< 3	< 3
B	128	66	106	20
Sc	7	8	12	13
V	10	20	50	137
Cr	< 5	7	10	26
Mn	42	98	230	163
Co	< 5	< 5	12	11
Ni	< 5	< 5	21	14
Cu	71	67	94	33
Zn	66	147	200	126
Ga	35	52	55	46
Ge	< 6	< 6	< 6	< 6
Sr	12	8	21	19
Y	20	24	28	73
Mo	< 7	< 7	< 7	10
Ag	< 1	1	1	1
Cd	< 6	< 6	< 6	< 6
Sn	50	68	80	68
Ba	607	380	580	250
Yb	2	3	4	6
Pb	24	44	35	34
Bi	< 3	< 3	< 3	< 3

	QUARTZ		GRAUPEN		VERMICULES	
	181	161	181	161	181	161
1	▤ ░	▤ ░	● ○	●		▩
2	▤ ░	░	●	●		
3	▤ ░	▤ ░	●	○		
4	░	░	○	●		
5	▤ ░	░	● ○	●	▩	
6	░	░	●	●		
7	▤ ░	░	● ○			
8	░	░	●	●		
9	░	░	●	●		
10	░	░		○		
11	▤ ░	░		○		
12	▤ ░	▤ ░	○	○		▩
13	░	░	○	● ○	▩	
14	░	▤ ░	○	○	▩	
15	▤ ░	▤ ░				▩
16	░	▤ ░	○		▩	▩
17	▤ ░	▤ ░	○		▩	▩
18	▤ ░	░	○			▩
19	░	▤ ░				

▤ Quartz en aiguilles

○ Graupen ovoïdes

● Graupen globuleux

▩ Vermicules

░ Grains de quartz anguleux ou poussière de quartz

Figure 2. Répartition verticale des principaux constituants pétrographiques des niveaux argileux.

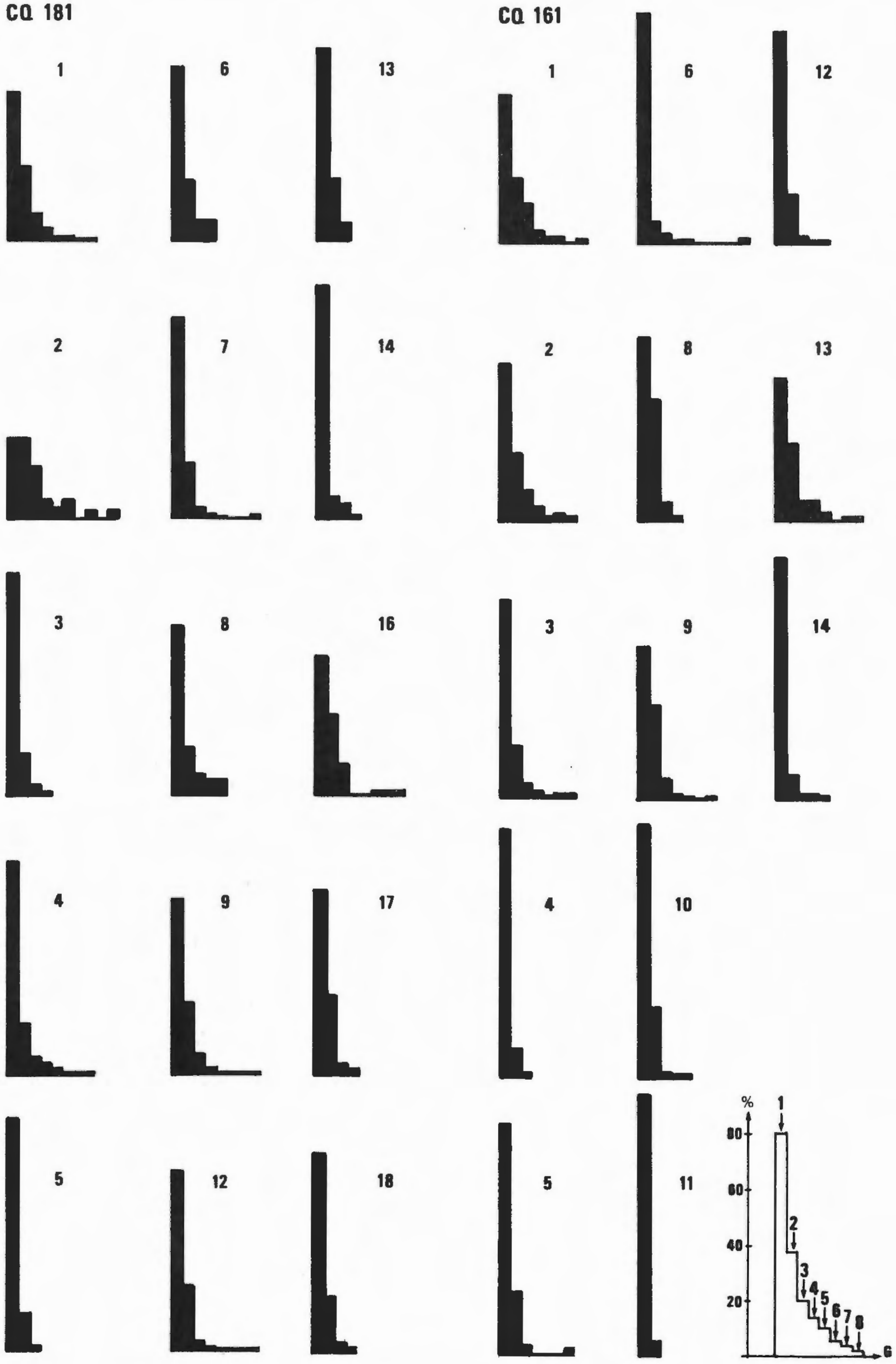

Figure 3. Variations de taille des graupen.

à la partie basale de la veine. Grâce à ce dernier caractère, il est donc possible de distinguer dans la veine Balmer:

- une partie inférieure riche en vermicules,
- une partie supérieure presque dépourvue de vermicules.

Etude quantitative (fig. 3 et tabl. 1)

Deux techniques ont été utilisées: la mesure de la taille des graupen d'une part et les recherches des éléments en traces par spectrométrie optique d'émission.

La figure 3 représente les histogrammes correspondant aux variations de la taille des graupen mesurée perpendiculairement à la stratification. Les classes (G) (fig. 3) retenues sont les suivantes:

1 = taille inférieure à 0, 04 mm
2 = 0, 04 - 0, 08
3 = 0, 08 - 0, 12
4 = 0, 12 - 0, 16
5 = 0, 16 - 0, 20
6 = 0, 20 - 0, 24
7 = 0, 24 - 0, 28
8 = 0, 28 - 0, 32
9 = 0, 32 - 0, 36

Certains niveaux présentant des histogrammes tout à fait similaires peuvent être correlés. Ce sont par exemple 181-1 et 161-1 ou 181-5 et 161-4. D'autres histogrammes comme 181-2 et 161-2 peuvent être rapprochés en raison du grand nombre de classes observées.

Nous avons procédé par ailleurs à des recherches d'éléments rares. Les résultats sont exposés dans le tableau 1. A titre de comparaison, figurent sur ce tableau les analyses réalisées plus au NE, en CQ 186, c'est-à-dire en N 1780, E 8625, 5500. Les résultats sont très encourageants.

Enfin, signalons pour terminer que des analyses de microthermoluminescence sur roche totale sont en cours de réalisation.

Conclusions

D'après la composition pétrographique et le faciès, il semble bien que les niveaux argileux de la veine Balmer représentent des strato-tonsteins[7] dont les corrélations s'avèrent difficiles. Cependant, des études plus complètes permettront probablement de mettre en évidence des orthotonsteins dont l'intérêt pour l'établissement de corrélations à grande distance est considérable.

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[2] Bouroz, A.: Corrélations des tonstein d'origine volcanique entre les bassins houillers de Sarre-Lorraine et du Nord-Pas-de-Calais; C.R. Acad. Sc., t. 264, p. 2729-2732, Paris (1967).

[3] Francis, E.H.: Les tonstein du Royaume-Uni.; Ann. Soc. géol. Nord, t. LXXXIX, p. 209-214, 2 fig., 1 pl., Lille (1969).

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[5] Burger, K.: Monographie des Kaolin-Kohlentonsteins Zollverein 8 in den Essener Schichten (Westfal B 1) des niederrheinisch-westfalischen Steinkohlenreviers. Forsch. des Land. Nordrh. Westf., Nr. 2125 (Teil I), V Tab., 26 Abb., 21 Taf., Nr. 2126 (Teil II) 48 Abb., 39 Taf., 89 Tab.; Westdentscherverlag. Koln und Opladen (1971).

[6] C.I.P.C.: Lexique international de pétrographie des charbons du Comité international de pétrographie des charbons, 2è édition; C.N.R.S., Paris (1963).

[7] Bouroz, A.: Sur la pluralité des tonstein (A propos d'une cinérite oligocène du Japon); Ann. Soc. géol. Nord, t. LXXXII, p. 77-94, 2 fig., 6 pl., Lille (1962).

8. PALYNOLOGIC STUDY OF COALS AND ASSOCIATED CLASTICS OF THE KOOTENAY FORMATION, CROWSNEST AREA

82G,5

Project 710091

Arthur R. Sweet

The objective of this study is to provide a palynological zonation of and a basis for correlating coal seams within the Kootenay Coal Basin. Palynomorphs have been extracted from coals ranging up to medium volatile bituminous in rank (23% VM). Approximately 100 pollen and microspore species and 5 megaspore species were identified. Most of these are long ranging forms making a definite age assignment difficult. Both Rouse[1], working with the middle and lower part of the Kootenay Formation in the Michel–Fernie area, and Pocock[2], working with assemblages from the type section at Grassy Mountain, proposed a Late Jurassic age for these intervals. The recovery of *Shizosporis reliculatus* from the upper part of the Kootenay Formation at Michel leaves open the possibility of an Early Cretaceous age assignment for these beds.

A general trend towards the relative increase in gymnospermous pollen throughout the coals of the Kootenay Formation is suggested by the abundance (from 60 to 80%) of pollen in the uppermost coals (C and D seams) at Michel as compared to coals from the Beaver Mines area where pollen constitutes only 25% of the assemblage. (The Beaver Mines coal is inferred to be correlated with the lower part of the Kootenay Formation.) Results from a preliminary examination of some of the lower coals at Michel supports this proposed trend.

Total seam samples of the C and D seams at Michel were found to have similar pollen and spore histograms. However, differences were noted in accessory spore types. The reliability in using the latter in the identification of these seams has yet to be established.

The study of samples from specific petrographic intervals from the Lower C seam demonstrated a relationship between the relative abundance of bisaccate pollen and the amount of vitrinite, thus indicating a correlation with arborescent type vegetation.

---

[1] Rouse, G.E.: Plant microfossils from the Kootenay coal measures strata of British Columbia; Micropaleontology, v. 5, p. 303-304 (1959).

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CORDILLERAN GEOLOGY

9. LATE PALEOZOIC TO MID-TRIASSIC SEDIMENTARY-VOLCANIC SEQUENCE ON NORTHEASTERN VANCOUVER ISLAND

92E,K,L

Project 680038

Donald Carlisle*

Summary

As a consequence of major movements on several northerly and northwesterly faults, a large and hitherto unsuspected occurrence of late Paleozoic bioclastic and coralline limestone is exposed in the region between Schoen Lake and Victoria Peak. The limestone, which is probably correlative with the Buttle Lake Formation of the Sicker Group is overlain, apparently conformably, by laminated siliceous and calcareous argillites and shales which are pervasively intruded by basalt sills having an aggregate thickness several times that of the intruded sediments. The sills are compositionally very similar to, and undoubtedly cogenetic with some 20,000 feet of pillow lava, pillow breccia and flows of the overlying Karmutsen Subgroup. Daonella of probable Upper Ladinian (Middle Triassic) age has been found in the upper part of the sediment-sill sequence. Taken in conjunction with the Karnian (Upper Triassic) ammonoid fauna near the top of the Karmutsen and in the overlying Quatsino Limestone, this new fossil occurrence provides a basis for roughly estimating the rate of accumulation of Karmutsen volcanic rocks. It is suggested that deep to very shallow submarine emplacement of sills may have been precursive to eruption of pillows and pillow breccias.

Structural Setting

Structural mapping has been facilitated by subdivision of the Karmutsen Group into three distinct and persistent units as shown in Figure 1.** The subdivision remains valid at least as far westwards as Nimpkish Valley. As in the Bute Inlet map-area structures comprise broad, open folds along northwesterly axes, pre-Island Intrusive, and pre- and post-intrusive vertical faults. Beginning with the White River Fault along the westerly edge of the Bute Inlet map-area and progressing westward, a succession of north and northwesterly trending oblique-slip faults has brought successively older rocks to the surface. The White River Fault and the Tlowils Creek, Adam River and Eve River Faults shown on Figure 2 have an aggregate net dextral slip of approximately 9 miles and a net vertical displacement, up to the west, of 10,000 feet. The Gerald Creek Fault which may be the largest fault in the map-area has a vertical stratigraphic separation of 10,000 feet, up-on-the-west.

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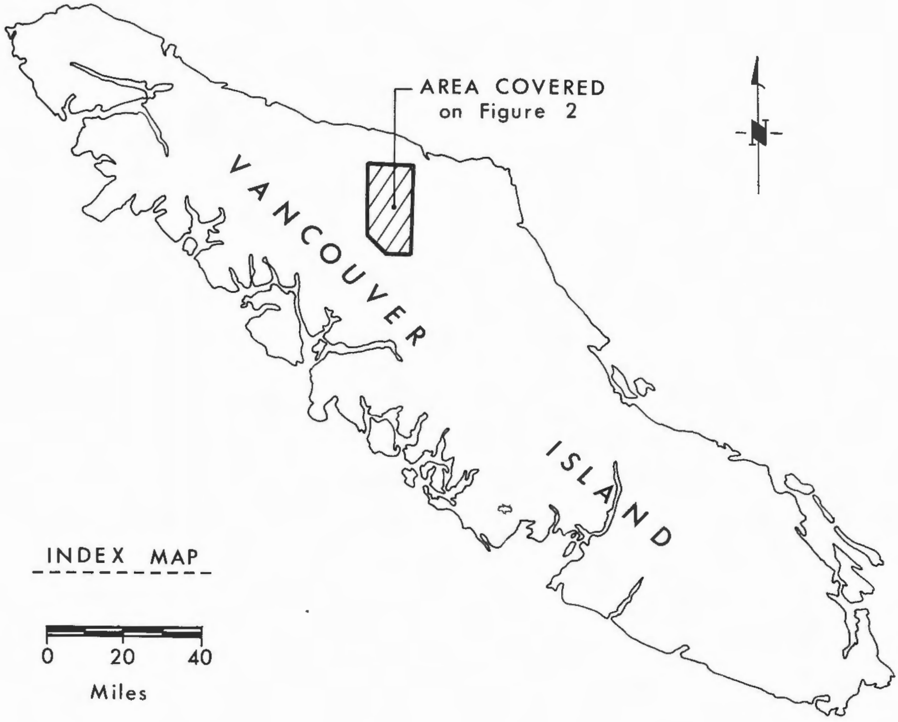
**In addition to the pre-Karmutsen rocks discussed in this report, Figure 1 includes all of the stratigraphic column which was inadvertently omitted from Geol. Surv. Can. Paper 72-1, Pt. A, p. 21-23.



Several lesser faults parallel with the Gerald Creek Fault have demonstrable left lateral components of slip. Together, these fault sets express regional north-northwesterly extension.

Late Paleozoic Limestone

Southwest of the Gerald Creek Fault (Fig. 2), particularly in the vicinity of Nisnac and Schoen Lakes and on the lower northeast flank of Mount Adam, relatively unmetamorphosed, well bedded, light to medium blue-grey fossiliferous limestone is exposed with lesser amounts of darker siliceous limestone and some mafic sills. A section measured one-quarter mile north of Nisnac Lake to Gerald Creek Fault contains 670 feet of coarse to fine bioclastic and coralline limestone and 150 feet of sill. Large rugose corals collected northeast of Schoen Lake from the same fault block were identified as caninoid by E.C. Wilson indicating "an age range of Mississippian through Permian". He reported in addition smaller corallites which "lack the dilate septa in the cardinal quadrants which juvenile Caninia should have". Caninia(?)sp. has been reported by Yole[2] from the Buttle Lake limestone in Strathcona Park but the Early Permian age suggested for that unit is based mainly on Bryozoa and Brachiopoda.

Samples of a coralline limestone, apparently identical with that near Schoen Lake, and exposed over a thickness of 100 feet on the lower northeast flank of Mount Adam (elev. 2,300') have been examined for insoluble microfossils by B.E.B. Cameron who provided the following preliminary report:

GSC loc. 86301, NTS 92 L/1 east; 50°07'57"N; 126°10'52"W.

The insoluble residue of this limestone yielded the following fossils:

- Miscellaneous:
  - fish teeth
  - abundant bryozoa
  - abundant productid brachiopod spines
  - brachiopod fragments
- Ostracoda:
  - *Rectobairdia* sp.
  - *Bairdiacypris* sp.
- Foraminifera:
  - *Globivalvulina* sp.
  - *Climacammina* sp.
  - *Palaeotextularia* (2 spp.)
  - *Palaeobigenerina*? sp.
- Conodontophorida:
  - *Streptognathodus* sp.
  - *Idiognathodus* sp. (aff. *Streptognathodus*)
  - *Ozarkodina* sp.
  - hindiodellid

In general the total assemblage is of Lower Permian to Upper Carboniferous (Pennsylvanian) age. A check of available literature indicates the specimens of *Streptognathodus* and *Idiognathodus* are probably new species which show greatest affinities with Middle or Upper Pennsylvanian (Desmoinesian to Virgilian) assemblages known in the U.S.A. (Kansas, Missouri).

Correlative limestone is exposed on the lower east flank of Mount Schoen and on the lower north flanks of Kokummi Mountain and Victoria Peak within the thermal aureal of a large quartz diorite pluton. Muller[3] has reported similar coralline limestone from Magee Creek containing silicified foraminifera of probable Early Pennsylvanian age.

Middle Triassic sediment-sill unit

In the field, an apparently consistent formational differentiation can be made between the late Paleozoic limestone and the overlying sediment-sill unit on the basis of the first appearance of overwhelmingly abundant basaltic sills. The sills have good columnar jointing which distinguishes them, at a distance, from Karmutsen flows or pillow lavas. All of the rocks are concordant. The writer suggests that the appearance of abundant sills reflects, fairly closely, a change in sedimentary facies from non-fissile, thickly bedded biogenetic limestone to fissile, thinly bedded and laminated, pelagic sediments, mainly siliceous and calcareous shale and wacke. The younger fissile unit is simply more susceptible to silling. Considerable significance is also attached to the fact that this sequential change in sedimentary facies, from coarsely bioclastic limestone to laminated and siliceous shale, is in the same direction as that shown by the post-Karmutsen succession from Quatsino Limestone to Parson Bay Formation and also by a high proportion of the very thin and sporadic intervolcanic sedimentary sequences within the upper

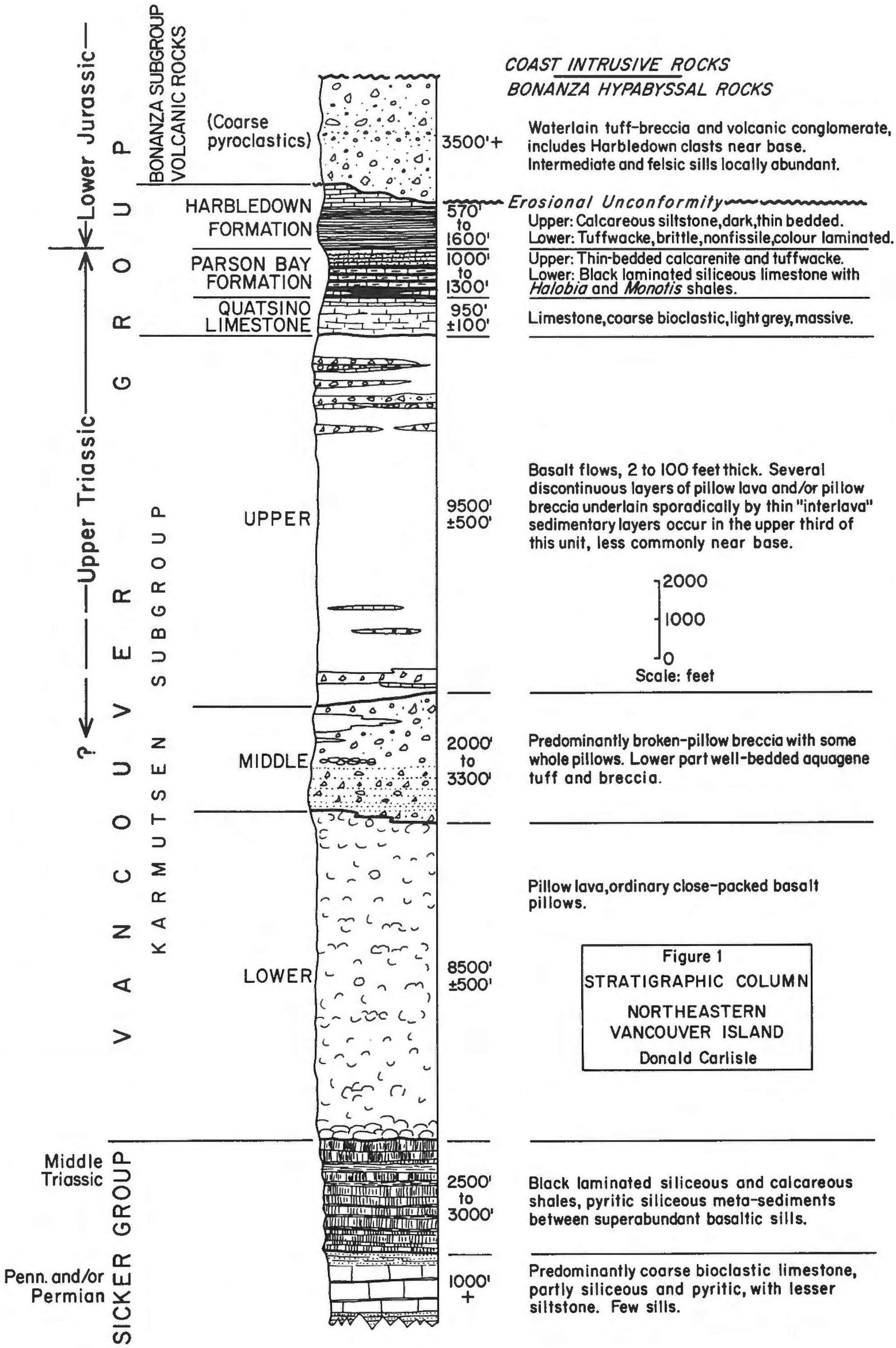


Figure 1
STRATIGRAPHIC COLUMN
NORTHEASTERN VANCOUVER ISLAND
Donald Carlisle

Karmutsen Subgroup. Both facies are considered to represent shallow water environments; the older in each case being richly organic and productive, the younger being pelagic and starved.

The sedimentary layers between the sills are from less than one foot to roughly 200 feet in thickness. They are silicated along the contacts which reinforces their cherty appearance, and they are commonly distorted or partly engulfed by the basalt. For the most part, they are noticeably pyritic and rusty weathering. The total thickness of sedimentary rock within the whole sediment-sill unit may be as little as 500 or 600 feet.

In 1971, members of a mineral exploration group discovered a five-foot-thick layer of pelecypod-rich fissile black shale within one of the siliceous sedimentary layers in a steep gully on the northeast flank of Mount Schoen (elev. 3,250'). The occurrence is approximately two-thirds of the way from the base to the top of the sediment-sill unit. E. T. Tozer has provided the following preliminary report on collections by the writer:

> Daonella sp; group of D. tyrolensis. Age: Middle Triassic, probably early Upper Ladinian.

In view of the structural and apparent stratigraphic conformity of the late Paleozoic and Middle Triassic sedimentary rocks, and the characteristic sequence from coarse bioclastic limestone to pelagic laminated siliceous shale noted above, the writer has placed all of these rocks in the Sicker Group. Similar sedimentary rocks, invariably invaded by sills, but not yet dated, in the Nootka Sound area also have been referred to the Sicker Group by Muller[3]. At Magee Creek they overlie the limestone of probable Early Pennsylvanian age.

Emplacement of sills

The basalt sills are obviously later than the sediments and similar columnar jointed sills occur, with much diminishing frequency upward, in the lower part of the Karmutsen Subgroup, but it does not necessarily follow that all of the sills were emplaced after the beginning of pillow lava eruption. Petrographically, the sills are essentially identical with lower Karmutsen pillow cores and chemically they are only slightly less silicic and slightly richer in iron and magnesium than pillow cores. Similar sills intrude Sicker sedimentary rocks elsewhere. Muller[4] and Fyles[5] have considered diabases and gabbros intruding Sicker sediments on central and southern Vancouver Island to be probably comagmatic with Karmutsen volcanic rocks. Those on the east side of Buttle Lake display decreasing grain size upward through the Sicker sequence and those immediately beneath the Karmutsen pillow lavas have deformed the strata in a manner strongly suggesting to this writer emplacement into soft, wet sediments. There is every reason to believe that marine sedimentation continued up to the time of deposition of pillows. The first basalt to make its way to the sea floor at the initiation of Karmutsen volcanism must have encountered near pristine, perhaps consolidated, but probably unlithified sediments and some, at least, may well have been injected more or less along the bedding at various levels below the sediment-water interface. The accumulation of sills would strengthen the section, making brittle fracture to the surface more likely and leading to eruptions of pillow lava on the sea floor itself. In later times whenever access to the sea floor became blocked, basalt sills would develop both within the growing Karmutsen pile and in older sediments.

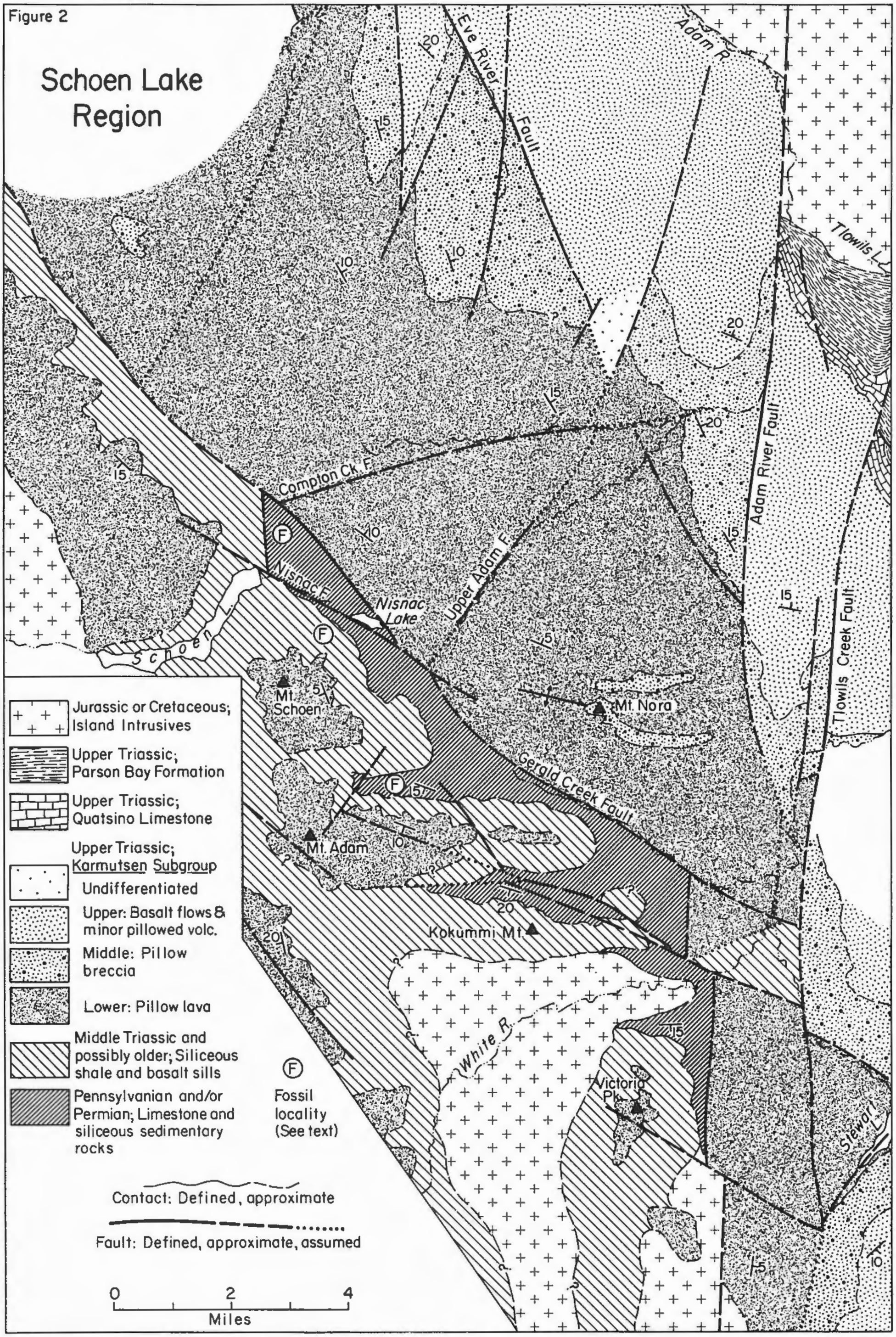


Figure 2
Schoen Lake Region
Eve River Fault
Adam R.
Tlowils L.
Compton Ck. F.
Upper Adam F.
Adam River Fault
Tlowils Creek Fault
Nisnac F.
Nisnac Lake
Schoen L.
Mt. Schoen
Mt. Nora
Gerald Creek Fault
Mt. Adam
Kokummi Mt.
White R.
Victoria Pk.
Stewart L.
20
15
10
10
20
15
20
15
10
15
15
5
5
15
10
20
20
15
15
10
5
Jurassic or Cretaceous; Island Intrusives
Upper Triassic; Parson Bay Formation
Upper Triassic; Quatsino Limestone
Upper Triassic; Karmutsen Subgroup
Undifferentiated
Upper: Basalt flows & minor pillowed volc.
Middle: Pillow breccia
Lower: Pillow lava
Middle Triassic and possibly older; Siliceous shale and basalt sills
Pennsylvanian and/or Permian; Limestone and siliceous sedimentary rocks
F
Fossil locality (See text)
Contact: Defined, approximate
Fault: Defined, approximate, assumed
0
2
4
Miles

Karmutsen Accumulation and Subsidence Rates

Ammonite fauna characteristic of but one zone, the Upper Karnian Dilleri Zone, occur both in intervolcanic beds in the uppermost 2,000 feet of Karmutsen flows and also in 1,000 feet or more of overlying Quatsino Limestone[1]. Using the rather crude estimate of 1 1/2 million years for the average duration of a Triassic ammonoid zone[6] and assuming that roughly one half of the Dilleri Zone is represented in the Karmutsen intervolcanic beds, we obtain a rate of accumulation of grossly 0.1 cm of volcanic flow per year.

Because of the newly discovered Daonella in sediments originally only 100 to 200 feet below the base of Karmutsen pillows, it can now be estimated that the entire 20,000 feet of Karmutsen pillows, pillow breccias and flows accumulated in a span of from 5 to 10 million years (Upper Ladinian to Upper Karnian). From this the aggregate rate of accumulation is again grossly in the order of 0.1 cm per year. By way of comparison, similar reasoning yields apparent aggregate rates of accumulation for the Quatsino Limestone (Upper Dilleri Zone) and for the Parson Bay Formation (Welleri to Lower Suessi Zones), neglecting compaction, cannibalism, erosion and intrastratal colution, one-half and one-thirtieth respectively of the rate of accumulation of the volcanic rocks. Since allowances for post-depositional thinning are not necessary for the volcanic rocks, and since shallow water limestones occur below, within and above the Karmutsen Subgroup, the accumulation rate of 0.1 cm per year is equally acceptable as an aggregate order-of-magmitude rate of regional subsidence for at least the later part of the Triassic.

Parts of field work were supported by grants from the University of California and from the National Science Foundation Undergraduate Research Participation Program. Particular acknowledgment is made for the excellent field mapping by R.L. Hill and S. Kuniyoshi.

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[2] Yole, R.W.: An early Permian fauna from Vancouver Island, British Columbia; Bull. Can. Petrol. Geol., v. 11, p. 138-149 (1963).

[3] Muller, J.E.: Nootka Sound area, British Columbia (92E); Part A, April to October, 1971; Geol. Surv. Can., Paper 72-1, Pt. A, p. 33-36 (1972).

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[5] Fyles, J.T.: Geology of the Cowichan Lake area, Vancouver Island, B.C.; B.C. Dept. Mines Bull. 37 (1955).

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GEOCHEMISTRY

10. LAKE SEDIMENTS FROM PERMAFROST REGIONS: Zn, Cu, Ni, Co and Pb CONTENT OF THE SUB-2000 MICRON PARTICLE SIZE RANGES

Aerial

Project 700046

R. J. Allan and R. T. Crook

Introduction

From December, 1971 to May, 1972, a study was conducted to determine the Zn, Cu, Ni, Co and Pb concentrations in each of eight different particle-size ranges of selected lake sediments from permafrost regions in the Northwest Territories. A search through available literature showed that very few studies of this nature, if any, have been published on lake sediments.

A group of eight samples were chosen for this study (Table 1). These sediments represented five different environmental and geological areas in subarctic and arctic regions of Canada. These areas are underlain by five different rock types (Table 1). The samples had varying trace element concentration, as shown by previous analysis of the total, <80 mesh ($<177\mu$), sample. The sediments were first sieved to less than 2 mm. Very few, if any, greater than 2 mm particles were encountered during this procedure. The less than 2 mm fraction was then subjected to a procedure of soil leaches, mineral dispersion and fractionation[1]. This leaching and dispersion procedure, carried out on the <2 mm fraction first removed all carbonates and exchangeable cations, then organics, then amorphous coatings of Fe and Mn hydroxides, and finally amorphous oxides of Si and Al. These leaches have been stored for future analysis. This "cleansed" sample was then fractionated into eight particle size ranges. Analysis of each size range was made for Zn, Cu, Ni, Co, Pb, Fe and Mn, by atomic absorption spectrophotometry following an $HF-HNO_3-HClO_4$ total dissolution. The results, in parts per million concentration, are listed in Table 1. Data for certain samples are presented in Figures 1, 2 and 3. All of the samples selected were of medium to high concentrations in one or more elements relative to the average regional concentration levels, so that a readily measurable concentration, above the instrumental detection limit for each element, could be obtained.

Results

The results are given in terms of trace element concentration in each size range. The highest Zn values in the clay fraction were in samples which came from lakes adjacent to known ore deposits containing Zn (Table 1). High Zn concentrations were also found in the $<2\ \mu$ clays of samples from a lake near a large gossan in an Archean acid volcanic area and also from a lake in an Archean basalt area. The highest copper concentration (8070 ppm Cu) is in the $\ll 2\mu$ fraction of a sample from a lake adjacent to the High Lake deposit. This known, but undeveloped, deposit in the Northwest Territories consists of 5 million tons Cu-Zn set in an Archean acid volcanic belt. Of the three

TABLE 1

Trace element concentrations in particle size ranges of lake sediments from Arctic Canada

SAMPLE NUMBER	PARTICLE SIZE RANGES							
	SAND				SILT			CLAY
	2000μ - 500μ	500μ - 250μ	250μ - 105μ	105μ - 53μ	53μ - 20μ	20μ - 5μ	5μ - 2μ	<2μ
ZINC				ppm				
1	no sample	68	31	49	96	635	1294	2894
2	216	189	221	347	562	1059	1735	3790
3	50	47	110	187	684	2853	4688	6120
4	40	30	27	29	53	143	395	2495
5	118	79	63	48	91	205	785	3593
6	226	180	143	150	94	88	143	537
7	123	116	132	150	198	258	253	738
8	100	107	88	79	94	168	332	1390
COPPER								
1	no sample	11	5	9	7	35	50	138
2	297	231	237	308	471	975	1583	8070
3	20	9	231	29	40	101	135	221
4	9	7	5	6	6	9	19	122
5	24	20	27	16	19	68	192	672
6	235	249	234	234	169	233	398	2000
7	166	156	161	174	167	156	120	685
8	36	36	33	25	36	23	28	154
NICKEL								
1	no sample	24	15	23	26	69	77	100
2	26	21	21	24	30	38	58	50
3	43	39	45	55	69	112	119	143
4	9	13	6	9	11	17	26	87
5	79	62	52	49	39	89	134	248
6	66	51	49	73	75	41	41	93
7	49	39	47	53	60	67	67	130
8	904	858	583	362	296	214	197	530

Table 1 (continued)

COBALT								
1	no sample	5	2	3	5	19	18	20
2	8	5	8	8	10	13	19	21
3	10	6	8	16	23	45	60	70
4	1	1	1	1	1	1	6	20
5	24	19	15	11	15	29	57	109
6	45	31	27	26	16	11	16	58
7	27	24	26	29	35	37	32	72
8	138	107	42	29	19	19	19	59
LEAD								
1	no sample	4	4	4	28	19	4	64
2	20	28	25	34	31	36	87	450
3	12	24	19	31	33	57	71	135
4	39	31	16	17	19	16	30	101
5	17	13	28	17	22	22	34	89
6	4	4	19	4	19	4	4	48
7	16	4	4	4	4	16	22	42
8	4	39	4	4	16	13	13	47

SAMPLE DESCRIPTIONS

1. From a lake (65° 55'N; 108° 22'W) adjacent to a 10-million-ton Zn ore deposit in the Hackett River area, in Archean acid volcanic rocks.
2. From a lake (67° 23'N; 110° 51'W) adjacent to a 5-million-ton Cu-Zn ore deposit in the High Lake area, in Archean acid volcanic rocks.
3. From a lake (67° 28'N; 110° 57'W) adjacent to a large gossan in the High Lake area, in Archean acid volcanic rocks.
4. From a lake (75° 33'N; 96° 09'W) near a 1-million-ton Pb-Zn ore deposit, on Little Cornwallis Island, in Paleozoic carbonate rocks.
5. From a lake (64° 16'N; 115° 25'W) in the Indin Lake area, in Archean basic volcanic rocks.
6. From a lake (67° 24'N: 116° 27'W) adjacent to a 3-million-ton Cu ore deposit, in the Coppermine area, in Proterozoic basic volcanic rocks.
7. From a lake (67° 22'N; 116° 18'W) in the Coppermine area, in Proterozoic basic volcanic rocks.
8. From a lake (66° 54'N; 115° 13'W) in the Muskox Intrusion area, in ultrabasic intrusive rocks.

other relatively high copper values, one came from a lake adjacent to a 3-million-ton Cu deposit in the Hackett River area, N. W. T. The other two were from Archean and Proterozoic basalt areas of regionally higher Cu concentrations. Similarly, the highest Pb (450 ppm Pb) was in the < 2 μ fraction of a sample taken from a lake adjacent to the High Lake Cu-Zn-Pb ore deposit which produced the highest Cu and one of the highest Zn concentrations. The highest Ni concentration (904 ppm Ni) was found in the 2000μ to 500μ size fraction of a sample taken from a lake which is found in an ultrabasic intrusive area, the Muskox Intrusion, which is characterized by regionally higher Ni and Co concentrations. The highest Co value (138 ppm Co) was also found in the 2000 μ to 500 μ size fraction of the same sample in which the highest Ni concentration was observed. The one other relatively high Co concentration was found in the < 2 μ fraction of a sediment taken from a lake in an Archean basalt area.

All of the samples had high concentrations of trace elements associated with adjacent ore deposits or the surrounding rock types.

Discussion

Most of the samples showed the highest concentrations in the finer size fractions (Figs. 1, 2 and 3). The highest concentration of every element was, in all cases but two, in the < 2 μ fraction (Table 1). Normally there was a sharp decrease in concentration from the < 2 μ fraction to the 5μ to 20 μ fraction. However, relatively high concentrations were normally maintained until a particle size range of 50 μ to 100 μ was reached. Few samples had significantly

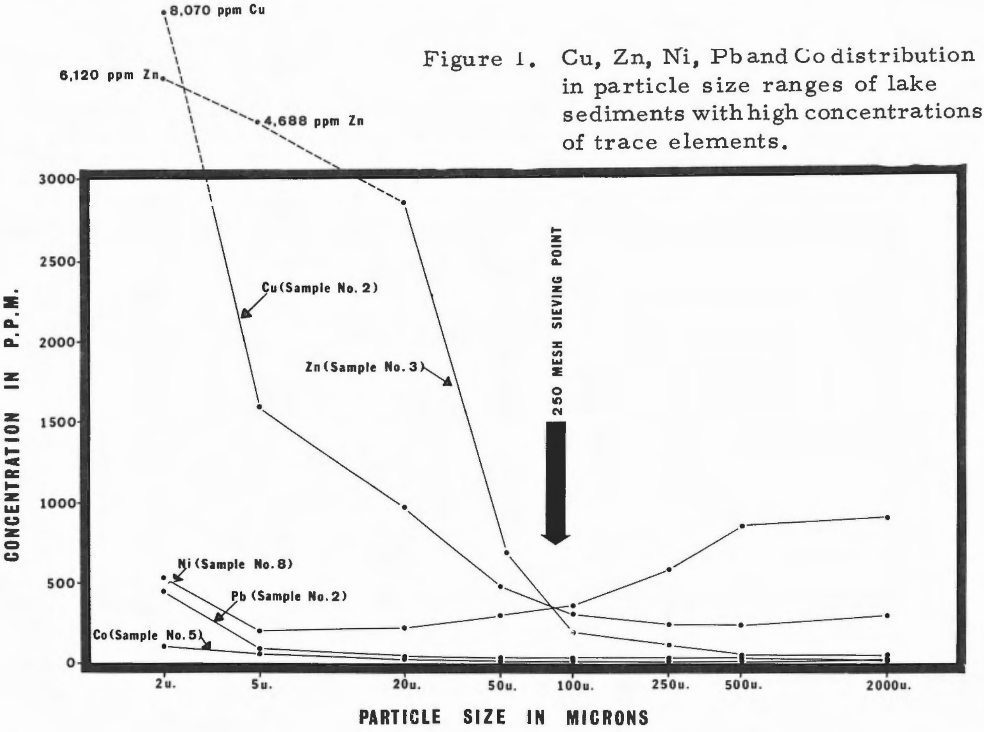

Figure 1. Cu, Zn, Ni, Pb and Co distribution in particle size ranges of lake sediments with high concentrations of trace elements.

higher concentrations in the coarser fractions (>50μ) compared to the finer fractions (<50μ), as mentioned. The only exception to the rule was sample 8 for Ni and Co. This sample came from an ultrabasic intrusive area of regionally higher Ni and Co background concentrations. In this sample,

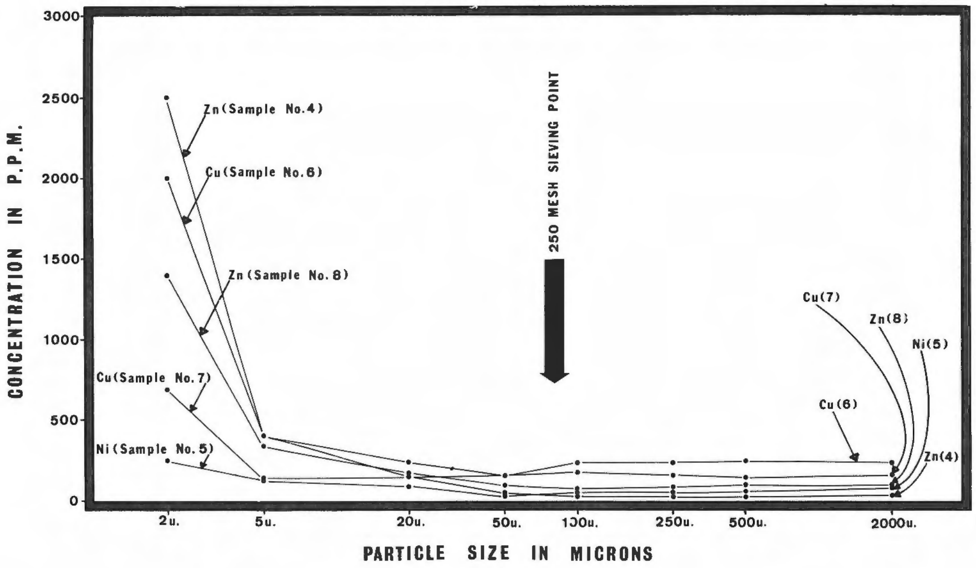

Figure 2. Cu, Zn and Ni distribution in particle size ranges of lake sediments with intermediate concentrations of trace elements.

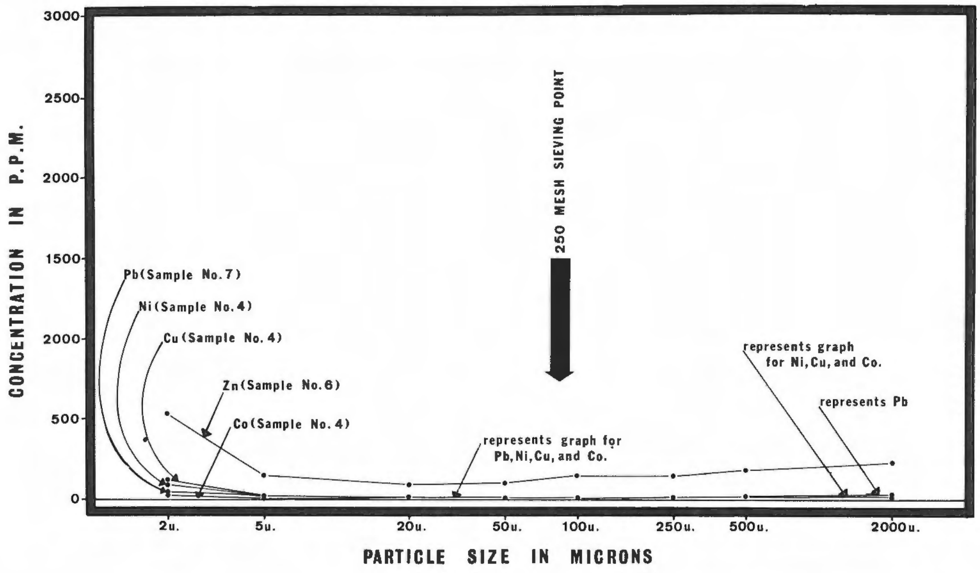

Figure 3. Cu, Zn, Ni, Pb and Co distribution in particle size ranges of lake sediments with low concentrations of trace elements.

the sand fraction had relatively higher concentrations of Ni and Co, with the highest concentrations being in the coarse sands.

In most surficial materials, the 50 µ particle size is the break between the sand and silt fractions. The sand fractions are usually composed of rock fragments or aggregates of several minerals characteristic of the parent rocks. Trace elements in the >50µ fraction should show a slight increase in concentration as the fraction becomes coarser and so, more closely approaches the parent rock in composition (Table 1, Figs. 1 and 2). The < 50 µ portion, consisting of the silt and clay fractions, is normally composed of quartz, feldspars, micas and various secondary layer silicates such as amphiboles and pyroxenes. In this <50µ fraction we find increasing quantities of trace elements with a decrease in particle size (Figs. 1, 2 and 3).

Because these samples have been leached by several procedures (pH5 NaOAc; H_2O_2; Na-citrate-dithionite) it is unlikely that a very large concentration of trace elements remain in an adsorbed form, that is, in the form of cations sorbed on the surface of fine particles coated by organics or amorphous iron and manganese hydroxides. The increases in concentration of trace elements observed in the finer fractions must then be due to trace element cations in the actual crystal lattices of the minerals in these finer fractions. These can presumably occur in three forms: (1) in the form of minor accessory minerals of high trace element content; (2) in the form of isomorphously substituted elements in the actual lattices of the nonlayer silicate minerals, such as feldspars or in the lattices of layer silicates, such as biotites; or (3) as specifically absorbed trace elements in the interlayers of secondary layer silicates such as illites or vermiculites. Because sorption processes depend on the total available surface area, we should expect this process to produce greater concentrations of trace elements in the very fine silts and especially in the clays. In the < 50 µ fraction, the concentrations in the coarse silt fraction are possibly due to factors (1) and (2) above. In the medium silt fraction, factors (2) and (3) are probably dominant. In the fine silt the nonlayer silicate minerals are replaced by layer silicates so that factor (3) becomes of major importance relative to factor (2). In the clay fraction the high concentrations are possibly due to factors (3) and (2). There may be an effect of the accessory heavy minerals in even the finest size fractions, but this effect possibly decreases with a decrease in particle size. Because of the above effects, the trace element concentrations should increase with a decrease in particle size (Table 1; Figs. 1, 2, and 3).

We should also expect to find high concentrations of trace elements in the leaches themselves. This would be due to the removal and dissolution of the organics and the Fe and Mn hydroxide coatings, and therefore, most of the adsorbed cations, from the surface of the particles.

As seen from the discussion above of the >50 µ and <50µ fractions, the size range immediately on either side of the 50 µ level should have the lowest concentrations of trace elements. These deductions are substantiated by the results presented in Table 1 and Figures 1, 2 and 3. Because the relative concentrations of the elements can be related (Table 1) to the estimated size of the mineralization which is the source of each trace element, it is then the finer fractions which are responsible for the anomalies due to the nearby presence of oxidation and leaching of sulphides. Also, in areas where unusually high background values for one or more elements are encountered, i. e., sample 8 in the ultrabasic intrusive area, which is regionally higher in Ni and Co, it might be found that using the finer fractions of the sediment for analysis would give concentrations closer to those desired in discerning anomalous areas due to the presence of sulphides.

In prospecting for sulphide deposits, using inorganic lake sediments, the above results indicate that the finer the fraction selected for analysis, the better the results because trace element contrasts will be increased. However, the various size fractions less than 50µ (approximately 250 mesh) usually must be separated by a wet sedimentation technique. Therefore, the total <50µ size fraction appears to be the one most economically suited to any survey where large numbers of samples are collected.

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11. POTENTIAL OF COMBINED GC-MS AS A SENSITIVE TOOL IN EXPLORATION GEOCHEMISTRY

Project 690091

I. R. Jonasson

The Instrumentation

An integrated GC-MS unit consists of two basically different instruments. The gas chromatograph (GC) is designed to separate and measure a large number of chemical constituents, including those present as trace concentrations, which may occur in either a gas or liquid phase. The obvious application is therefore to direct sampling of planetary or soil atmospheres for trace materials of immediate interest. In many cases, however, the trace material sought may be present in microgram or picogram quantities only, levels which are at the threshold or below the sensitivity limits of conventional GC detectors such as flame ionization gauges or electron capture devices.

The integration of a GC with a mass spectrometer (MS) can offer a method for direct sampling and quantitative analysis of gaseous constituents at picogram levels. With the acquisition of the instrumentation described briefly herein, the Geochemistry Section has undertaken an extensive critical survey of the potential of using such gaseous emanations to detect deeply buried ore deposits. The project both continues the mercury studies initiated three years ago and extends similar investigations to less familiar gases.

Work performed to date on these units has consisted essentially of testing and sample gas analyses. Alkylmercurials can be easily characterized by their mass spectra and can be detected at nanogram levels.

Applications in Geochemistry: 1. Pathfinders to metal deposits

In the immediate vicinity of a buried ore deposit a wide variety of volatile and gaseous materials occur which are either derived from the orebody by slow chemical processes or owe their origins to the same processes that originally formed the ore deposit. In both cases, however, such vapours are directly indicative of the presence of what may be economic mineralization.

The vapours are quite mobile and generally can permeate covering rock and soil to reach the surface above the deposit. In some instances distance travelled may be around 600 metres. Thus a sampling program designed to tap soil gases will locate these pathfinder vapours and thereby indicate the presence of mineralization[1]. Perhaps the vapour most in the news at present is mercury metal – a species now infamous as a noxious pollutant. From the viewpoint of a geochemist mercury is singularly important as an indicator of polymetallic sulphide deposits (lead, silver, zinc, antimony). Its presence in soil atmosphere (and terrestrial atmosphere) has been utilized extensively to map shallow underground veins of such deposits. Some rather unique physiochemical properties of mercury have enabled it to be detected at nanogram concentrations by conventional atomic spectroscopic techniques. However, detection limits for mercury in soil atmospheres are such that more sensitive detection methods are required to find more deeply buried deposits. GC-MS fulfils these requirements completely and allows potential evaluation of the types of mercury vapours which may exist in the gases sampled. Information gleaned from these studies may then produce data which may help interpret better, exploration methods based on the measurement of soil mercury ions.

Other vapours and gases are potentially just as useful as mercury but usually their concentrations in soil gases are two to three orders of magnitude lower or higher. Examples of such vapours are sulphur-dioxide, hydrogen sulphide, carbon dioxide, iodine, bromine which are associated with deposits of heavy metals, copper, uranium, iron, gold, tin, nickel and rare metals. The presence of iodine and bromine may also indicate proximity of fossil fuels. Volatile hydrocarbons and carboxylic acids in soil gases may lead to the same type of deposit. The value of seeking such vapours is enhanced in cold climates and permafrost regions since lower temperatures and frozen (immobile) conditions allow for increased accumulation of these pathfinder materials in the soils and soil gases. There is sufficient data available in the foreign literature to support this contention. The supporting list of references with this essay provides examples of the uses of all the aforementioned vapours. Other vapours of great interest are considered to occur only at picogram concentrations in soil atmospheres. These include various organometallic compounds and hydrides which, in part, owe their origins to bacterial and chemical action within the soils themselves. For example, dimethylmercury and other alkylmercurials, alkylarsines (arsenic) and arsine, alkylstibines (antimony) and stibine, selenium and tellurium hydrides and various organic derivatives may occur in the presence of copper and base metal mineralization. Moreover, these rarer trace elements are very sensitive indicators of specific types of deposits and the mere presence of say. tellurium compounds may be regarded as a valuable piece of geochemical information since these compounds would only reach significant and detectable levels if extensive metallic sulphides were nearby. A mass spectrometer is the only analytical tool capable of detecting and identifying the very low concentrations of these vapours.

Applications to Geochemistry: 2. Fluid-gas Inclusions

Fluid inclusion studies are increasingly being used in the search for hydrothermal ore deposits. The Russians are presently leaders in the field of fluid inclusion research and its application to exploration for economic ore deposits. Since these fluids are preserved relics of the hydrothermal solutions that produced the enclosing minerals, their composition should reflect the ore potential of the vein system[2,3]. Our present knowledge of the chemical relationship between solution and precipitated mineral phases is sufficient to allow interpretation of ore potential from the chemistry of hydrothermal solutions as represented by fluid inclusions[4, 5].

The method requires the analysis of minute fluid inclusions from quartz, calcite and sphalerite in veins for their dissolved gases and for the isotopic compositions of carbon, oxygen, hydrogen and sulphur [3]. GC-MS is used to analyze for hydrogen sulphide, sulphur dioxide, hydrogen chloride, hydrogen fluoride, ammonia, carbon dioxide, nitric oxide, hydrogen, oxygen, carbon monoxide and methane[6]. These data along with metal cation ratios can be used to prepare contour maps of vein systems which can be interpreted to define direction and potential of ore occurrence [7].

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GEOPHYSICS

12. AIRBORNE RESISTIVITY ELECTROMAGNETIC SYSTEM

Project 680089

A. Becker and A. K. Sinha

The Airborne Resistivity Electromagnetic System (ARES) is quite a new concept in airborne electromagnetic exploration which has been conceived by the Electrical Methods Section[1] and is now under active development. The method, which allows the frequency of the transmitter current to be varied to achieve a uniform depth of penetration at all times irrespective of the ground conductivity, has been shown theoretically to be equally good for mining exploration and geological mapping.

In the last few months, extensive theoretical studies have been undertaken to study the various aspects of the method under different geological conditions. The system has been simulated on a digital computer and the results show the advantage of this system over many existing airborne systems. Figure 1* shows the simulated ARES result over a two-layer earth section where the substratum is infinitely resistive. The geological section is shown at the bottom and the frequency plots are shown for various values of the resistivity of the first layer ρ_1, from 20 Ω-m to 200 Ω-m. The interesting thing to note is that when the frequencies are plotted on a log-scale, the shape of the ARES response does not depend at all on the value of ρ_1. This plot at 60° phase angle between the primary and the secondary fields shows the remarkable correlation between the ARES plot and the subsurface topography.

Computer-generated anomalies have also been obtained over several known geological sections in Ontario, Quebec and Manitoba and the results have been very promising in each area. As a side product, a generalized computer program has been written to obtain the electromagnetic response of an n-layer earth with arbitrary conductivities and thicknesses excited by dipolar sources. Several master-charts for the ARES anomalies over two- and three-layer earth sections have been plotted and methods of interpretation of the data are being explored now. This method seems to have a good potential for mapping the thickness of overburden and for detecting sulphide conductors. Application of the system could even be extended to permafrost regions.

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*For Figure 1 see next page.

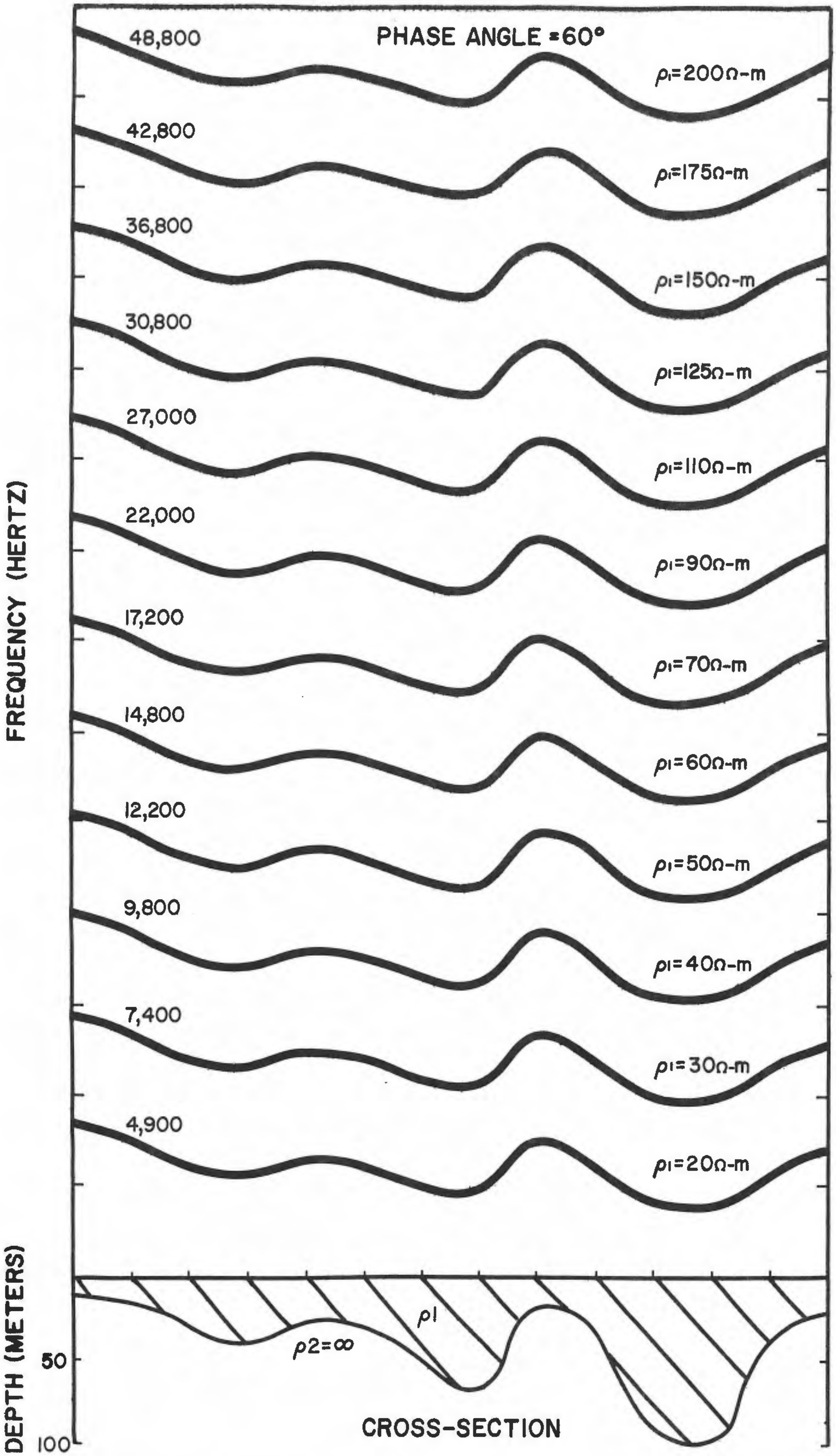

Figure 1. Simulated ARES result over a two-layer geological cross-section for values of ρ_1 from 20 to 200 ohm-metres.

13. DEVELOPMENT OF AN AUTOMATED OMEGA NAVIGATION SYSTEM FOR OFFSHORE AIRBORNE GEOPHYSICAL SURVEYS

Project 650007

Margaret E. Bower

Work is continuing on the computerized data acquisition and navigation system for the National Aeronautical Establishment's North Star aircraft which has been used during the past 8 years to carry out aeromagnetic surveys of the continental shelves and deep ocean adjacent to eastern Canada. Flight testing will begin shortly. The original plan was to use two computers linked together, but this was found to create more problems than it solved. Therefore the program has been reorganized to use one computer only, an Interdata Model 4 with expanded command set and 48 K bytes of memory.

The data acquisition part of the program reads all the peripheral devices, puts the data into the form required, and sends it to the magnetic tape via a selector channel. It also provides digital display on a typewriter and storage scope, analog display on two tracks of chart, and operating status on the computer panel lights.

The navigation program works concurrently with the data acquisition program by means of a two-level, real-time operating system. Initial experiments with the Omega V. L. F. navigation system showed that (1) the Omega alone is not sufficiently reliable with the present station configuration, and (2) that the published skywave tables are not adequate. The Omega is therefore 'rate-aided' with doppler, drift and heading, read twice a second through a synchro-digital converter. An Omega ground station is used to obtain skywave corrections (differential Omega); these may be transmitted to the aircraft every 10 minutes if necessary.

Six Omega LOP's (Line of Position) are used; they may be any station pair on either 10.2 or 13.6 KHz. Each intersection is assigned a weight, depending mainly on the angle at which the lines cross. In the event that large navigation errors occur or that it is necessary to restart the program over the ocean, the difference frequency of 3.4 KHz may be used at first since it gives lane widths of around 24 miles. Static tests show that the program can pull into its true position from as much as 17 miles away.

The Omega receivers have a cycle time of 10 seconds and a built-in time delay of 60-70 seconds, therefore the doppler, drift and heading are used to update the position every half second. Every 10 seconds the Omega position and the 60-second-old doppler position are used to compute a most probable position. Data from all sources is checked for validity, and the system will operate on doppler only or Omega only. The current operating status is always displayed on the panel lights, and the operator may initiate certain changes via the keyboard while the program is running. The most probable position is displayed for the navigator every 10 seconds, and he can get the current position at any time by pushing a button.

Further development of this system may involve the use of Kalman filtering of the incoming signals, and a more efficient real-time operating system for the computer.

14. A MODEL STUDY OF REFLECTED SEISMIC WAVES FROM THE BOTTOM OF THE PERMAFROST LAYER

Project 680037

J.A. Hunter

During the past field season where shallow seismic techniques were applied to investigating properties of permafrost, it became apparent that no well-defined reflected seismic events could be associated with the bottom of permafrost in regions where the permafrost layer is known to be thin. Two explanations are put forward:

(1) the reflected seismic compressional wave arrives so close behind the "direct" wave that the two wave trains overlap, hence no clear separation of events; and,

(2) the nature of the permafrost boundary is such that it cannot support a reflection.

If the reflected event is indeed interfering with the direct arrival this might be manifested by rapid attenuation of the first arrival by destructive interference. Such high attenuations are observed on field records, but these can also be explained by divergence of the seismic wave-front as the velocity increases with depth within the permafrost zone.

If the lower boundary of the permafrost layer constitutes a gradual velocity decrease with increasing temperature forming a gradational seismic boundary (such as may occur in clays) the reflected event may be severely attenuated. However, for coarser grained materials (silts and sands) recent laboratory measurements of temperature-velocity relationships by Aptikaev[1] show that the transistions are sharp, occurring over narrow temperature ranges and that velocity contrasts are large.

In order to assess the importance of the frozen-unfrozen boundary several simple mathematical models have been designed following the form given by Figure 1. A single velocity V_1 is assumed for the permafrost layer for

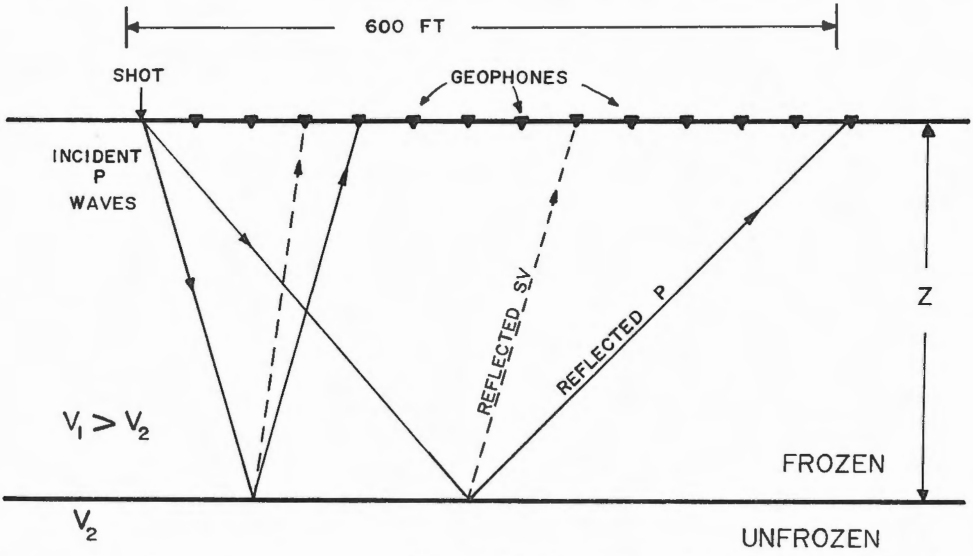

Figure 1. Permafrost layer model used in the study of reflection amplitudes.

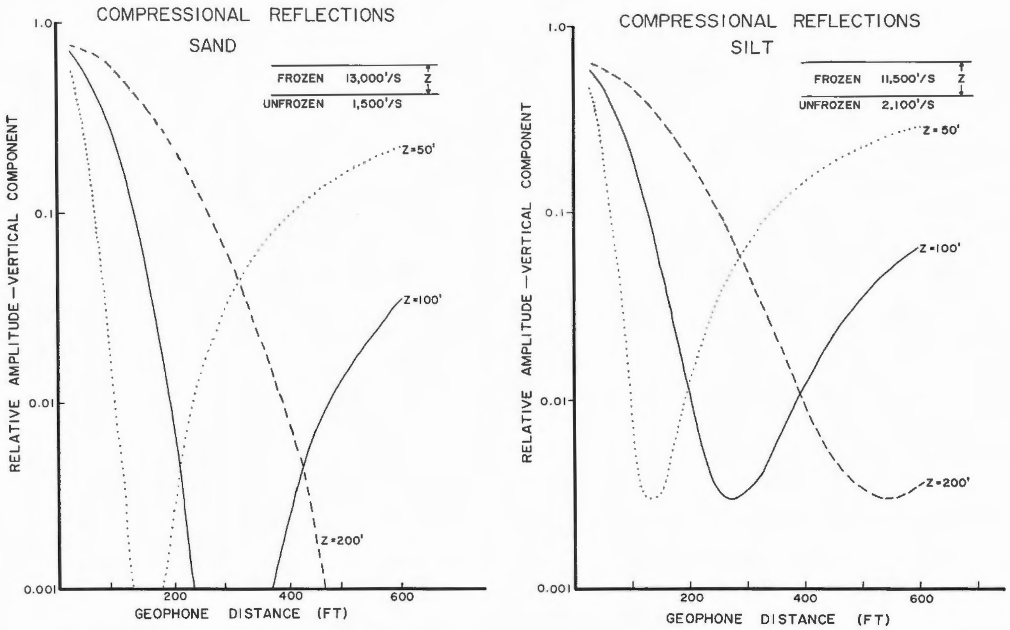

Figure 2. Computed compressional reflection amplitudes for models of (a) sand; and (b) silt from velocity values given by Aptikaev (1964).

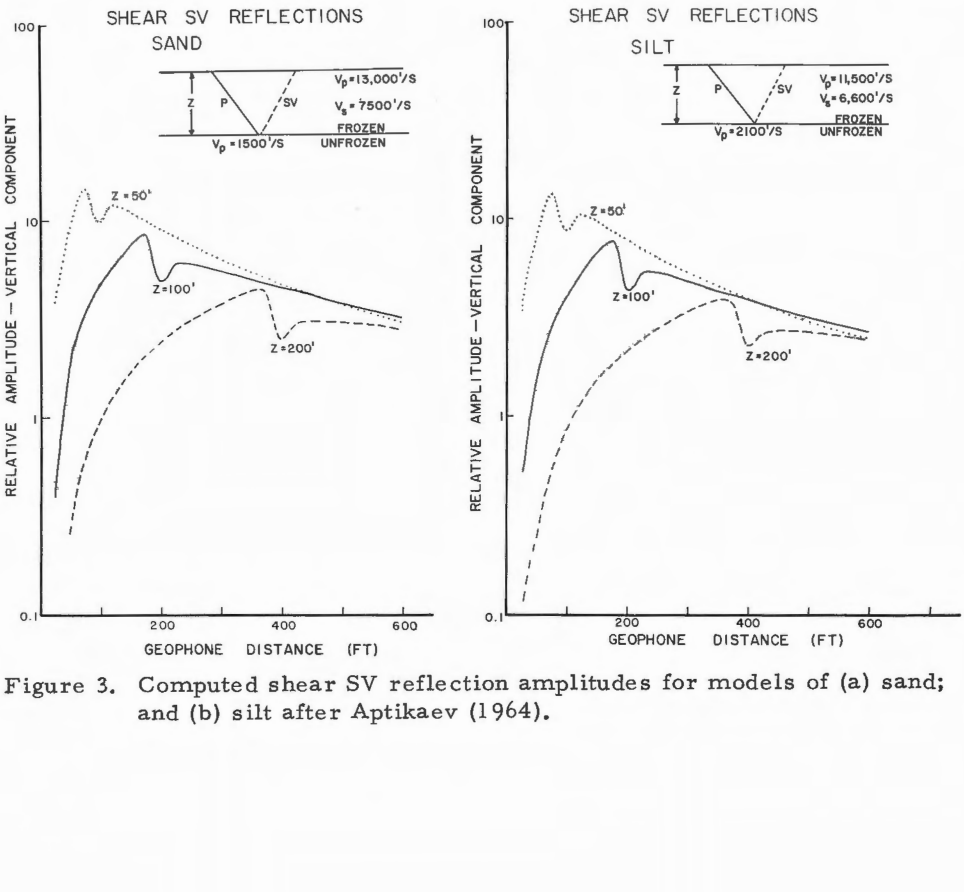

Figure 3. Computed shear SV reflection amplitudes for models of (a) sand; and (b) silt after Aptikaev (1964).

various types of materials[1] and the unfrozen velocity of the same material is assigned to V_2. Assuming an incident plane compressional wave on the lower plane boundary, amplitudes are computed for the reflected compressional (P) and shear (SV) waves using solutions of the Zoeppritz amplitude equations for non-normal incidence[2]. After correcting for wave spreading and reflection from the upper free surface, the relative components of motion are computed as would be detected by a spread of vertical geophones 600 feet long and at 25-foot spacing. The computer program written for the analysis uses as its basis a subroutine of solutions of the Zoeppritz equations written by Dr. R. F. Mereu of the University of Western Ontario.

Some of the more interesting results are shown in Figures 2 and 3 for silt and sand and for various thicknesses of permafrost. For compressional reflections, amplitudes increase as the incident angle increases, suggesting that at large distances from the shot the reflected event may become prominent. However at these distances the difference in travel time between the direct wave and the reflected waves may be insignificantly small. Estimates of depths from extremely wide-angle reflections may be erroneous if one attempts to fit a curve to a restricted portion of the travel-time distance curve. Also, the phase shift of the reflected pulse with respect to the direct arrival is 180° in all cases, suggesting destructive interference between the two events when travel time differences are small.

The converted SV reflected wave for an incident compressional wave appears to maintain high amplitudes over the geophone spread length for the models examined. This suggests that converted later events may be important in the interpretation of structure of the bottom of permafrost. In the light of these results a search for such later events on shallow seismic records from the Mackenzie Delta is presently underway.

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15. ELECTRICAL ROCK PROPERTIES

Aerial

Project 630049

T.J. Katsube and L.S. Collett

Study on electrical properties of rocks is being carried out for the purpose of aiding in development and improvement of new and existing ground and airborne electrical and electromagnetic exploration methods. Various measuring systems have been set up for the frequency range from 10^{-2} to 10^{8} Hz, mainly to accumulate data on electrical rock properties, and to study the electrical mechanism of rocks.

At present these measuring systems can be divided into a group that consists of standard measuring systems set up to measure large quantities of dry rock specimens on a production line basis for the frequency range from 10^{2} to 3×10^{7} Hz, and a group that consists of various systems set up to study the electrical mechanism of dry and moist rocks for the frequency range from 10^{-2} to 10^{8} Hz. One of the most important subjects in this study is to find electrical characteristics that can be used to distinguish between different types of minerals, rocks, rock structures and other situations (amount of moisture, liquid or frozen states), by electrical or electromagnetic methods applied at the earth surface.

The standard measuring system[1] for the frequency range of 10^{2} to 3×10^{9} Hz, that went into operation in October 1971, has been working under satisfactory conditions. The measurement accuracy is being maintained at about ±2.0% of international standards. All measurements are recorded on standard measurement forms, the values on these forms are punched on tape and fed to the computer. For one specimen there are about 13 values measured at each frequency, and therefore about 180 readings are taken for the entire frequency range of 10^{2} to 3×10^{7} Hz. These measurements are computed in a matter of minutes.

A suite of dry igneous rocks has been measured by the standard measuring system (10^{2} - 3×10^{7} Hz) in room atmosphere. The results are being used for study of the electrical mechanism of rocks. A suite of serpentinite specimen has also been measured by the same system. Results indicate that they are comparatively conductive even under dry state in room temperature

The measurement of these serpentinite specimens has resulted in finding that there is an error in the conventional concept of the electrical characteristics of rocks that exhibit large values of permittivity (or dielectric constant). It has been realized both in theory and practice that conductive rocks can exhibit large values of permittivity or dielectric constant, due to insufficient considerations of micro-airgaps (1-10 microns) between the specimen and electrodes[2]. This fact was noticed because of the high accuracy of the standard measuring system.

A new development since November 1971 is the study on the electrical nonlinear phenomena in rocks[3]. Electrical currents that flow through rocks generally increase linearly with applied voltage. However, there are cases where, above a certain voltage or a certain current density, the rate of current increase rises above the normal rate. This is referred to as the electrical nonlinear phenomenon. This phenomenon can also be presented in terms of conductivity increase with applied voltage. Usually this phenomenon is seen below 10^{3} Hz. When this nonlinear phenomenon occurs, it becomes impossible to make proper electrical measurements of rocks. This phenomenon occurs in various kinds of dry and moist rocks. The concept of "nonlinearity" is similar to that of "decomposition voltage" of electrodes immersed in an electrolyte. The decomposition voltage is a characteristic of conductors immersed in liquids, and it varies according to the type of conductor. It is thus possible, that the nonlinear study of minerals could form a basis of a new geophysical technique, especially in borehole logging, for detecting not only the existence, but also the type of minerals in the ground.

[1] Katsube, T. J. and L. S. Collett: Electrical rock properties; *in* Report of Activities, April to October 1971; Geol. Surv. Can. Paper 72-1, Pt. A, p. 52 (1971).

[2] Katsube, T. J. and L. S. Collett: Measuring techniques for rocks with high permittivity and high loss; presented at the Symposium on Electrical Parameters of Rocks; University of Utah, Mar. 15-17, 1972 (1972).

[3] Katsube, T. J. and L. S. Collett: Electrical nonlinear phenomena in rocks; presented at the Symposium on Electrical Parameters of Rocks; University of Utah, Mar. 15-17; 1972 (1972).

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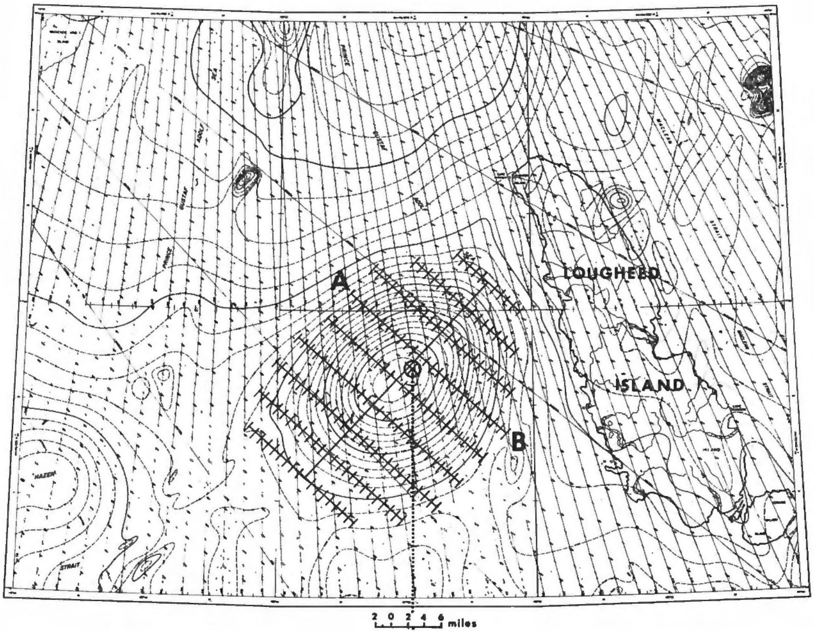
16. AN AUTOMATIC MULTI-MODEL MAGNETIC INTERPRETATION METHOD USING THE POWELL ALGORITHM

Project 680121

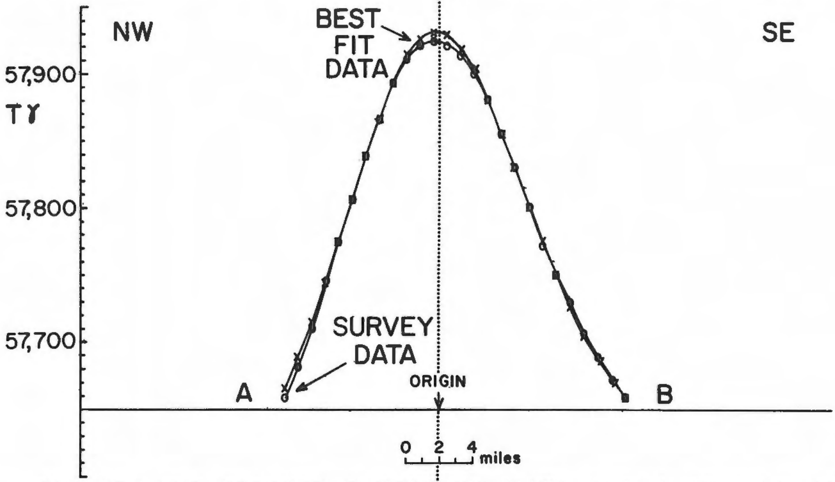
P. H. McGrath and P. J. Hood

An automatic multi-model computer method has been developed at the Geological Survey of Canada for the quantitative interpretation of magnetic data. The computer obtains a best-fit model anomaly curve for a set of discrete observed data by least squares matching theoretical data with the observed data. The interpreter selects the particular geometrical model which is to be used by the computer for the curve matching procedure. The models available in the program are the vertical prism, the thick plate, dyke, sloping step, etc. The theoretical magnetic anomalies for the various geometrical models are generated by a numerical integration of the expression representing the magnetic effect of a finite thin plate[1]. Because the magnetic anomalies produced by the various model shapes are nonlinear in parameters of shape and position, it is necessary to use an iterative procedure in order to obtain the values for the various model parameters which yield a least-squares best-fit model anomaly curve. The computer program uses the Powell[2] algorithm for this purpose.

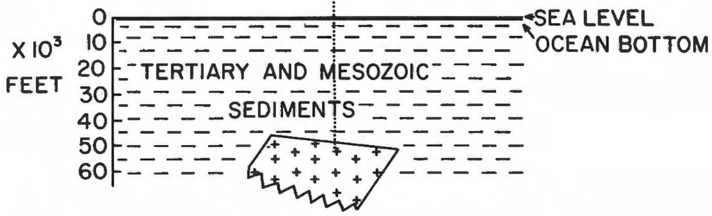
To illustrate the application of the new method, an example was selected in the Canadian Arctic Islands in the centre of the Sverdrup sedimentary basin which contains a thick sequence of upper Paleozoic to lower Tertiary strata[3,4]. The peak of the anomaly is situated 20 miles due east of Lougheed Island where Tertiary sediments occur. Inspection of bathymetric chart 897 published by the Canadian Hydrographic Service in 1967, indicates that the water depth in the area is between 450 and 500 feet.



AEROMAGNETIC SURVEY MAPS, LOUGHEED ISLAND BASIN



SURVEY AND COMPUTED BEST-FIT DATA ALONG PROFILE AB



Because there are known basic intrusions (dykes) in the area, and from a consideration of the shape of the anomaly itself, it was decided to use the thick plate as a model for the causative body – a circular basic intrusion. The known intrusions in the area are either Cretaceous or Tertiary in age, and because the magnetic pole has remained essentially in its present position since Cretaceous time, it was assumed that the causative body was polarized in a direction close to that of the present earth's main field. The thickness and strike length of the body were initially estimated from the anomaly. An initial depth estimate was determined using Peters half-slope rule, and the dip was assumed to be vertical.

The computer program required 57 iterations to proceed to a final solution, and the number of plates used for the numerical integration was 5. The best-fit data are shown in Figure 1, together with the original survey data. The depth to the centre of the top was calculated by the computer to be 49,900 feet below sea level and the top slopes at 6 degrees to the southeast. The dip of the model plates is 56 degrees to the northeast. The dimensions of the cross-section of the body in a horizontal plane are approximately 50,000 by 100,000 feet. The effective susceptibility contrast was calculated to be 6960×10^{-6} emu/cc, which would indicate that remanent magnetism plays an important part in the production of the anomaly. Thus the igneous body is a very large intrusive that could be expected to have some tectonic effects on the overlying sediments that it intrudes, and has perhaps produced some structural conditions of conducive to the entrapment of petroleum.

A paper describing the technique in greater detail has been submitted to the journal "Geophysics" for publication.

[1] Grant, F.S., and West, G.F.: Interpretation theory in applied geophysics; New York, McGraw-Hill Book Co., 583 p. (1965).

[2] Powell, M.J.D.: A method for minimizing a sum of squares of nonlinear functions without calculating derivatives; Computer J., v. 7, p. 303-307 (1965).

[3] Douglas, R.J.W., *et al.*: Geology and petroleum potentialities of northern Canada; Geol. Surv. Can., Paper 63-31, 28 p. (1963).

[4] Fortier, Y.O., *et al.*: Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin); Geol. Surv. Can., Memoir 320, 671 p. (1963).

MINERALOGY

17. MICA GROUP MINERALS AND RELATED SILICATES IN CANADIAN MINERAL DEPOSITS

General

Project 700067

J. Rimsaite

The purpose of the project is to establish environmental conditions and chronological order of geological events leading to the formation of mineral deposits. To achieve this goal, the relationships between a mineral deposit and the following geological events in the area are considered:

(a) ultrabasic rocks and pegmatitic activity (probable source, metasomatism);
(b) tectonic and metamorphic events (remobilization, redeposition); and
(c) oxidation and diagenesis (leaching, redeposition, secondary concentration).

Micas and related silicates which represent the above rocks and events have been chosen for the study along three following lines:

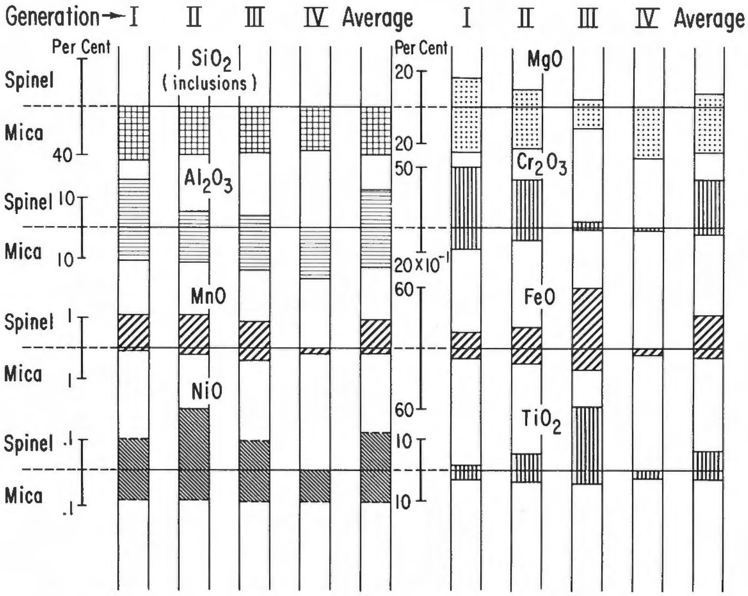
1. geochemical relationship between primary minerals in ultrabasic rocks to study the difference between coexisting and cogenetic minerals;
2. loss of protons from primary olivine and phlogopite during serpentinization to establish which elements are removed from the lattice of primary minerals during the crystal-structural change; and studies of reactions between the removed ions;
3. studies of chemical, optical and X-ray properties of micas which are susceptible to environmental changes and can be used for studies of metamorphic grades and for the distinction between pre- and post-metamorphic mica-generations.

1. Distribution of seven oxides between zoned spinel and mica in Canadian kimberlite

Distributions of major and minor constituents between the phenocrysts of mica and zoned spinel have been studied using average compositions and chemical compositions of cogenetic varieties of the mica and spinel. Mica phenocrysts represent four phases, whereas the spinel represents only three phases of crystallization. Chemical evolutions of mica and spinel phenocrysts are represented diagrammatically in Figure 1. Iron, Ti, Mg and Cr show the same trends in both mica and spinel, whereas concentrations of Al and Mn show opposite trends. The latter increase in mica and decrease in spinel with the sequence of crystallization.

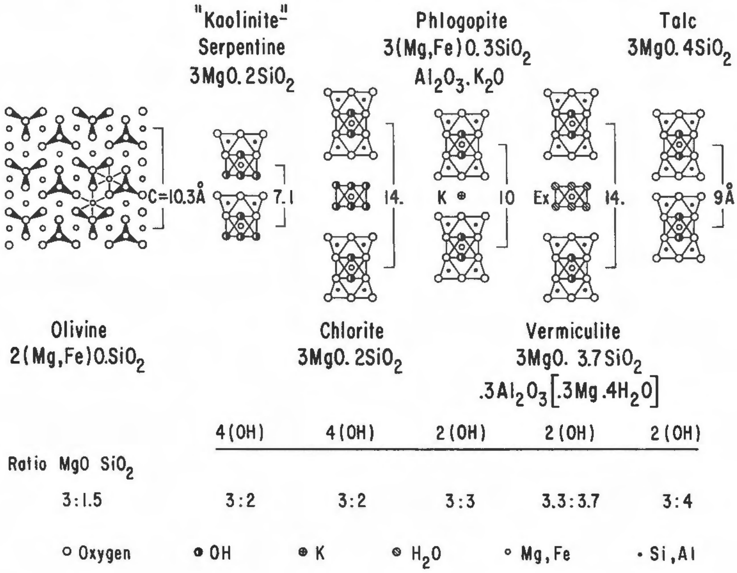
Depending on sampling, the distribution coefficients can be used for the following purposes:

(i) to study general partition of the seven oxides between the mica and spinel (using average compositions);
(ii) to study the partition of the seven constituents between the cogenetic phases of the mica and spinel, and follow the trend with changing environmental conditions during successive phases of crystallization. The oxides that exhibit opposite trends in the mica and spinel (Mn, Al) appear to be useful indicators of changing environmental conditions;



CHEMICAL COMPOSITIONS OF ZONED SPINEL AND MICA

Figure 1. Chemical evolution of zoned spinel (3 generations) and mica (4 generations) in kimberlite from the Upper Canada Mine, Ontario.



ALTERATION OF OLIVINE AND PHLOGOPITE IN SERPENTINITE

GSC

Figure 2-1. Structural and chemical differences between primary olivine and phlogopite and their alteration products: serpentine, chlorite, vermiculite and talc.

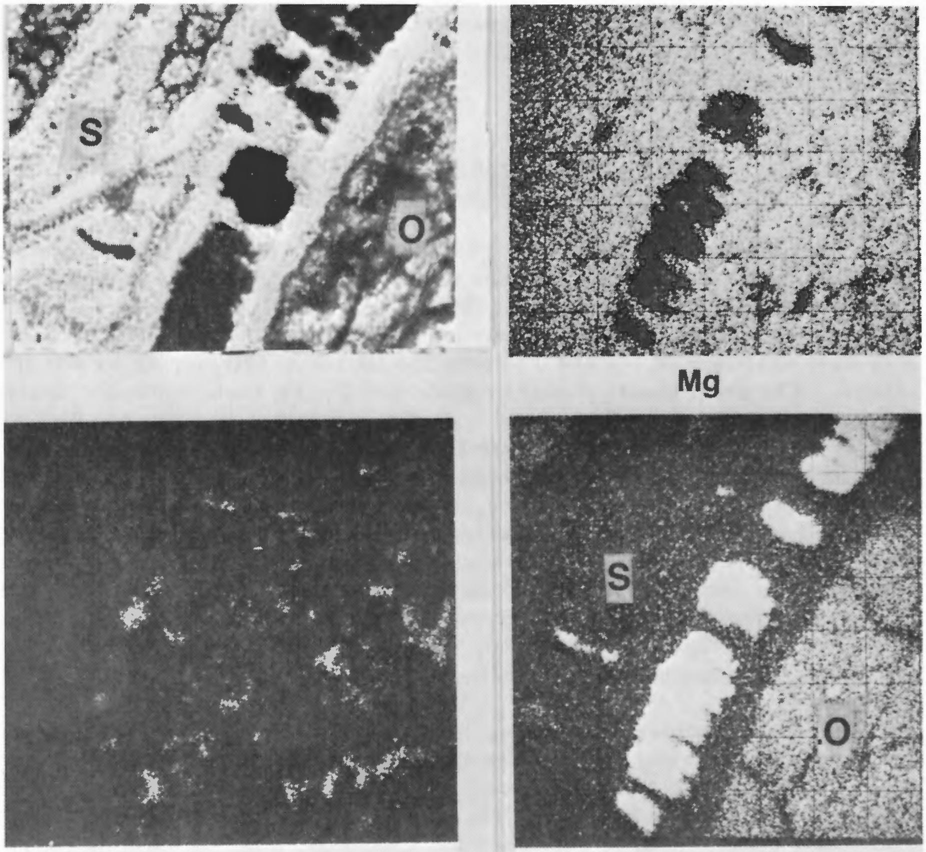


Figure 2-2, upper left: photomicrograph showing serpentine veinlet (s) in olivine (o) and X-ray scanning pictures for Mg, Al, Fe, K and Ni. Scanning area 150 x 150 microns. (Note differences in concentration of iron and Ni-specks in serpentine (s)).

(iii) differences between distribution coefficients obtained on coexisting and cogenetic phases can be applied for the distinguishing between cogenetic and coexisting minerals.

2. Losses of protons and octahedral cations from phlogopite and olivine in serpentinites

The ultrabasic rocks from Canadian mineral deposits are usually altered to serpentinites. When olivine alters to serpentine (chlorite) and phlogopite to vermiculite and talc, the ratio of (Mg, Fe)O to SiO_2 decreases as shown in Figure 2-1. This chemical and structural change can take place either by the preferential loss of Mg and Fe from the lattice of olivine, or by addition of silica. The preliminary electron probe and X-ray spectrographic analyses by G.R. Lachance, A.G. Plant and J. Gravel on selected primary minerals and their alteration products indicate that olivine alters to serpentine by losing Fe, Ni and/or Mg (Fig. 2-2), whereas phlogopite alters to vermiculite and chlorite by losing interlayer protons, titania and (usually) alumina. Serpentines have been classified on the basis of their origin, sequence of crystallization and textures into three groups and ten genetic types. In the rocks examined, talc forms from serpentine and vermiculite by dehydration. The ions removed from altered primary minerals either crystallize in the parent mineral and rock (Fig. 2-2, Fe and Ni), or can be removed by aqueous solutions away from the source and redeposited to form secondary Mg, Fe and Ni deposits.

Secondary minerals forming during reactions between the protons released from the primary minerals and those introduced from outer sources (H_2O, C, Ca) include: nickeliferous goethite, hematite, magnetite, stichtite, magnesite, dolomite and calcite. The alteration products have been studied by DTA and TG analyses in collaboration with R.H. Lake of the Mines Branch and by X-ray diffraction by M. Bonardi and G. Pringle. X-ray diffractometer method was developed for the determination of phlogopite remnants in vermiculite and vice versa (Fig. 2-3). More detailed discussion on genesis of secondary alteration products in serpentinized ultrabasic rocks will be presented at the forthcoming International Clay Conference in Madrid.

Experimental research on the loss of protons from mica was conducted by Dr. Farmer at the Macaulay Institute, Aberdeen, in collaboration with the other research institutions on specimens submitted by the project leader.

3. Properties of micas in the temperature range of metamorphic reactions

The principal mica varieties: biotite, muscovite, phlogopite, lepidolite and fine-grained micaceous alteration products were heated at temperatures between 450° C and 1200° C. Chemical, optical and X-ray properties were determined before and after heating. It was found that before changing to anhydrous minerals, the micas lose some hydrogen and hydroxyl ions by dehydration and/or oxidation. The anionic framework of the micas is more susceptible to environmental changes than their cationic composition. Because most of the nickel and chromium deposits are affected by low and/or high grade metamorphism, it is important to determine effects of increasing

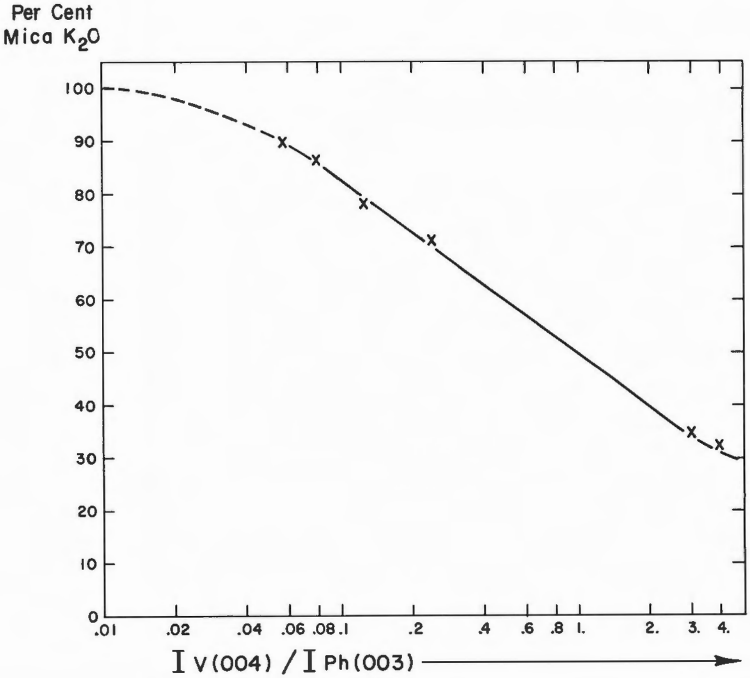


Figure 2-3. Relationship between vermiculite content determined by X-ray diffraction and potassium content of mica.

temperature on stabilities and properties of the micas. In order to establish the relationship between changing properties of micas and changes in environmental conditions, the following comparisons were made:

(a) correlation between oxidation and dehydration and DTA, TG and IR charts of mica;
(b) the relationship between X-ray and optical properties and proportion of dehydration and oxidation of iron was established (Table 1 and Figs. 1 and 2);
(c) stabilities of radiogenic and adsorbed atmospheric argon in relation to temperature and atmospheric composition was studied and reported in Table 1, three last columns;
(d) new high temperatures optically isotropic and anhydrous crystalline phases were studied by X-ray diffraction, including: corundum, hematite, magnetite, leucite; The biotite containing ferrous iron oxidizes to ferribiotite, and with increasing temperature, changes to oxides; whereas micas that contain little or no iron, first change to optically amorphous phase and with increasing time of dehydration, recrystallize to olivine, leucite and spinel.

Results of this study provide data on proportions of retained radiogenic argon and introduced (or "strongly adsorbed") commercial and atmospheric argon in relation to dehydration, oxidation and heating temperature. Optical and X-ray data are provided for identification of oxidized and/or dehydrated micas in a concentrate and in a small portion of a flake. The double X-ray

TABLE 1

Potassium, Iron and Hydroxyl Group Contents, Isotopic Composition of Argon In Original and Heated Micas, and New Anhydrous Phases

Specimen No.		Heating Conditions		Weight %						cc/g x 10^{-6} at STP		K-Ar "age"
Original	This Paper	°C	Atmosphere	K	Fe_2O_3	FeO	H_2O	F	Cl	Ar_{Ra}	Ar_{Atm}	m.y.
Mg-6	1	untreated		7.3	10.0	24.9	2.5	0.6	.2	313	9	825
	1S	650	argon	7.3	23.2	13.0	0.4	0.6		28	2721	90
11	2	untreated		7.8	6.1	10.5	1.32	3.67	.08	382	12	937
	2S	650	argon	7.7	14.0	2.2	0.33	3.61		340	484	866
	2SC	650	argon &									
		650	air	7.9	17.0	0.0	0.00	3.85	.1	349	57	867
	2B	900	argon		13.2	2.8	0.00	3.4				
	2E	1000	air		16.0			1.83				
	2V	1265	reduced P	Olivine & Leucite								
	2R	1300	air	Spinel & Leucite								
44f	3f	untreated		7.8	9.1	23.4	2.32	0.41	.20	278	36	760
	3S	650	argon	7.7	31.4	2.6	0.02	0.34	.14	213	336	637
	3SC	650	argon &									
		650	air	7.7	32.8	1.7	0.02	0.4	.03	213	213	540
44w	3w	untreated		5.5	31.5	2.9	4.0	0.4				
	3wC	650	air		34.8	0.1	0.21	0.09				
	3R	1200	air	Hematite								
	3V	1250	reduced P	Magnetite								
	3F	1400	air	Spinel								
27	4	untreated		7.8	1.9	20.8	3.57	0.52	.03	980	20	1840
	4A	450	air	7.8	11.4	11.4	1.76	0.54		992	20	1870
	4S	650	argon	7.7	12.1	11.6	0.74	0.67		487	1460	1180
500hrs	4C	650	air	7.8	24.0	0.1	0.07	0.52		614	15	1355
	4D	650	reduced P	7.8	20.9	2.6	0.08	0.58		523	10	1210
	4V	1250	reduced P	Olivine & Leucite								
	4F	1400	air	Spinel								
5c	5	untreated		7.6	1.3	1.3	3.04	3.15		446	8	980
	5B	900	argon	7.6	2.7	0.0	0.70	3.10		93	123	250
	5E	1000	air		2.8	0.0	0.50	2.89				
	5R	1200	air		2.7	0.0	0.00	0.08	(Olivine, Leucite)			
	5V	1260	reduced P	Olivine & Leucite								
	5F	1400	air	Olivine & Leucite								
K-100	6	untreated		7.8	2.2	6.1	3.31	0.40		42	1	121
	6S	650	argon	7.9	6.3	1.7	2.35	0.38		38	980	109 ± 66
	6SC	650	argon &									
		650	air	7.8	7.5	1.1	2.16	0.34		35	580	126 ± 36
	6B	900	argon	7.9	9.1	0.0	0.8	0.36		4	760	12 ± 55
	6R	1147	air	(Olivine, Fo_{82}, Leucite, Glass n = 1.532, Phlogopite)								
NE-50	7	untreated		8.9	2.8	0.9	4.30	0.19		360	22	900
	7S	650	argon	8.8	3.7	0.2	3.0	0.16		265	32	740
150hrs	7C	650	air	8.8	3.8	0.0	2.0	0.14		158	8	400
	7R	1205	air	Spinel								
	7V	1215	reduced P	Spinel & Leucite								
ground	7f	1200	reduced P	Corundum & Glass								
115L	8	untreated		8.2	0.2	0.1	2.70	3.78		1621	16	2435
	8S	650	argon	8.2	0.3	0.0	1.80	2.99		1422	57	2255
	8R	1250	air	Leucite								
HN-47	9	untreated		7.1	0.3	0.3	5.99	0.00	03	82	2	290
	9S	550	argon	7.4	0.6	0.0	2.0	0.00		65	572	210
	9SC	550	argon &									
		550	air	7.1	0.6		1.1			51	440	171
G-31	10	untreated		1.6	1.9	8.9	9.82	0.04	.06	26	6	357
	10S	550	argon	1.6	6.8	5.5	3.34			0	750	0
	10C	600	air	1.7	0.0					8	768	113
	10R	750	air	Spinel								

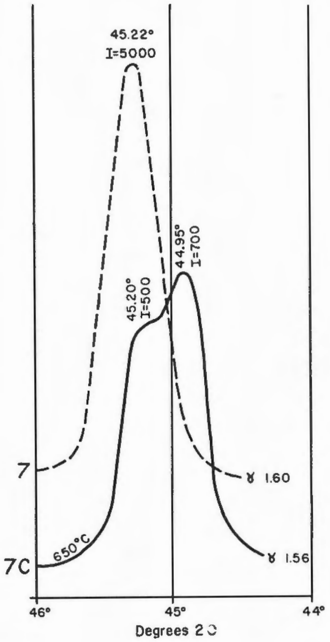


Figure 3-1. X-ray properties of unheated (7) and heated (7C) muscovite.

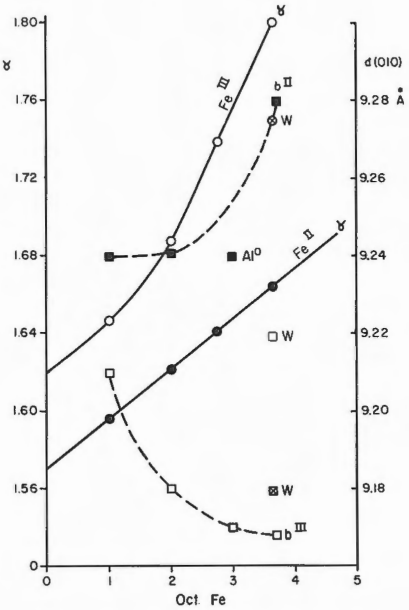


Figure 3-2. X-ray and optical properties of unheated and heated biotites.

reflections frequently observed in metamorphic micas are shown to be due to changing cell dimensions and heterogeneity of the mica (Fig. 3-1). The relationship between the γ-index of refraction, ferric iron content and ferrous iron content are shown in Figure 3-2 curves Fe^{III}-γ and Fe^{II}-γ. The b-spacing of the unit cell increases with increasing ferrous iron (curve b-II) and decreases with increasing ferric iron (curve b-III). It is proposed to apply partly dehydrated natural micas in studies of metamorphic environment.

A paper on this subject was presented at the Third International Conference on Thermal Analysis in Davos, Switzerland.

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[1] Farmer, V. C. et al.: Evidence for loss of protons and octahedral iron from oxidized biotites and vermiculites; Mineral. Mag., v. 38, p. 121-137 (1971).

MINERAL DEPOSITS

18. PROPOSED CLASSIFICATION OF COPPER DEPOSITS

General

Project 700059

R.V. Kirkham

Much as it might be advisable to avoid the precarious subject of the classification of ore deposits, general studies demand some sort of classification. A meaningful grouping can greatly facilitate the study and description of deposits while, on the other hand, a poorly construed one can lead to false comparisons and can create much confusion. Many types of classification have been suggested but in recent years drastic changes in ideas of genesis of certain types of deposits have, to varying degrees, made existing classifications unsatisfactory.

The classification of copper deposits proposed is based on geology but strong emphasis is also given to economic considerations. Unquestionably the geology of copper deposits is complex, but if economics are emphasized, only a few types appear to be of major importance. These types form the main classes or "super groups" listed in Table 1. Possibly as exploration and studies continue significant new types of deposits will have to be added to this list and some classes will have to be revised. However, for the time being the writer feels that this classification will serve as a satisfactory framework for the discussion and description of copper deposits in Canada.

The seven main classes are meant to reflect genesis. Undoubtedly, with our rather poor understanding of the origins of certain types of deposits, any genetic classification will not be accepted by all geologists and could be disproved in a relatively short period of time. Nevertheless, the writer has not encountered a satisfactory nongenetic classification of copper deposits and some supposed "nongenetic" classifications, when analyzed in detail, are really genetic in nature. Despite what has been stated about the supposed superiority of nongenetic classification[1, 2, 3] the fact remains that in classifying deposits we are attempting to recognize deposits of similar origins, nature and economic potential. We want to identify those processes that lead to economic concentrations of metals. Hence, unless a classification has a firm genetic foundation it will be of very limited value and could be quite misleading. Nevertheless, it should be pointed out that the writer has no basic argument against certain uses of nongenetic classifications. For instance, it could be very useful to refer to Pb-Zn deposits in carbonate rocks but elaboration is necessary when genesis and economic potential are to be considered.

Similar problems exist when one tries to classify deposits according to tectonic and geosynclinal cycles. Although for any given area this has proved to be a very useful exercise, there is no justification to use it as a basis for general deposit classification. Not only is it based on the unwarranted assumption that all deposits are related to "tectonic and geosynclinal cycles" but it presupposes that we know a great deal more about "geosynclines" and mobile belts than we really do. For example, problems of periodic movements along mobile belts and modern theories of plate tectonics have not been adequately considered in most discussions, and although the origins of some deposits may in some manner be related to tectonics, the processes controlling their formation may show a diversity of tectonic relationships.

There is, for example, a reasonable body of evidence indicating that many of the volcanogenic class of deposits are related to subaqueous felsic volcanism. Even though such environments might most often be preserved in rocks of the early stages of "eugeosynclinal development" it is obvious that they need not be restricted to such environments. The same type of problem exists for porphyry deposits. Although many of them are related to late- or post-orogenic intrusions, there is no justification for considering that the ones related to Triassic and Jurassic intrusions in the Canadian Cordillera are late- or post-tectonic.

If a satisfactory, reasonably objective classification is to be developed from the framework outlined in Table 1, then strong emphasis should be given to the contained metals. Formation of an orebody undoubtedly requires a rather specific set of physical-chemical conditions. These very specialized conditions should be reflected in the chemical composition of the resulting deposits. For certain types of deposits major metal content or ratios of major metals should adequately define the kind of deposit involved, while for others, complicated statistical treatment of major and minor elements may be necessary to uniquely identify the type of deposit. As Stanton and Richards[4] stated, the "chemical petrography" of ore deposits, in general, is very poorly known; yet such data should yield a wealth of information about deposits. In view of the possible usefulness of this type of information it is surprising that so little progress has been made in this field.

For many studies it is as important to know that an element is not present in significant amounts as it is to know that it is present. For example, to compare the composition of porphyry and volcanogenic polymetallic deposits, one should analyze porphyry deposits for lead and zinc and polymetallic deposits for molybdenum. Hence, typical assay data should be supplemented by additional analyses to adequately characterize and compare deposits. Such information will probably prove to be of immense value in the study of deformed and metamorphosed deposits. For such deposits many of their original features may have been obliterated beyond recognition; however, their metal contents could have remained relatively unaffected and act as a "fingerprint" of the initial origin.

The terms "magmatic", "volcanic" and "sedimentary" are meant simply to indicate those deposits formed by "magmatic", "volcanic" and "sedimentary" processes, respectively. Sedimentary deposits, for example, could include both syngenetic and epigenetic deposits which were formed during deposition and diagenesis of the host strata.

"Hydrothermal" as used here refers simply to heated waters with no specific origin implied for the water or dissolved elements. "Magmatic-hydrothermal" is not meant to infer that the water was necessarily of magmatic origin; however, it is implicit that magmatic processes were involved. "Magmatic-hydrothermal", as a class, for instance, could include both magmatic waters or meteoric waters "driven" by a magmatic heat source. The same reasoning can be applied to "volcanic-hydrothermal"; however, it is implicit that the ore depositional processes occurred at or near the surface and were closely related to volcanic processes. It is obvious that there is only slight distinction between "magmatic-hydrothermal" and "volcanic-hydrothermal" as used here. "Exhalative" means deposited at or very close to the surface. The volcanogenic polymetallic class is meant to include deposits that are thought to have formed both beneath and on the surface. Both surface and subsurface types of ore are thought to occur in many massive sulphide districts.

TABLE 1

Tentative Classification of Copper Deposits

Suggested Names	Inferred Genetic Type	Characteristic Metals	Examples
1. Magmatic nickel-copper or simply nickel-copper deposits	magmatic deposits associated with mafic and ultramafic igneous rocks	Ni, Cu (Co, Pt)	Sudbury district, Great Lakes Nickel, Giant Mascot
2. Carbonatite or alkaline complex deposits	"late stage" magmatic and/or magmatic-hydrothermal deposits associated with carbonatites and alkaline complexes	Cu (Ti, Fe, P_2O_5, Zr, Mo, etc.)	Palabora, South Africa
3. Porphyry copper deposits	magmatic-hydrothermal	Cu, Mo (Au, Ag)	Bethlehem, Brenda, Granisle
4. Contact metasomatic or skarn deposits	magmatic-hydrothermal	Cu (Fe, Mo, W, Zn, Au, Ag, etc.)	Gaspé Copper, Craigmont, Phoenix
5. Volcanogenic poly-metallic (massive iron sulphide) or volcanic exhalative deposits	volcanic-hydrothermal-exhalative	Cu, Zn (Pb, Au, Ag)	Noranda district, Bathurst district, Whalesback, Western Mines
6. Copper sulphide-native copper deposits in volcanic sequences	volcanic (?)-hydrothermal(?)	Cu (Ag)	Keweenaw Peninsula, Coppermine River area, Mamainse Point
7. Sedimentary or alternatively concordant and peneconcordant deposits in sedimentary sequences	sedimentary (includes aspects of diagenesis)	Cu (Mo, Co, Pb, Zn, Ag, V, U, etc.)	White Pine, Redstone, Dorchester
8. Miscellaneous deposits	mainly hydrothermal and magmatic-hydrothermal vein and replacement deposits	Cu, Pb, Zn, Ag, Au As, Sb, etc.	Chibougamau district, Icon-Sullivan, Alwin, Churchill

The copper sulphide-native copper class of deposits in volcanic sequences is perhaps the most problematic and poorly understood. It includes many very distinctive types of deposits but similarities of mineralogy and metal contents and the fact that they occur in volcanic piles seem to justify grouping them for now as a separate major "super group" of deposits. However, it can be demonstrated that these deposits and those of the sedimentary group occur together in many areas and their general similarities in mineralogy and metal contents suggest that there may be some common genetic links.

There are not many examples of the carbonatite or alkaline complex group of deposits, but the importance of the Palabora carbonatite deposit in South Africa justifies the inclusion of this group as a major type of copper deposit. Moreover, there are a sufficient number of copper and molybdenum occurrences known to be associated with alkaline rocks to indicate that such rocks warrant close attention as possible sources of these metals. Copper with some associated nickel is known to occur in the mafic border phases of some alkaline complexes (e.g., Marathon Complex, Ontario). Even though this type of mineralization occurs in alkaline complexes its general nature indicates that it belongs to the magmatic nickel-copper group of deposits.

The miscellaneous category is meant to comprise a great variety of deposits, including both minor copper producers and important copper producers whose origin or "genetic grouping" is much in doubt (e.g., Chibougamau district). As more information is gathered it might be possible to separate some major new classes of deposits from this miscellaneous category. However, in general, although many of these deposits are very interesting mineralogically and geologically, economically most of them do not warrant as much attention as other types of deposits.

Undoubtedly several sub-types of deposits can be outlined for each of the major classes. Probably some of the major groups contain at least 10 to 20 distinct sub-types, but this level of information will not be considered here.

Although this type of "economic-genetic" classification has been established to facilitate the study and description of copper deposits, there is no reason why similar schemes could not be constructed for other types of deposits. The method simply involves identification of important economic types of deposits, separation into major genetic or inferred genetic groups and establishment of their diagnostic and fundamental features. Unquestionably there will be many minor types of deposits not satisfactorily accounted for by this method and periodic rearrangement of the classes will be necessary, but the method puts proper emphasis on economic considerations and should effectively isolate important groups of deposits for further study.

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General

19. PORPHYRY DEPOSITS

Project 700059

R. V. Kirkham

Porphyry deposits present some special classification problems. For a long time these deposits have been recognized as the world's most important source of copper and molybdenum, yet there is still some question as to what exactly constitutes a "porphyry deposit". This question is especially important at this time when porphyry deposits are being sought and examined in widely separated parts of the world.

The problem to some degree arises from the fact that, to the writer's knowledge, there is no entirely satisfactory concise geological definition of a "porphyry deposit". Geologists working with such deposits generally have very definite ideas about their overall nature and can readily describe the details of individual deposits. But few people have ventured definitions. Those of Parsons[1, 2] are rather lengthy and, since they are based largely on mining technology, they include deposits of different geologic types. Lowell and Guilbert[3] recently presented the following definition of a "porphyry deposit": "... a copper and/or molybdenum sulfide deposit consisting of disseminated and stockwork veinlet sulfide mineralization emplaced in various host rocks that have been altered by hydrothermal solutions into roughly concentric zonal patterns". This definition requires a systematic zonal distribution of sulphide and alteration minerals and although it might be found to fit many porphyry deposits, it will be a long time before this feature can be substantiated and, moreover, there are also reasons to doubt its universal application.

The following short definition of a porphyry deposit is offered: "A porphyry deposit is a large, low to medium grade deposit in which the hypogene sulphides are primarily structurally controlled and which is spatially and genetically related to felsic or intermediate porphyritic intrusions".

Large size is emphasized to separate typical economic porphyry deposits from the numerous minor copper and molybdenum occurrences associated with granitic rocks. The writer suspects that there is a complete continuum from scattered minor veinlets and pods associated with granitic rocks to economic porphyry deposits; hence, some arbitrary lower limit on size is necessary to define what is meant by "large". However, this is a difficult decision to make in view of the fact that in some mines only small high grade portions are being exploited of what are otherwise typical, low grade porphyry deposits. Perhaps no fixed lower limit on "large" should be established but rather it should be kept in mind that when all of the low grade copper-molybdenum mineralization and the associated barren pyritic material is considered the mass of rock involved is commonly greater than several tens of millions of tons. In the past deposits smaller than this have not normally been considered porphyry deposits.

Although very high grade material is found in some porphyry deposits the overall grade is generally low to medium. Low grade is arbitrarily taken to be less than one per cent copper (0.2% MoS_2 for molybdenum deposits) and medium grade between one and two per cent copper (0.2 to 0.5% MoS_2 for molybdenum deposits).

The key to the possible usefulness of this concise definition lies in the appreciation of the fundamental importance of structural control. As mentioned by Parsons[1, 2] some workers have placed undue emphasis on the importance of "disseminated" mineralization in intrusive rocks. Most if not all porphyry deposits are characterized by intensely fractured and veined rocks. The fractures and veinlets range from microscopic to regional in scale and have played a very important role in the localization of sulphides and alteration minerals. The spectrum of structural controls in porphyry deposits ranges from regionally controlled vein systems (e.g., Butte and Chuquicamata), to crackled zones and stockworks typical of most porphyry deposits, and includes breccia pipes (e.g., Cananea and Highland Valley). Although parts of some deposits consist essentially of pervasive disseminated mineralization, these rocks are highly fractured at some localities, and show textural evidence of significant recrystallization at others. The mineralization and recrystallization in the latter were perhaps controlled initially by fractures that have since been healed. Despite the three-dimensional pervasive nature of mineralization in some deposits, extensive fracturing, and in places, brecciation and associated pervasive alteration indicate that the mineralization was superimposed on its host rocks and for the most part was not present as a primary igneous constituent.

Chemical controls are clearly secondary in importance. Although sulphides show a preference for particular rock types in some deposits, typical porphyry mineralization is relatively unselective in its choice of host rocks.

Emphasis on structural control serves to separate porphyry deposits from contact metasomatic or skarn deposits for which the chemical nature of the host rocks has obviously been a very important factor in shaping and localizing the resulting mineral deposits. Because of similar mining problems in some areas typical skarn deposits have been called porphyry deposits. Yet, as inferred by Buseck[4], there are fundamental geological differences between the two types of deposits. However, the writer is firmly convinced that in some districts the two types of deposits are intimately genetically related. Skarns of low and medium grade are very common as parts of much larger porphyry deposits and in many districts the presence of carbonate-rich sediments has played a very important role in determining the overall shapes of porphyry deposits. However, the importance of the chemical nature of host rocks for such deposits has resulted in the development of a significantly different "geologic" type of deposit.

The justification for the name "porphyry deposit" is the well established close association of these deposits with markedly porphyritic felsic and/or intermediate intrusions, whether or not the mineralization is in the intrusions or adjacent rocks. Kirkham[5] and several other geologists have given their reasons for believing that there is not only a close spatial but also a genetic relationship between the porphyries and mineral deposits. It should be emphasized, however, that in consideration of porphyry deposits a clear separation should be made between host intrusions and possible source or genetically related intrusive rocks! In the past this separation has not always been made. For some porphyry deposits it has been established that some of the host intrusive rocks cannot be genetically related to the deposit. For instance, a significant amount of the San Manuel-Kalamazoo Laramide porphyry deposit in Arizona occurs in the Precambrian Oracle quartz monzonite Here the emplacement of the sulphides is structurally controlled in the Oracle quartz monzonite and much younger intrusions but the mineralization is also obviously spatially and probably genetically related to Laramide porphyries. Although it might be relatively easy to recognize such relationships when the host rocks are of vastly different age than that of the deposit, it could be extremely difficult where the deposits and intrusions are approximately the same age. The porphyries that are directly genetically related might be reflected at surface by only minor dykes and larger bodies might occur only at some depth below the mineralized zone at surface. The Highland Valley district in British Columbia may be an example of this type. In this sense even though the orebodies might be in intrusive host rocks they should be considered as a special case of the "wall-rock" porphyry deposits of Titley[6] and not tacitly assumed to be directly genetically related to their host intrusions.

The definition presented here is based entirely on hypogene characteristics of porphyry deposits, even though many deposits outside of Canada have very significant supergene enrichment. Rather than include this aspect of their geology in the definition the writer would prefer simply to refer to such deposits as enriched, leached, oxidized or weathered porphyry deposits.

As can be noted the definition is not restrictive as to cutoff grade or metal content, although it does emphasize large size, structural control and genetic relationship to porphyritic felsic to intermediate intrusions. Provided these requisites are met the writer sees no reason why apparently subeconomic or essentially barren pyritic zones cannot be called "porphyry deposits" or that deposits with significant amounts of tungsten or other metals such as the Glacier Gulch molybdenum deposit in British Columbia with its significant tungsten or the Potato Hills tungsten deposit in the Yukon[7] cannot be called porphyry deposits. It is also quite possible that some sort of continuum might exist between typical porphyry copper and molybdenum deposits and tin-tungsten greisen deposits.

Although this short definition does not cover all important aspects of porphyry deposits, the writer feels that it includes a sufficient number of geological features to identify uniquely all or most porphyry deposits and will serve as a satisfactory means by which deposits of similar geologic origin can be compared in widely separated parts of the world.

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20. LEAD ISOTOPE DATA FOR GALENAS FROM DEPOSITS IN THE BULKLEY VALLEY REGION, BRITISH COLUMBIA

Projects 680060, 700059

R.I. Thorpe and R.V. Kirkham

Introduction

The Bulkley Valley is located in west-central British Columbia and is underlain mainly by Jurassic and Cretaceous volcanic and sedimentary rocks. In places these rocks have been intruded by uppermost Cretaceous and Lower Tertiary granitic, porphyritic and felsitic plutons. Numerous metalliferous deposits and occurrences are known in the area and reasonably intensive exploration has been carried out since the early part of the century.

Several distinct types of deposits have been recognized. These are copper sulphide occurrences that are widely distributed in the Lower Jurassic volcanic rocks; copper-zinc mineralization in volcanic rocks in one area; the unusual Sam Goosly silver-copper deposit in the southern part of the region[1, 2]; a number of porphyry molybdenum and copper deposits; and numerous base and precious metal sulphide-sulphosalt vein and replacement deposits (some with Sb, As, W, Mo, U, Ni, Co, Bi, Te), which are clustered around certain intrusive centres. In some districts porphyry and vein deposits occur together. Some of the porphyry deposits and the Sam Goosly deposit seem to offer the most immediate economic potential; however, vein deposits have been productive in the past (Silver Standard, Rocher Deboule, Red Rose, Cronin-Babine, Henderson (Sil Van)), and the Bradina deposits are presently being brought into production.

All of the galenas, except RK 65-138, are from the base and precious metal vein deposits that occur clustered around intrusive centres. The RK 65-138 galena is from a minor late quartz-carbonate vein that cuts the quartz vein stockwork of the Glacier Gulch porphyry molybdenum deposit. Some of the veins occur in districts that show a zonation of sulphides and metals and from general geological information it appears as if this type of deposit is in some way genetically related to the spatially associated intrusions.

Of the 20 analyses presented, 14 are for galenas from 10 properties in the Hudson Bay Mountain district near Smithers. These samples were collected from widely separated localities over a 60-square-mile area and represent deposits ranging from veins that have produced lead, through veins with only minor quantities of lead, to a minor late-stage galena-bearing vein that cuts the quartz vein stockwork of the Glacier Gulch molybdenum deposit. Nine of the galenas are from a group of sulphide-sulphosalt veins which Kirkham[3] has shown are zonally distributed about the contact metamorphic aureole in the area.

Results

One previous lead isotope analysis for galena from the region, from the Silver Standard mine, has been presented by Russell and Farquhar[4], and is in excellent agreement with the data presented here. The analytical results obtained in this study are given in Table 1 and the sample localities and generalized geology are shown in Figure 1. The results are presented graphically in Figure 2.

The most striking feature of the data is a close clustering of values in an area beyond the zero position on the model curve. Both the Geological Survey of Canada and the University of British Columbia sets of data, which are relative to absolute values for the Broken Hill standard as reported by Stacey, Delevaux and Ulrych[5], show consistent relationships.

The lead from the Tetra property is near the model curve of Stacey, Delevaux and Ulrych[5] and can be calculated to lie on a model curve with $\mu = 8.935$ and to have an apparent age of about 310 m.y. The Bradina specimen plots off the end of the model curve, but is slightly and significantly less radiogenic than the remaining specimens. Plots of x (Pb^{206}/Pb^{204}) versus y (Pb^{207}/Pb^{204}) and the calculated Pb^{204} content against x, y and the Pb^{207}/Pb^{206} ratio suggest that the scatter of the remaining data is due to Pb^{204} error and that the true compositional differences are very small indeed. The average composition of these galenas, excluding the double-spike values (these are excluded, for the present, so that further consideration of the analyses is based on a consistent set of data), $x = 18.916$, $y = 15.578$ and z (Pb^{208}/Pb^{204}) $= 38.396$.

The above average when plotted with the Tetra and Bradina values yields linear relationships on x-y and x-z plots, but this relationship is most convincing on a plot of Pb^{207}/Pb^{206} versus Pb^{208}/Pb^{206} where Pb^{204} error is eliminated. This relationship and the fact that the majority of the galena analyses form a very tight cluster are strong factors supporting (1) a source of great extent which contained very homogeneous lead, (2) a single genetic process for the formation of the veins over a very large region, (3) introduction

LEGEND

UPPER CRETACEOUS AND TERTIARY

v v v volcanic and sedimentary rocks

MAINLY UPPER CRETACEOUS AND LOWER TERTIARY

+ + + quartz monzonite, granodiorite, quartz diorite and porphyritic and fine-grained equivalents

MIDDLE JURASSIC - CRETACEOUS

· · · sedimentary and volcanic rocks

MAINLY LOWER JURASSIC

☐ volcanic rocks

● sample locality ━ fault ◆ porphyry deposit

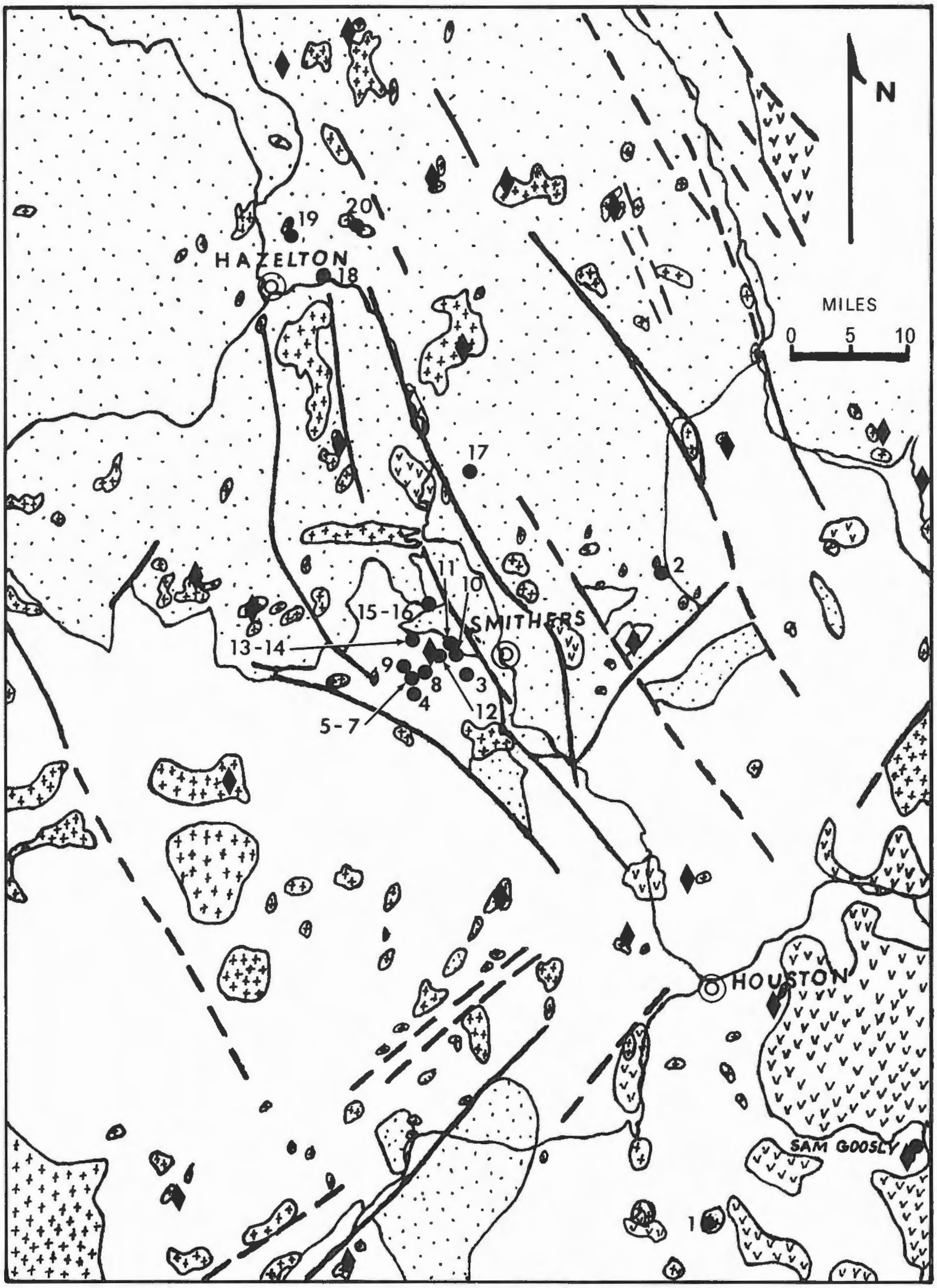

Figure 1: Generalized geological map of the Bulkley Valley region showing sample localities.

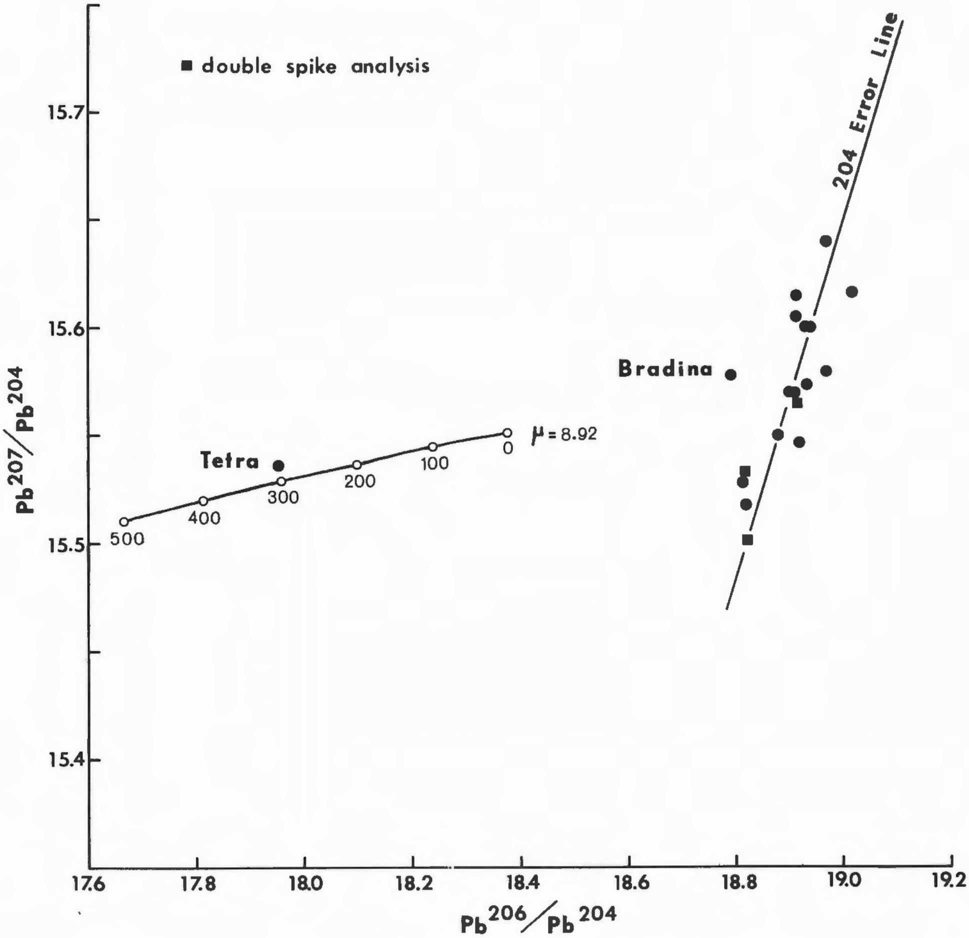

Figure 2: Plot of Pb^{207}/Pb^{204} against Pb^{206}/Pb^{204} showing the relation of the data to a model curve adjusted from Stacey et al.[5] and to a Pb^{204} error line.

of the lead into veins in various types of host rocks without detectable contamination from these rocks, either during or after vein formation, and (4) formation of most of the deposits within a relatively short span of time, probably no more than a few million years.

Kirkham[5] has reported K-Ar dates of 67 ± 5 and 60 ± 5 m.y. for porphyry intrusions related spatially and probably genetically to the Glacier Gulch molybdenum deposit in the Hudson Bay Mountain district, and K-Ar dates of 63 ± 4 and 65 ± 6 m.y. for biotite and hornblende, respectively, from molybdenite-bearing veinlets in this deposit. A date of 69 ± 3 m.y. was obtained by Carter on the same vein biotite. Geological relationships indicate that the porphyry deposit and probably most veins in the district formed prior to the emplacement of the stock on which the date of 67 ± 5 m.y. was obtained. This relationship is compatible with the date of 69 ± 3 m.y. obtained by Carter for the vein biotite from the molybdenum deposit. Kirkham[8] has obtained a date of 72 ± 3 m.y. on hornblende from an intrusion which is probably genetically related to the Jan porphyry deposit about 30 miles west of

TABLE 1

Lead isotope analyses for galenas from the Bulkley Valley region, British Columbia

No.	Sample No.	Property	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}	Laboratory
1.	TQ71-167	Bradina	18.790	15.578	38.317	U.B.C.
2.	TQ71-162	Cronin-Babine	18.911	15.605	38.493	U.B.C.
3.	RK66-79	Snowshoe	18.93	15.60	38.45	G.S.C.
4.	RK64-10	King Tut	18.97	15.58	38.44	G.S.C.
5.	RK65-39	Henderson	18.90	15.57	38.38	G.S.C.
6.	RK65-39	Henderson (rerun)	18.97	15.64	38.53	G.S.C.
7.	RK65-39	Henderson (rerun)	18.933	15.573	38.404	U.B.C.
8.	RK65-13	Canary	18.91	15.57	38.42	G.S.C.
9.	RK65-31	Coronado East	18.88	15.55	38.29	G.S.C.
10.	RK65-3	Glacier Gulch (South)	18.91	15.57	38.42	G.S.C.
11.	RK63-104	Glacier Gulch (North)	18.94	15.60	38.42	G.S.C.
12.	RK65-138	Glacier Gulch (Moly.)	18.920	15.547	38.304	U.B.C.
13.	RK65-109	Silver Lake	18.814	15.528	38.233	U.B.C.
14.	RK65-109*	Silver Lake (rerun)	18.818	15.533	38.250	U.B.C.
15.	RK65-104	Evelyn	18.913	15.615	38.496	U.B.C.
16.	RK65-104*	Evelyn (rerun)	18.821	15.501	38.120	U.B.C.
17.	TQ71-156	Tetra	17.951	15.536	37.762	U.B.C.
18.	TQ71-172*	Mohawk (Erie)	18.916	15.565	38.361	U.B.C.
19.	TQ71-171	Silver Standard	18.820	15.518	38.216	U.B.C.
20.	TQ71-158	Sunrise	19.015	15.617	38.482	U.B.C.

* double spike analysis

Smithers. Carter[9] has also obtained comparable dates for the Rocher Deboule stock about 6 miles south of Hazelton and the Sunsets Creek pluton about 20 miles south of Smithers. Both of these stocks have mineralization associated with them. On this basis it is concluded that the galenas analyzed, other than those from the Tetra and Bradina properties, were probably formed about 70 m.y. ago.

If 70 m.y. is accepted as the time of formation of the deposits, further calculations can be made as to the possible environments in which the lead has evolved. Galena from the Tetra property clearly consists of B-type lead, that is lead with a model age distinctly older than the age of the host rocks. Other localities in the world from which B-type lead has been reported are extremely rare. However, even though the lead may have been regenerated from a lead deposit of Paleozoic age, it is still possible that its original evolution was single-stage. Furthermore, it is possible that the ordinary lead component of all the other specimens has evolved in a system with identical parameters. These parameters include $\mu = 8.935$ and a value for W (Th^{232}/PB^{204}) of 33.74, if the other model curve parameters that are selected are those of Stacey, Delevaux and Ulrych[5].

Models for the radiogenic leads

For the radiogenic galenas a portion or all of the lead must have evolved for at least part of its history in an environment with a μ value considerably greater than that for the model curve. For a simple two-stage evolution an approximate model can be derived assuming that the Tetra and Bradina galenas are genetically related to the others. The youngest possible age for development of the uranium-rich environment would be 310 m.y., the model lead age of the Tetra galena. Calculation at a μ_1 value of 8.92 yields a μ_2 value of 25.5 and a Th/U ratio of 2.049 for the second stage; this corresponds to a W value of 52.25. The Bradina lead can be explained as due to a slightly lower μ_2 value, about 22.4, or by a more recent start of the second stage of evolution. Consideration of an x-z plot of the data indicates that it is unlikely that the initiation of the second stage took place more than 850 m.y. ago, since this would require an increase in the W value of the primary environment to more than 35.5 which seems unlikely (p. 22)[5]. For the case of t_1 = 850 m.y. (and t_2, time of mineralization, at 70 m.y.) a value of μ_2 of about 13.9 can be calculated and this gives a W_2 value of about 28.5. The average for the three double-spike analyses, which should be closer to absolute values, suggests that the above model could require slight adjustment; but the principal change would be a decrease in the μ_1 value to perhaps as low as 8.84.

While the above model provides an adequate explanation, it is difficult to visualize the geological nature of the event, at some considerable time prior to mineralization, responsible for an increase in the U/Pb ratio of the evolution environment. This event would have to have affected the primary source environment uniformly over a wide area and presumably would have consisted of magmatism initiated in the mantle with appreciable incorporation of crustal material or partial melting in the mantle and segregation of this more felsic phase. While not discarding the above two-stage model, it might be more reasonable to assume that the homogenizing process was the magmatism which produced the plutons that are spatially and probably genetically related to the veins. By this model it would appear that a regional batholithic homogenization of crustal material would be necessary. The average isotopic composition of the lead in this crustal material, resulting from a multitude of evolution histories, would be visualized as the same as that resulting from a simple two-stage model. Doe[10] has pointed out that the average isotopic composition of rock lead from Precambrian and Paleozoic upper crustal crystalline rocks of North America, eliminating two highly radiogenic samples, is $x = 19.14$, $y = 15.55$ and $z = 38.89$. These x and y values are approximately the present ratios that would be predicted for a homogeneous source giving rise to the radiogenic galenas of the Bulkley Valley region, while the z value is somewhat higher than the predicted value of about 38.5. By the latter model the Bradina lead could be considered as a product of contamination of the homogeneous magmatic-hydrothermal lead by regenerated lead of the Tetra-type.

From the data there is little basis to choose between these models. The low Th/U ratio of the uranium-rich evolution environment would seem to favour a source homogenized from clastic sediments and crystalline metamorphic rocks below granulite facies (p. 51)[10]. On the other hand, the need to call upon two separate cases of remobilization of old lead in this model makes the simple two-stage model slightly more attractive.

Variants of the second model are possible insofar as consideration of the Bradina and Tetra deposits are concerned. The Bradina data may be explained, as in the first model, by a slightly lower μ value in the source environment, or a somewhat older time of emplacement. If in fact the μ value was lower, the latter deposit could be younger than 70 m.y. Similarly, the Tetra deposit may be genetically unrelated to the other deposits. The deposit could have formed shortly after deposition of the host Jurassic or Cretaceous sediments, or at any more recent date, and possibly significantly different processes were important in its genesis.

Genesis of the veins

As noted above the lead isotope data indicate a very homogeneous source of ore leads over a very broad region. The necessary corollaries would seem to be that (1) the vein deposits are all related in some way, and probably of magmatic-hydrothermal genesis, (2) plutonic bodies associated with the deposits developed over a short time span throughout the region, (3) these plutonic bodies had identical or very similar ancestries, (4) the lead deposited in the veins had its source in the plutonic bodies and (5) deposition of the lead in veins in various types of host rocks took place without significant contamination from the wall-rocks. The lead isotope information thus seems to put very definite constraints on any model for genesis of the plutons or for this type of lead-bearing vein in the region.

For the Hudson Bay Mountain district it is obvious from the tight cluster of analyses that there is no significant variation of isotope ratios as a function of zonal position in the district, amount of lead in the vein or, from the analysis of RK 65-138, as a function of the time of vein formation. No evidence of contamination from wall-rocks, similar to that recognized by Stacey *et al.*[11], for mining districts in Utah, is detectable. These observations indicate that lead isotope compositions of vein galenas cannot be used in any obvious way in exploration for porphyry deposits in the Bulkley Valley region.

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21. INTERPRETATION OF LEAD ISOTOPE DATA FOR BASE METAL AND GOLD DEPOSITS, SLAVE PROVINCE, NORTHWEST TERRITORIES

75,76
65,66

Project 710043

R.I. Thorpe

Recent lead isotope analyses for a number of base metal deposits in the Slave Province have made it possible to confirm and refine the conclusions Robertson and Cumming[1] arrived at on the basis of data primarily from gold deposits in that province. The authors concluded that the data reflected the development of inhomogeneity in the earth (presumably evolution of crustal material from a uniform mantle) at 4070 ± 200 m.y. They were not specific as to the genesis of the gold and base metal deposits but apparently considered that from about 4070 m.y. to 2820 m.y. (time of formation of the deposits) the lead of the gold veins evolved in environments with Th/U ratios of about 4.3 but with variable μ values from about 8 to 11, while the lead of the base metal deposits evolved in environments with Th/U about 3.5 and similarly variable μ. They placed the time of formation of both types of deposits at about 2820 m.y.

The available lead isotope data for some of the largest known base metal deposits and showings in the Slave Province are presented in Table 1 and graphically in Figure 1. The recent Hackett River and Indian Mountain analyses were kindly provided by Dr. D.F. Sangster of the Geological Survey of Canada. The analysis for Indian Mountain from Russell and Farquhar[2] is questionable; the author has transposed the x (Pb^{206}/Pb^{204}) and y (Pb^{207}/Pb^{204}) values from those reported because in plots of x and y versus % Pb^{204}, and also in an x-y plot, the transposed values closely fit the pattern indicated by the other data. Because of this, little weight is given this analysis in the following discussion. The lead isotopic analyses for galenas from the gold veins

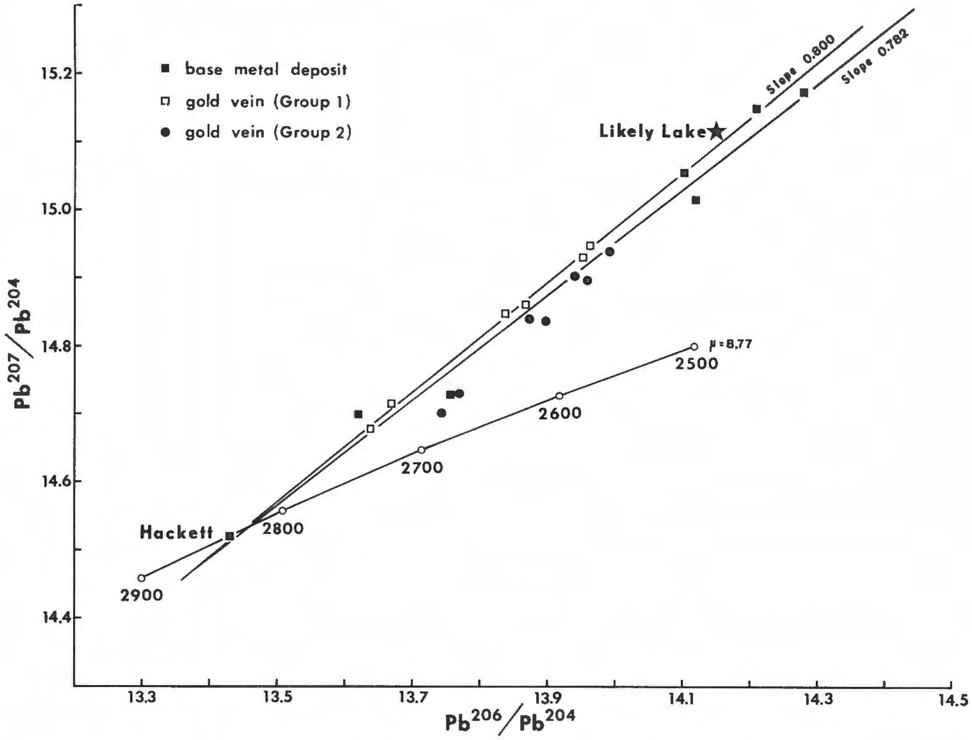

Figure 1: Plot of Pb^{207}/Pb^{204} against Pb^{206}/Pb^{204} showing the closely similar anomalous lead lines with slopes of 0.782 and 0.800 defined by the data for base metal and Group 1 gold deposits, respectively, of the southern Slave Province.

(data from Robertson and Cumming[1]) have been corrected in relation to presently accepted values for the absolute isotopic ratios of the Broken Hill Standard.

All deposits considered here have Archean sedimentary or volcanic host rocks which have been assigned to the Yellowknife Supergroup. The Hackett River deposit (65°50'N, 108°20'W) is a large Zn-Pb-Ag-Cu deposit of more than 10 million tons and is geographically separated from the other deposits; it occurs in sediments and pyroclastic rocks and has a number of characteristics common to massive sulphide deposits of the Precambrian Shield, including an alteration pipe[4, 5]. The Indian Mountain Lake deposit appears to be of the same type[5] and the Victory Lake deposit may also be similar[6], although in part the mineralization here has a greater lateral distribution. The Turnback Lake deposit is closely associated with a metamorphosed carbonate horizon and the mineralization has been remobilized by pegmatite dykes which intimately penetrate the horizon[5]. These four base metal deposits have all been metamorphosed, presumably by the Kenoran orogeny. The Homer Lake mineralization is of generally similar type but is located in shears and fractures in the volcanic rocks and along the margins of a quartz-porphyry dyke[5, 6]. The Walsh Lake specimen of Robertson and Cumming is presumed to come from the latter showing. The main gold deposits in the vicinity of Yellowknife occur here and there within the Con and Giant-Campbell schist zones. The deposits are large, lenticular masses of fine-grained quartz with numerous partings of sericite schist, and are separated from the chlorite schist of the unmineralized parts of the zones by envelopes of sericite schist. The large schist zones are quite irregular, apparently folded, structures. The other gold deposits are generally of more simple quartz vein type, although the gold-quartz bodies expand and become more irregular in places.

TABLE 1

Lead isotope analyses for galenas from base metal and gold deposits, Slave Province, Northwest Territories

Base Metal Deposits

Sample No.	Property	$x\ \left(\frac{Pb^{206}}{Pb^{204}}\right)$	$y\ \left(\frac{Pb^{207}}{Pb^{204}}\right)$	$z\ \left(\frac{Pb^{208}}{Pb^{204}}\right)$	Reference or Lab.
SP-1570	Hackett River	13.43	14.52	33.21	G.S.C.
SP-1497	Indian Mtn. Lake	13.62	14.70	33.38	G.S.C.
TQ-71-309	Homer Lake	14.101	15.058	33.930	U.B.C.
TQ-71-267	Turnback Lake	14.209	15.154	33.954	U.B.C.
TQ-71-308	Victory Lake	14.279	15.177	33.880	U.B.C.
	Indian Mtn. Lake	14.119	15.018	33.571	Robertson & Cumming
	Walsh Lake	13.755	14.73	33.08	Robertson & Cumming
457	Indian Mtn. Lake	15.69?	16.15?	36.13	Russell & Farquhar

Gold Deposits (data adjusted from Robertson and Cumming)

	Property	$x\ \left(\frac{Pb^{206}}{Pb^{204}}\right)$	$y\ \left(\frac{Pb^{207}}{Pb^{204}}\right)$	$z\ \left(\frac{Pb^{208}}{Pb^{204}}\right)$
Group 1	Ptarmigan	13.669	14.716	33.604
	Ptarmigan	13.637	14.679	33.492
	Tom Pit	13.837	14.849	33.731
	Con	13.867	14.862	33.731
	Crestaurum	13.952	14.932	33.797
	Negus	13.962	14.949	33.849
Group 2	Giant	13.940	14.905	33.868
	Con	13.896	14.838	33.833
	Negus	13.873	14.941	33.902
	Negus	13.991	14.841	33.723
	Horseshoe Is.	13.959	14.899	33.841
	Dome	13.768	14.732	33.549
	Discovery	13.743	14.702	33.484
	Likely Lake	14.147	15.117	34.098

Lead from the Hackett River deposit is considered to be of the ordinary type since it plots near the model curve and is nearly identical to recent analyses of lead from massive sulphide deposits in the Superior Province. The model lead age of the deposit is about 2835 m.y. on a model curve with $\mu = 8.77$ and other basic parameters as given by Stacey et al.[3]. The other base metal deposits indicate varying degrees of radiogenic contamination. An excellent linear relationship exists between the University of British Columbia analyses for the Victory Lake, Turnback Lake and Homer Lake galenas, the Geological Survey of Canada analysis for Indian Mountain Lake, and the Robertson and Cumming[1] analyses for Indian Mountain Lake and Walsh Lake. When the Robertson and Cumming data are corrected to the presently accepted absolute values for the Broken Hill Standard, the scatter is increased but a correlation line passes closer to the data point for the Hackett River deposit. Using the corrected values the slope of a best-fit linear regression line indicates a Pb^{207}/Pb^{206} ratio for the radiogenic component of about 0.782.

On the x-y plot 6 of the analyses for galenas from the gold veins are very close to a line through the Hackett River sample and having a slope of 0.800, not very different from the line generated by the base metal deposits. These gold veins are designated Group 1 on the basis of their lead isotope characteristics. The remaining 7 samples from the gold veins appear to form a distinct group, which apparently has suffered greater contamination with thorium lead, with a linear distribution very near a Pb^{204} error line on the x-y plot. The slope of this line is roughly 0.944, but this value could be as great as 1.018 if the Likely Lake specimen, for which the exact character of mineralization is not known, is included in this group. The validity of this grouping of the gold vein data is certainly questionable in view of the probable error limits to be assigned to the isotope ratios. However, some justification for the grouping appears to be given by a plot of Pb^{207}/Pb^{206} versus Pb^{208}/Pb^{206} where analyses of Group 1 show a linear relation and analyses of Group 2 fall in a separate irregular area.

Interpretation and Discussion of Genesis of the Deposits

Massive sulphide deposits of the type represented by Hackett River and Indian Mountain Lake are now generally accepted as of volcanogenic-hydrothermal-exhalative origin. By this genetic model the model age of the ore should date the host volcanics as well, and the volcanics of the Yellowknife Supergroup should thus have an age of about 2835 m.y.

The contamination of the lead in the base metal deposits and the first group of gold veins probably took place at the time of or closely following formation of the deposits. Since these deposits show a close linear relationship with the Hackett River deposit they must also have been formed at about 2835 m.y. ago. The Pb^{207}/Pb^{206} ratio of the contaminating radiogenic lead in combination with a date of 2835 m.y. for the time of mineralization suggests a source age for the radiogenic component of 3970 m.y. in the case of the base metal deposits and of 4020 m.y. in the case of the first group of gold veins. This difference in age is of no significance in view of the probable error limits to be assigned, but the source age suggested here is a little lower than the 4070 m.y. age of Robertson and Cumming. A few more isotopic analysis for these deposits should more closely define the age of the source of this old radiogenic lead.

The process by which the older radiogenic lead is extracted from its source and mixed with the ordinary lead is not known. Presumably the ordinary lead was extracted from the magmatic source of the volcanics in hydrothermal fluids which developed alteration pipes near the surface, and possibly extracted more ordinary lead from the volcanics undergoing alteration. If part of the path of these fluids was through 4000 m.y. basement rocks some contamination could readily occur. However, this mechanism would seem to be too restricted to be the cause of contamination of all the base metal deposits included in this study from the southern Slave Province. The fact that there is a wide variation in the amount of contamination in galenas from a single deposit, for example Indian Mountain Lake, also restricts the mechanism of contamination. It is tempting to suggest that sea water 2835 m.y. ago had such an old radiogenic lead composition and that it was the source of contamination. This might be an acceptable theory insofar as the base metal deposits are concerned, but its applicability to the group of gold veins showing similar contamination is doubtful.

Since the Indian Mountain, Turnback and Victory deposits have been metamorphosed, and the Homer Lake deposit has been at least tectonically deformed and mobilized, a further possibility is that contamination has taken place during a tectonic and metamorphic event which closely followed formation of the volcanics and their intimately associated base metal deposits. By this model some of the gold veins would have been formed during this event, which must have post-dated deposition of sediments of the Yellowknife Supergroup in which the Ptarmigan and Tom Pit veins occur. Boyle[7] has in fact postulated that the gold deposits of the Yellowknife area were formed during regional metamorphism of the host rocks. In this case a metamorphic hydrothermal process could be the one responsible for contamination of the base metal deposits and formation of some of the gold veins, although association with a presently unrecognized post-extrusion magmatic event is possible.

The fact, noted above, that galena from a single deposit has been variably contaminated precludes the conclusion of Robertson and Cumming[1] that the linearity of the lead isotope data is due to the evolution of the lead of the deposits in distinct environments with different μ values.

If a valid grouping is represented by the Group 2 gold vein data, the interpretation of such a high slope (Pb^{207}/Pb^{206} ratio) becomes difficult, if not impossible. Possibly the apparently linear relation could represent a further contamination of lead of the first group by lead derived from the host volcanic rocks during a metamorphic (and hydrothermal?) event at about 2725 m.y. This date is in good, although possibly fortuitous, agreement with a date of 2690 $\pm$20 m.y. deduced by Thorpe[8] for the Western Granodiorite which intrudes the western margin of the Yellowknife volcanic belt. A metamorphic character for this second event would seem to be favoured by the fact that analyses for a single vein-schist-zone system, as represented by the Negus mine, fall into both Groups 1 and 2. Boyle[7] has presented considerable evidence indicating post-depositional remobilization of metallic elements in the gold deposits. By this model the Discovery and Dome veins, both with Yellowknife Supergroup sediments as the host rocks, could be largely or entirely of metamorphic origin. To test this very tentative conclusion more lead isotope analyses should be done on galenas from the gold veins in the southern Slave Province.

Further lead isotope studies should also solve the question of whether or not gold-bearing veins have been formed within the same region during two distinct epochs. Perhaps in some cases the second epoch is represented only by a regeneration or updating of deposits more or less in situ, and additional data might also make some deductions possible in this regard.

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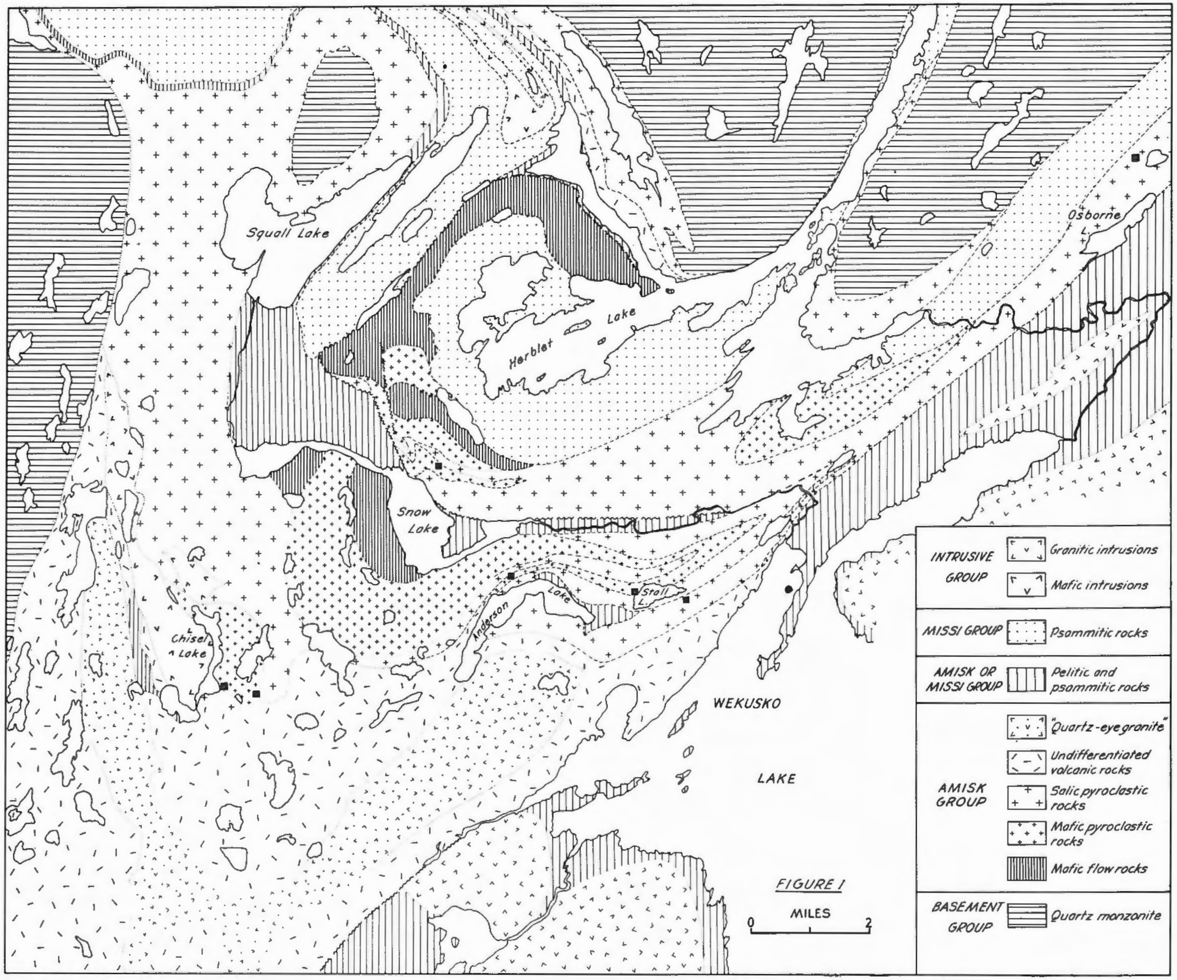

FIGURE I

#22. Moore and Froese

PRECAMBRIAN GEOLOGY

22. GEOLOGICAL SETTING OF THE SNOW LAKE AREA

Project 700065

63 K/16, J/13

J.M. Moore and E. Froese

The broad geological features of the Snow Lake area are shown in Figure 1. This sketch map is based on our observations, supplemented by data from earlier mapping in the area by others[1, 2, 3, 4]. The stratified rocks may be subdivided into three lithologic types. Most metavolcanic rocks in the area have been previously assigned to the Amisk Group and overlying psammitic rocks have been included in the Missi Group. The third lithologic type comprises interlayered pelitic and psammitic rocks, the stratigraphic relationships of which are uncertain. The terms pelitic and psammitic refer to metamorphic rocks derived, respectively, from shales and sandstones. Granitic gneiss domes in the northern part of the area are thought to represent the basement on which the stratified rocks were deposited. This view has been previously expressed by Bailes[5]. A variety of later plutons is present in the southern part of the area.

Near Squall Lake, the psammitic rocks of the Missi Group overlie pelitic rocks, whereas near Snow Lake there is an intervening wedge of volcanic rocks between the pelitic unit and the psammites. Harrison[1] included all these rocks in the Snow Group. This implies either volcanism contemporaneous with the deposition of some of the psammites or a stratigraphic thinning of the volcanic rocks. Bailes[5] suggested, as an alternative interpretation, that the pelitic rocks belong to the Amisk Group and occur, in part, interlayered with volcanic rocks. A third possibility to account for the volcanic wedge north of Snow Lake is early thrusting of volcanic rocks over younger pelitic rocks. This relationship, favoured in particular by one of us (J.M.M.), has the advantage of leaving all volcanic rocks in the Amisk Group and most sediments in the Missi Group.

Minor and major structural features demonstrate three deformation events, which may be closely associated in time (Fig. 2). Amisk rocks generally display a prominent planar fabric S_1, expressed by mineral lenticles and flattened fragments, which is subparallel to the layering S_0. In a few places, S_1 is seen to be the axial surface of folds varying in size from hand specimen to outcrop scale and, more rarely, to megascopic scale in case of the Nor-Acme anticline and some folds at Chisel Lake. There is a possibility that discontinuous outcrops of pelitic rocks define an F_1 fold with a very sharp hinge between Wekusko and Herblet Lakes. This interpretation would make the pelitic rocks along Snow Creek and those at Anderson and Stall Lakes stratigraphically equivalent. In the eastern part of the area, the F_1 folds are isoclinal but near Chisel Lake some open F_1 folds are present. The second set of folds, F_2, produced the dominant northeasterly structural grain of the area. S_1 schistosity and F_1 axial traces are deformed by these folds and, in biotite-bearing rocks, a new axial-plane foliation, S_2, is produced. Elongation and mineral lineation in Amisk rocks may date from either the first or second deformation; crenulations represent the deformation of S_1 by F_2. The third phase produced open folds, prominent in the northern part of the area

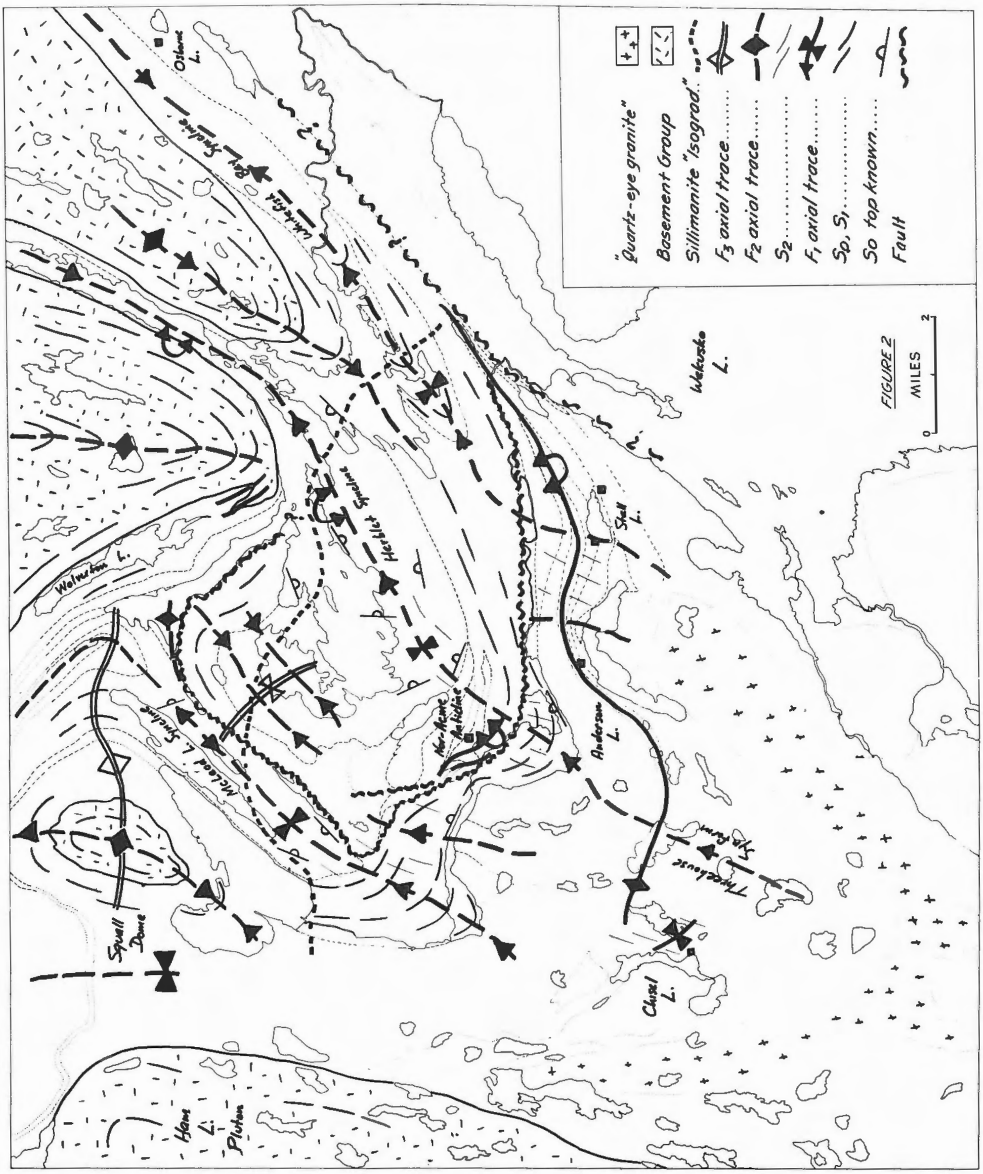
"Quartz-eye granite"
Basement Group
Sillimanite "isograd"
F_3 axial trace
F_2 axial trace
S_2
F_1 axial trace
S_0, S_1
S_0 top known
Fault
Osborne L.
Whitefish Bay Syncline
Wolverton L.
Herblet Syncline
Nor-Acme Anticline
McLeod L. Syncline
Squall Dome
Ham L. Pluton
Anderson L.
Stall L.
Wekusko L.
Chisel L.
Threehouse Synform
MILES
0
2

FIGURE 2

where F_2 antiforms were deformed into domes. The McLeod Lake synform was folded through 90 degrees around the east side of Squall Dome (as noted by Harrison[1]).

Metamorphic grade increases towards the north. Pelitic rocks in the southern half of the area are characterized by staurolite; those associated with sulphide deposits may contain abundant kyanite and chlorite. Northward, staurolite becomes unstable and sillimanite appears, shown approximately by the sillimanite isograd. Rocks in the sillimanite zone are relatively poor in primary structures and show more intense deformation, but major lithologic and structural features are continuous across the sillimanite isograd, which, in the Snow Lake area, corresponds to the "Kisseynew Front". Here it clearly is a metamorphic boundary.

The base metal deposits at Chisel Lake, Anderson Lake and Stall Lake occur in salic pyroclastic rocks close to the boundary with mafic units. The favourable horizon commonly is marked by the presence of interlayered pelitic rocks. It is probable that these deposits are stratigraphically equivalent, although it has not been possible to trace continuous markers between Chisel Lake and Anderson Lake. One difficulty is the complex interference pattern near Chisel Lake, produced by F_2 folds imposed on open F_1 folds. The Osborne Lake mine is entirely in salic pyroclastic rocks, some distance from the other deposits, but it would be close to the same stratigraphic horizon. The structural patterns determined by detailed explorations in the mines are consistent with observations on the surface. F_1 and F_2 are distinct at Chisel Lake and ore shoots are elongated parallel to F_2 axes[6]. At Anderson and Stall Lakes, there is a single strong lineation to which the orebodies are parallel[7] representing both L_1 and L_2.

Pelitic sediments in pyroclastic rocks are promising exploration targets; even discontinuous occurrences may mark favourable horizons. The pelitic rocks along Snow Creek deserve particular attention, because in this locality base metal deposits have not yet been discovered. Sulphide deposits are absent in psammitic rocks of the Missi Group. Consequently, when dealing with quartzofeldspathic rocks, it is important to separate derivatives of psammites and of salic pyroclastic rocks.

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STRATIGRAPHY

23. NOTE ON LOWER ELK POINT, NORTH FLANK OF TATHLINA UPLIFT

85E

H.R. Belyea

The C.S. Laferte River A-66 hole at 61°45'7.5"N., 118°41'29"W. (Fig. 1) cored part of the lower Elk Point Group. This core provides important information on lithology and correlation of rock units on the north flank of the Tathlina Uplift not available at the time of submission of the paper by Belyea[1]. The following note is essentially an addendum to that paper.

Precambrian

Reddish brown porphyry of the Cameron Bay Group was identified from the deepest core by P.F. Hoffman (pers. com.).

Basal Beds

No samples or core were taken of the beds immediately above the basement. Electric log characteristics between 1,820 and 1,862 feet suggest a clastic sequence. Between 1,807 and 1,820 feet an arkose was cored which is reddish grey, purplish grey and light pinkish grey, poorly sorted, and fine to coarse grained. It is vaguely bedded, mostly flat-lying but with dips in some intervals up to 10 degrees; these steeper dipping beds showing a slight curvature suggestive of crossbedding. Bedding is recognizable partly as a result of layering of fibrous and elongate rock and mineral fragments, partly from colour change.

A cursory examination of thin sections reveals the presence of quartz grains, myrmekite, lithic fragments, "weathered" feldspars, and a small amount of green and brown mottled biotite. Some carbonate cement is present and anhydrite fills voids. Most quartz grains are rounded; a few are rounded on one side, jagged on the other and have obviously been broken; a large number, but not all, of the quartz grains retain parts of rims, the outside margins of which are commonly jagged. In one example, small carbonate grains are included between the original rounded quartz grain and the rim. The broken rims suggest that the quartz grains were derived from a second generation quartz sandstone or sandstones, some of which had carbonate content or cement. Lithic fragments include fragments of Cameron Bay Group similar to the basement, and at least two different types of quartzite as well as other fragments that were not identified.

The uppermost 3 1/2 feet of the basal arkose contains nodules of pink anhydrite.

Ernestina Lake Formation

The basal arkose is abruptly overlain by dolomites of the Ernestina Lake Formation. This formation is 6 1/2 feet thick and consists of light yellow-brown, fine-grained, arkosic dolomite. The content of rock and mineral fragments is scattered in the bottom 2 feet, increasing to nearly 50 per cent towards the top. Bedding planes within it are all horizontal.

The dolomites are very finely crystalline, euhedral rhombs, most of them less than 20 microns. Irregular clots of finer material may be argillaceous. Patches of granular calcite cement in places grade into the fine-grained dolomite or fill cavities lined by small dolimite rhombs. Anhydrite fills cavities and replaces dolomite in the upper part. A few grains of gypsum were noted. Mineral and rock fragments of the arkosic fraction are similar throughout, and also similar to those of the basal arkose. The following were identified: quartz, "weathered" feldspar, microcline, myrmekite, green biotite, muscovite and a variety of lithic fragments including at least two types of quartzite, one of which includes grains of quartz with wavy extinction due to strain. Most quartz grains are rounded with outside edges in many cases scalloped or slightly pitted. No replacement of quartz grains by carbonate was noted and this is not the cause of the scalloped effect. Quartz overgrowths are rare. The quartz grains are best interpreted as second generation derived from quartz sandstones and sandy argillites known to occur in the Proterozoic[1].

A small fauna includes a nautiloid, possible <u>Alveolites</u>, small gastropods and an ambocoelid brachiopod (A. W. Norris and A. E. H. Pedder) as

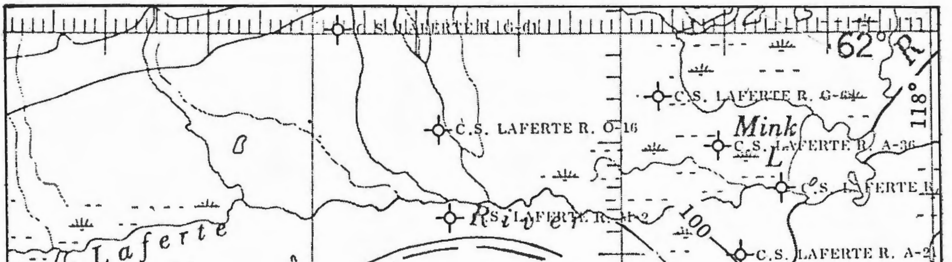

Figure 1. Index Map

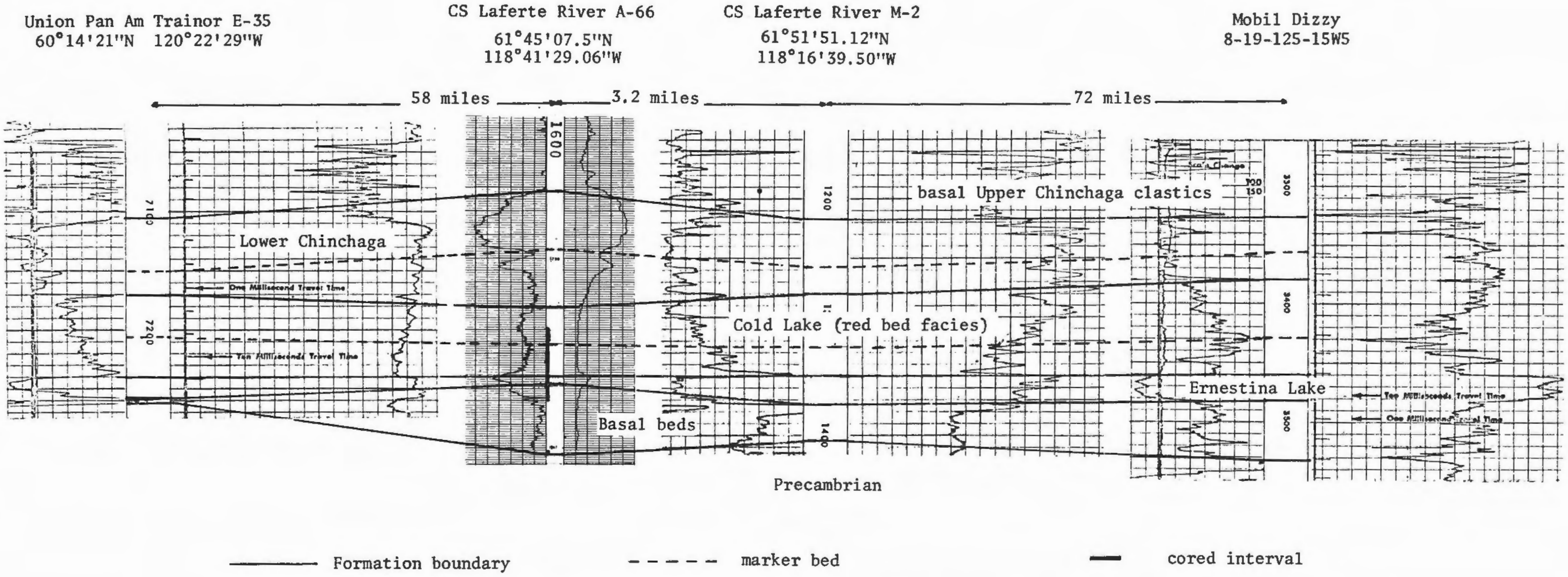

Figure 2. Correlation of rock units within Lower Elk Point on flanks of Tathlina Uplift.

well as Bisphaera sp. and Tolypammina sp., identified by T.P. Chamney. The macro-fauna as well as the lithology resemble that of the Fitzgerald Formation on Slave River (ref. 2, and pers. com.) which has been shown[3] to be the same rock unit as the Ernestina Lake of the subsurface. The anhydrite member that normally occurs at the top of the Ernestina Lake is not present.

Cold Lake Formation

The red-bed facies of the Cold Lake Formation occurs at this locality. Electric log characteristics are similar to those of the same facies on the southwest and southeast flanks of the Tathlina Uplift (Fig. 2) and a direct correlation may be postulated.

The formation is cored from 1,761 to 1,800 feet. The contact with the underlying Ernestina Lake apparently occurs between this core and the underlying one and was not recovered. The change in lithology is abrupt, the red mudstones contrasting sharply with the arkosic dolomite below.

The mudstones are made up of dark red-brown clay preserved as irregular, in part wispy layers that enclose laminae and small pods of silty argillaceous dolomite or dolomitic mudstone. Dolomite crystals are mostly less than 20 microns. Quartz silt grains are sharply angular, most of them about 60 microns or less in largest dimension but ranging up to 1 mm. A few grains of muscovite, biotite and iron oxide occur. No halite or angular cavities suggesting its former presence were noted. The basal 15 feet of the formation contain thin lenses of arkosic mudstone and arkose of composition similar to those in the Ernestina Lake and basal arkoses. Small patches and wisps of anhydrite are common between 1,761 and 1,800 feet.

The thickness of this unit as determined from mechanical logs is shown in Figure 2. Rapid thickening occurs where it intertongues with and is partly replaced by halite to the northeast and north[1].

The Cold Lake red bed facies is overlain by grey anhydritic, argillaceous mudstones that grade up to light grey anhydrite of the Lower Member of the Chinchaga Formation. It cannot be determined whether these grey mudstones are more closely related to the Cold Lake or to the Lower Member of the Chinchaga Formation. They seem to represent a transitional facies between the two.

The Laferte River area (Fig. 2) may be a low spur of the Tathlina Uplift or be separated from it by a channel in the Mills Lake area. Maximum relief of the basement, as indicated by the thickness of the Ernestina Lake and Cold Lake Formations in the holes drilled, is less than 75 feet. Basement of the upland area is predominantly granite; darker red and grey igneous rocks, some of which resemble rocks of the Cameron Bay Group, occur on the flanks. Sandstones and arkoses are thin or missing over the uplift or upland but vary from 20 to 80 feet on the flanks. Pre-Ernestina Lake red beds including anhydrite occur above the arkoses in the basin to the east and north. Their age is unknown—possibly they are equivalent to the Mirage Point Formation.

The Ernestina Lake Formation laps against the northern and eastern flanks of the uplift (Fig. 2). Cold Lake red beds onlap the uplift, progressively higher beds, as indicated by mechanical log characteristics, occuring in the higher areas (Fig. 2).

Addendum

The following note is based on a report by A.E. Foscolos received after submission of the paper. Mineral identification is by X-ray diffraction.

Basal arkose, 1,819.5 feet: quartz, Fe (chlorite), illite, anhydrite, calcite, dolomite (?). (The feldspars noted in the text are brown and probably completely altered, and appear as chlorite-illite in the X-ray analysis.)

Ernestina Lake Formation, arkosic dolomite, 1,803 feet: dolomite (major component), quartz, feldspar, amorphous siliceous material (probably the material identified as argillaceous in the text), trace illite.

Cold Lake Formation, red mudstone, 1,793 feet: a large amount of chlorite and illite (which includes muscovite and biotite identified by optical properites), a large amount of dolomite, minor quartz and feldspar. Optical examination shows red-brown iron oxide as blebs and lath-shaped fragments presumably an alteration product of micas.

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24. BAUMANN FIORD FORMATION EVAPORITES OF CENTRAL ELLESMERE ISLAND, ARCTIC CANADA

39W½
49E½

Project 710007

Grant D. Mossop

This report summarizes the interim results of research on the Baumann Fiord Formation evaporites of central Ellesmere Island, Arctic Canada. The project was initiated in the summer of 1971 in the form of a field survey carried out under the sponsorship of the Geological Survey of Canada. Laboratory work, focused principally upon the petrographic and geochemical characteristics of the Baumann Fiord rocks, has been performed at the Imperial College (London) during the academic year 1971-72. The study is supervised by Mr. D.J. Sherman (Department of Geology, Royal School of Mines) and is financially supported by the Royal Commission for the Exhibition of 1851.

Stratigraphic Setting and Tectonic History

The Baumann Fiord Formation is of Early Ordovician (Canadian) age. It forms part of a continuous succession of Upper Proterozoic to Upper Devonian rocks which collectively make up the Franklinian Miogeosynclinal sedimentary wedge. Late Devonian to Middle Pennsylvanian folding and faulting (Ellesmerian orogeny) has produced a structural trend approximately parallel to the depositional strike – that is, north-northeast across Ellesmere Island[1]. The sequence thins towards the east where it lies with demonstrable nonconformity on the Precambrian crystalline basement. To the west, on Axel Heiberg Island and westernmost Ellesmere Island the Franklinian rocks are overlain with profound angular unconformity by the rocks of the Sverdrup Basin[1].

The Baumann Fiord Formation is bounded below by the Lower Ordovician, shallow marine limestones of the Copes Bay Formation and above by Lower to Middle Ordovician, shallow marine carbonates of the Eleanor River Formation[2]. In the sections examined, measured thickness of the Baumann Fiord evaporites varied between 670 feet in the east and 1,850 feet in the west (i.e. thickening basinward).

A threefold division of the Baumann Fiord Formation was recognized over most of the study area. The thick basal A Member (up to 1,500 feet thick) characteristically consists of medium to fine crystalline anhydrite interbedded with very fine grained to micritic limestone in beds 2 to 10 feet thick. A prominent resistive limestone averaging 150 feet in thickness constitutes the B Member. The upper C Member (220 feet thick) closely resembles the A Member with its characteristically cyclical anhydrite-carbonate couples.

Detailed Stratigraphic Succession

Individual carbonate-anhydrite cycles in both the A and C Members of the Baumann Fiord Formation correlate with remarkable persistence and uniformity over large parts of the study area. Where lateral variation is observed, the following relationship is consistently apparent: carbonate units grade from west to east into anhydrite, with more total carbonate in the west than in the east. The limestones are evidently the basinward facies equivalent of the anhydrite, the extent of interfingering of the facies being considerable and on a large scale. It is interesting also to note that the uppermost shallow marine limestones of the Copes Bay Formation in the west are demonstrably time-equivalent to the basal Baumann Fiord anhydrite cycles to the east.

The consistent coupling of anhydrite and shallow marine carbonate in the Baumann Fiord evaporites itself suggests that these deposits may have originated as sabkha cycles. Numerous lines of petrographic evidence support this suggestion.

Petrographic Character and Interpretations - Limestones

The following summary of the petrographic character of the carbonates applies to the limestones of the B Member as well as to the numerous thin limestone stringers in the anhydrite of the A and C Members. A brief discussion of relevant sabkha analogs is included with each observation.

I. Limestones exclusively fine grained, apparently deposited as aragonitic lime mud in an environment analogous to the shallow lagoons adjacent to the Trucial Coast sabkha plain[3].

II. Finely laminated to massive, deposited in very quiet shallow water, the more massive muds possibly indicating a degree of bioturbation.

III. Pelleted. Fecal pellets are not a common constituent but where they occur the presence of browsing lagoonal organisms is indicated (analogous to the cerithid gastropods of the sabkha lagoons). The relative paucity of pelleted lime mud may be a function of the fact that Early Ordovician time witnesses only the beginnings of pelleting organism evolution.

IV. Shell fragments are rare except as isolated aggregates in pellets. Kinsman (ref. 3) has pointed out that recent sabkha lagoonal sediments are barren of fossils due to the fact that dead gastropods tend to float and are subsequently concentrated only in the immediate beach environment.

V. Dolomite is common in minor amounts in the lime mudstone, normally disseminated uniformly but occasionally concentrated along zones of permeability. The access of early diagenetic sabkha brines has apparently resulted in partial dolomitization of the limestone[4].

VI. Stromatolites together with less distinctive crypt-algal structures are common. These features, analogous to the high intertidal algal mats of the sabkha, have been variously interpreted as representing shallow subtidal to supratidal environments in the Recent[5].

VII. Flat-pebble conglomerates are common constituents of the carbonate stringers. Rarely more than one or two pebbles thick, they consist of lime mudstone clasts normally aligned horizontally but occasionally exhibiting an "edgewise" configuration. They are interpreted as resulting from auto-brecciation, transport and rounding by wave and/or current action associated with major marine transgression. That partial erosion of the sabkha anhydrite may have accompanied these major marine transgressions is evidenced by the commonly undulose or irregular nature of the contact between anhydrite and the overlying limestone of the succeeding cycle. These irregularities appear to be small-scale "cut-and-fill" structures.

VIII. Replacement anhydrites known to occur in limestones associated with many ancient sabkha sequences[6] are present in abundance in the lime mudstones of the Baumann Fiord Formation in the form of gypsum pseudomorphs. Castillated crystal boundaries and numerous unreplaced calcite relics characterize these pockets of replacement, the anhydrite having replaced the limestone and the gypsum subsequently pseudomorphing and replacing the anhydrite. It is thought that the conversion of anhydrite to gypsum occured by way of late hydration by meteoric waters.

Petrographic Character and Interpretations - Anhydrites

The anhydrite rocks of the Baumann Fiord Formation have a remarkably consistent textural character: medium to finely crystalline, light to dark bluish grey in hand specimen, often exhibiting a thinly layered or "bedded" appearance, the layering being due to colour zoning in an otherwise homogeneous or massive unit.

There is no evidence of the nodular structure characteristic of modern sabkha anhydrites. Indeed, the anhydrites of the Baumann Fiord evaporites have virtually none of the textural or morphological characteristics normally associated with anhydrite of sabkha origin. The problem of establishing the environment of deposition of the anhydrites is thus of considerable magnitude. Two lines of indirect argument have been developed in support of a supratidal origin for the anhydrites: firstly, the limestone stringers in the Baumann Fiord evaporites show considerable evidence of having been deposited in a shallow marine coastal complex of the type which is known to be associated with the only documented present-day environment of anhydrite development – the sabkha of the Persian Gulf. Secondly, on more regional stratigraphic grounds, the intrinsically cyclical nature and lateral variation of the coupled carbonate-anhydrite lithofacies is such that a sabkha cycle analog is compellingly attractive. To capsulise, save for the actual textural character of the anhydrites themselves, the Baumann Fiord evaporites exhibit strong indications of having been deposited as sabkha cycles.

An explanation of the apparently anomalous character of the anhydrite is possible upon detailed petrographic analysis of the crystal fabrics: anhydrite crystals are lath-shaped and show a distinct preferred orientation in thin section. In sections parallel to the long axis of the laths, the overall fabric resembles that of a mica schist.

This fabric is tentatively interpreted as having resulted from recrystallization and flowage of the anhydrite in response or orogenic compressional stresses. Any primary texture that might be expected to reflect the mode of origin of the anhydrite apparently has been obliterated by this episode of pervasive recrystallization.

Structural Style

The degree of structural deformation of the Franklinian sediments has only been sufficient to produce broad open folds (frequency 2-3 miles, amplitude 2,000-3,000 feet). It is the opinion of N.J. Price (pers. com.) that this relatively small degree of deformation may well be sufficient to induce flow in anhydrite strata. Experiments to test this hypothesis are currently being undertaken.

Related Research

A number of other problems relating to the Baumann Fiord evaporites also are under investigation:

I. Weathering. Due to the permafrost, the zone of active arctic weathering is rarely more than a few feet. Nonetheless, a thin surficial veneer of gypsum, the result of hydration of anhydrite, is commonly developed. Preliminary analyses indicate that strontium is preferentially leached from the anhydrite upon weathering and concentrated in the surficial efflorescent gypsum.

II. Chert concretions. In both the anhydrite and the limestones of the Baumann Fiord Formation oblate chert concretions have developed. The apparently unique association of optically length-slow chalcedony with evaporite rocks[8] makes these concretions the subject of special investigation.

III. Satin-Spar. Late fibrous gypsum veins are common in the basal beds of the Baumann Fiord evaporites in those regions near the shield where access to water from underlying strata has resulted in partial hydration of the anhydrite. Independent investigation has revealed that the origin of the veins is due to hydraulic fracturing, the excess volume of gypsum generated by hydration of anhydrite being reprecipitated in the veins and forming satin-spar[9].

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[2] Kerr, J.Wm.: Stratigraphy of central and eastern Ellesmere Island, Arctic Canada, Part II Ordovician; Geol. Surv. Can., Paper 67-27, 92 p. (1967).

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[4] Illing, L.V., Wells, A.J., and Taylor, J.C.M.: Penecontemporary dolomite in the Persian Gulf; Soc. Econ. Paleontol., Mineral. Spec. Publ. No. 13, p. 89-111 (1965).

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[7] Folk, R.L., and Pittman, J.S.: Length-slow chalcedony: A new testament for vanished evaporites; J.Sed. Petrol., v. 41, no. 4, p. 1045-1058 (1971).

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25. STRUCTURAL AND STRATIGRAPHIC STUDIES IN THE TECTONIC COMPLEX OF NORTHERN YUKON TERRITORY, NORTH OF PORCUPINE RIVER

107 B
117 A, B, C, D

Project 690005

D. K. Norris

During the field seasons of 1970 and 1971 the author spent a total time of approximately two months extending his regional investigations of the stratigraphy and structure of the Tectonic Complex between Richardson Mountains and the Alaska Boundary, north of Porcupine River. These investigations supplement the reconnaissance studies carried out there in 1962 during Operation Porcupine[1] as well as additional information gathered during a brief period in 1969[2]. A disastrous fire near the end of the 1970 field season resulted in the total loss of that summer's field notes covering the area under consideration here and hence some time was spent revisiting a few of the more important outcrops in 1971.

The Tectonic Complex north of latitude 67 degrees may be divided into a number of structurally high and low regions (Fig. 1). At its southern limit is Aklavik Arch, a composite structural feature extending northeast from Alaska to Campbell Uplift and perhaps beyond. It comprises Dave Lord-Cache

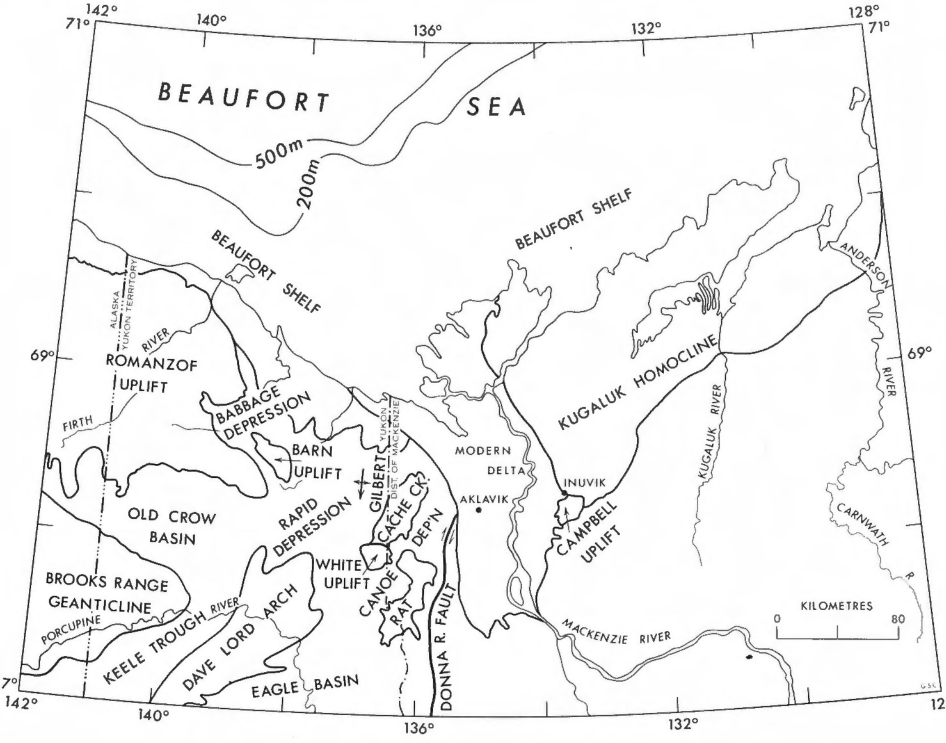


Figure 1. Principal geological elements of northern part of Tectonic Complex, northern Yukon Territory and northwestern District of Mackenzie[3].

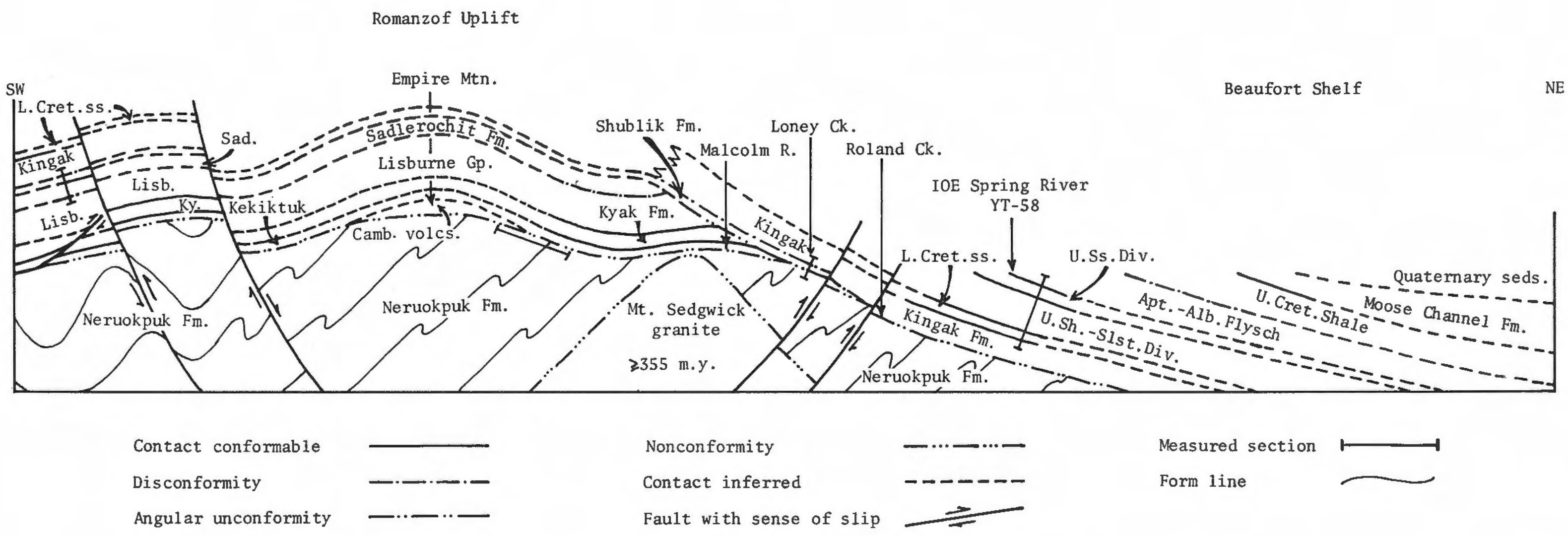


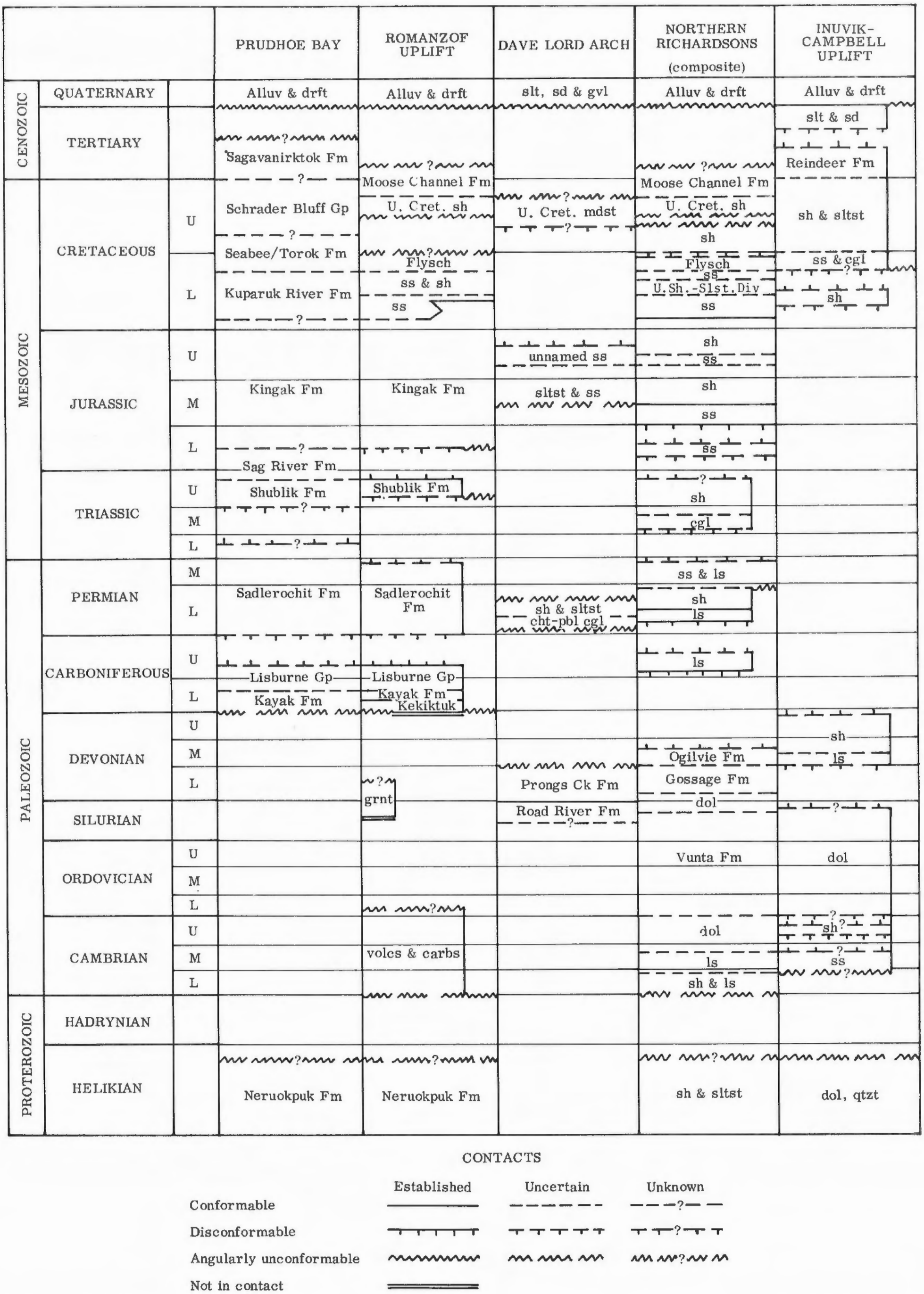
Figure 2. Structural and stratigraphic relations among rock units of northern Yukon Territory in the region of Romanzof Uplift, northern Yukon Territory (schematic).

Creek, Rat and Campbell Uplifts with attendant depressions arranged right-hand en échelon. North of it are southeast-plunging Romanzof Uplift, doubly plunging Barn Uplift, and the eastern limit of Brooks Range Geanticline. Among these uplifts are depressed regions containing intricately faulted and folded Mesozoic and younger rocks. On the north flank of the complex is Beaufort Shelf, largely submerged beneath Beaufort Sea to receive sediments and partly exposed, glaciated and eroded since the mid-Tertiary.

Approximately 20,500 feet (6,000 metres) of Neruokpuk Formation were measured and examined between Wolf Creek and Firth River (69° 04' N, 140° 15'W) in order to document its age, rock types and stratigraphic relations to other units. There, the formation is readily divided into a lower limestone and shale unit 4,200 feet (1,300 metres) thick which may be traced directly into map-unit Pznl of Brosgé et al.[4] in adjacent Demarcation Point map-area in Alaska. It is a formation and hence the Neruokpuk will be raised to group status in Canada in due course. Samples of this limestone were examined by T. T. Uyeno of the Geological Survey of Canada for conodonts or any other identifiable fossil remains but without success. It is overlain by a sequence of interbedded argillites and lithic sandstones 16,300 feet (5,000 metres) thick which can be subdivided into map-units and from which no fossils were recovered. The section had no base and no top. Insofar as the Neruokpuk strata generally dip in the same direction (southwest) from the lowermost exposures near the mouth of Firth River, it may be that the true thickness of the Neruokpuk is at least 40,000 feet (12,000 metres), or twice that measured here.

Immediately west of Firth River is a volcanic conglomerate with grey limestone phenoclasts and interbeds. It is estimated to be about 2,500 feet (760 metres) thick. Although deformed, the conglomerate appears, from regional mapping, to overlie progressively lower strata in the upturned Neruokpuk succession toward Alaska. There Dutro et al.[5] have recovered Lower as well as Upper Cambrian trilobites from it. Thus, if the stratigraphic relations between this Cambrian formation and the underlying Neruokpuk have been inferred correctly, the Neruokpuk in Canada is entirely older than the Early Cambrian[1]. Moreover, the acute deformation within it is largely of Precambrian age and is not Ellesmerian in the Romanzof Uplift. This conclusion does not discount the structural involvement of graptolite-bearing shales with the Neruokpuk in Barn Uplift, or the angular unconformity between Upper Devonian and Permian rocks in Dave Lord Arch (see Table 1) and in northern Richardson Mountains - situations which disclose obvious effects of the Ellesmerian orogeny in other parts of the Tectonic Complex.

Approximately 3.4 miles (5.3 km) east of the International Boundary at Ammerman Mountain, on the flank of Old Crow Basin (G.S.C. Loc. C-11874; 68° 21'N, 140° 52'W), poorly preserved plant impressions were recovered from dark grey slaty argillites previously assigned to the Neruopuk Formation[1] and which probably are not older than Devonian (D.C. McGregor, pers. comm., 1972). These appear to be morphologically similar to parts of specimens of Archaeopteris latifolia reported[6] to occur on the north flank of the Basin (G.S.C. Loc. C-16896; 68° 26'N, 140° 02'W). According to G.E. Rouse (pers. comm., 1972) "the presence of this plant species indicates the age lies between Late Givetian and Famennian, as species of Archaeopteris are found only in this interval". These plant-bearing beds near Ammerman Mountain strike sub-parallel to Aklavik Arch and their vertical dip attests to their involvement in the Ellesmerian orogeny, similar to



			PRUDHOE BAY	ROMANZOF UPLIFT	DAVE LORD ARCH	NORTHERN RICHARDSONS (composite)	INUVIK-CAMPBELL UPLIFT
CENOZOIC	QUATERNARY		Alluv & drft	Alluv & drft	slt, sd & gvl	Alluv & drft	Alluv & drft
	TERTIARY		Sagavanirktok Fm				slt & sd Reindeer Fm
MESOZOIC	CRETACEOUS	U	Schrader Bluff Gp	Moose Channel Fm U. Cret. sh	U. Cret. mdst	Moose Channel Fm U. Cret. sh sh	sh & sltst
		L	Seabee/Torok Fm Kuparuk River Fm	Flysch ss & sh ss		Flysch ss U.Sh.-Slst.Div ss	ss & cgl sh
	JURASSIC	U			unnamed ss	sh ss	
		M	Kingak Fm	Kingak Fm	sltst & ss	sh ss	
		L	Sag River Fm			ss	
	TRIASSIC	U	Shublik Fm	Shublik Fm		sh	
		M				cgl	
		L					
PALEOZOIC	PERMIAN	M				ss & ls	
		L	Sadlerochit Fm	Sadlerochit Fm	sh & sltst cht-pbl cgl	sh ls	
	CARBONIFEROUS	U				ls	
		L	Lisburne Gp Kayak Fm	Lisburne Gp Kayak Fm Kekiktuk			
	DEVONIAN	U					sh
		M				Ogilvie Fm	ls
		L		grnt	Prongs Ck Fm	Gossage Fm	
	SILURIAN				Road River Fm	dol	
	ORDOVICIAN	U				Vunta Fm	dol
		M					
		L					
	CAMBRIAN	U				dol	sh
		M		volcs & carbs		ls	ss
		L				sh & ls	
PROTEROZOIC	HADRYNIAN						
	HELIKIAN		Neruokpuk Fm	Neruokpuk Fm		sh & sltst	dol, qtzt

Table 1. Correlation chart for rock units between Prudhoe Bay, Alaska and the Inuvik – Campbell Uplift area, northwestern District of Mackenzie. Data for Prudhoe Bay adapted from Rickwood[11], and for the Inuvik – Campbell Uplift region in part after Pamenter[12].

the Devonian rocks cited earlier in Dave Lord Arch on Porcupine River 5 miles (8 km) upstream from the mouth of Driftwood River (Table 1).

The Kekiktuk Formation overlies the Neruokpuk with profound unconformity and the angle between bedding in the two formations is commonly 90 degrees, as seen for example along the south rim of Barn Uplift, and on the lower reaches of Malcolm River on the north flank of Romanzof Uplift. It is characteristically a chert and quartzite pebble-conglomerate although locally it grades abruptly into white quartzite. It forms the basal, northeastwardly transgressive deposit of the Carboniferous System in the Complex and is over lain conformably by the Kyak Formation.

The Kyak is characterized by carbonaceous shales, grey coaly quartzites and coal in the lower part, and calcareous shales and skeletal limestones above[7]. Spores in shale samples from the lower part of the formation on the north flank of Barn Uplift, and in Romanzof Uplift confirm an Early Carboniferous (Viséan) age (M.S. Barss, Interdepartmental Report, 1972) for the Kyak. The coal seams, moreover, are anthracites with ash content commonly less than 10 per cent (W.J. Montgomery, Interdepartmental Report). Their observed thickness did not exceed three feet (1 metre). Carbonaceous shales overlying the thick conglomerates in the structural high 7 miles (11 km) north of Bonnet Lake contained, in addition, Viséan spores (Barss, idem). This latter clastic succession was erroneously referred to the Brat Creek Formation[2] and now can be assigned with confidence to the Kekiktuk and Kyak Formations.

Because of the economic significance of the northeastern limit of the Lisburne Group, the cherty grey limestones immediately northwest of Driftwood River (G.S.C. Loc. C-4217; 67° 54'N, 137° 57'W) were re-examined. Foraminifera in them indicate that they are Late Chesteran in age (B. Mamet; Interdepartmental Report, 1972) and hence that they may be referred to the Alapah Formation of the Lisburne.

A careful search of the string of grey, exceedingly fractured, fault-bounded cherty dolomite outcrops 10 miles (16 km) southeast of Bonnet Lake failed to disclose any identifiable fossil remains. Herein they are assigned tentatively to the Precambrian Neruokpuk Formation along with the grey, quartzose limestones on the southeast flank of Barn Uplift and in the structural high north of Bonnet Lake. They are overlain unconformably by Jurassic sandstones and shales at their southern limit (68° 06'N, 137° 33'W). The absence of the Lisburne at the sub-Jurassic disconformity on the east flank of Barn Uplift, in the structural high north of Bonnet Lake, in northeastern Richardson Mountains and their apparent absence southeast of Bonnet Lake would suggest that the Lisburne equivalents on the east flank of White Uplift[7] and near the headwaters of Cache Creek[7] may be isolated erosional remnants covered and bounded on all sides by younger rocks (see Table 1).

The Permian Sadlerochit Formation was examined and measured on the southwest flank of Romanzof Uplift (68° 42.3'N, 139° 52'W). Although not well exposed, the succession is approximately 1,100 feet (340 metres) thick and comprises largely dark grey, noncalcareous mudstone with richly fossiliferous sandstone and limestone interbeds dated tentatively as early Middle Permian (Kungurian) in age (J.B. Waterhouse, pers. comm., 1972). It rests on grey, fine-crystalline limestones of the Wahoo Formation and is capped by cuesta-forming, slightly calcareous, dark grey, sparsely fossiliferous sandstones, as yet undated, but tentatively assigned to the Upper Triassic Shublik Formation. Lower Triassic rocks are unkown to the writer in the Sadlerochit in Canada, and lateral equivalents of the Ivishak Member in northeastern Alaska may be absent.

The Upper Triassic Shublik Formation comprises two facies, a lower sandstone or siltstone and an upper skeletal limestone, both locally abundantly fossiliferous and dated as Upper Triassic Norian (E. T. Tozer, Interdepartmental Reports). The two facies overlie one another only on the south flank of Romanzof Uplift and the limestone facies is largely confined to the north and east flanks. Thus the limestones appear to have overstepped the clastics in a northeasterly direction.

Shublik Formation outcrops discontinuously around the periphery of Romanzof Uplift in Canada. It lies disconformably upon the Sadlerochit on the south flank of the uplift and on the east it is observed to rest disconformably on either the Alapah or Wahoo Formations of the Lisburne Group (7). On the north flank at several locations between Loney Creek and Crow River it rests on deformed Neruokpuk and the thick carbonate and clastic sequence of the Kekiktuk, Kyak, Alapah, Wahoo and Sadlerochit Formations (Table 1) is absent. The fact that the Wahoo Formation is present in some of the northernmost exposures of the Lisburne in Romanzof Uplift, would suggest, moreover, that the sub-Shublik unconformity must cut down section abruptly through the Sadlerochit and underlying Carboniferous formations in order that the Shublik can rest on the Neruokpuk between Loney Creek and Crow River. This cutting down section must take place along a line parallel to the present northeast flank of British Mountains (see Fig. 2) and represent a hinge for uplift of contiguous regions to the northeast in the Late Permian and Early Triassic. The source of clastics for the Shublik was, therefore, to the north.

The Jurassic Kingak shales also outcrop discontinuously around the periphery of Romanzof Uplift and along with the Shublik are assumed to have covered the entire region. Of vital economic importance is the observed overstepping of the Shublik on the north flank of the uplift so that the Sadlerochit and Shublik Formations, the principal reservoir rocks at Prudhoe Bay (Table 1), are at least locally absent. This phenomenon may be observed (Pl. 1) on a small tributary to Spring River (69° 13'N, 139° 02'W). There intensely crumpled, faulted and differentially bevelled argillites and quartzites of the Neruokpuk Formation are immediately overlain unconformably by 20 feet (6 metres) of gently north-dipping, soft, black shales, followed in turn by 6 feet (2 metres) of conglomerate composed of subrounded pebbles of black, grey and banded chert and of white quartzite, averaging about 3/4 inch (2 cm) maximum dimension. Although the black shales were not found to contain fossils at this locality, foraminifera recovered from these rocks 1/2 mile (1 km) farther downstream (G. S. C. Loc. C-13086) indicate that they are Late Jurassic in age (T. P. Chamney, Interdepartmental Report, 1972) and hence referable to the Kingak Formation.

Around the north flank of Old Crow Basin are exposures of Jurassic and Lower Cretaceous, black, concretionary shale with thin, buff-weathering, quartz sandstone interbeds which, based on their fossil content, are as young as mid- to late Valanginian (J. A. Jeletzky, Interdepartmental Report, 1972). They are, therefore, temporal equivalents of part of the Lower Sandstone and Bluish Grey Shale Divisions in Aklavik Range and herein are referred to the upper part of the Kingak Formation (Table 1). Overlying them are fossiliferous, marine, buff-weathering, resistant sandstones representing offshore equivalents of the Coaly Quartzite Division and forming a readily mappable unit in the region. These are the youngest rocks known to the writer on the north flank of the basin.

In the vicinity of lower Babbage River occur lateral equivalents of the Aptian Upper Sandstone Division, and of the Aptian-Albian flysch sequence. Inoceramus sp. recovered from the latter (G.S.C. Loc. 53307, 68° 54'N, 138° 37'W) is suggestive of mid-Lower to Upper Cretaceous but does not prove this age (J.A. Jeletzky, pers. comm. 1972). Locally the flysch is cut by dykes of fine-grained, brown weathering lithic arenits up to 6 inches (15 cm) wide.

Because of their tectonic significance the youngest bedrock in Old Crow Basin was examined at two localities, the one along Porcupine River between Driftwood River and Dave Lord Creek and first described by McConnell[8] and the other on Upper Dave Lord Creek. The exposures along the Porcupine (G.S.C. Loc. C-11863; 67° 33.5'N, 138° 54'W) are essentially flat-lying, poorly consolidated, grey mudstones containing large Inoceramus sp. The rocks are, accordingly, Santonian to early Campanian in age (J.A. Jeletzky, Interdepartmental Report, 1972). Interbedded, dark grey marine shales and sandstones on Upper Dave Lord Creek (G.S.C. Loc. C-13085; 67° 16'N, 139° 24.5'W) strike parallel to Dave Lord Arch and dip 20 degrees northwest. They are Senonian, probably Campanian in age (W.S. Hopkins, Interdepartmental Report, 1972). Thus, the beds at these two localities are approximately the same age, and the fact that at the one the rocks are flat lying and at the other they are gently dipping off the flank of the Arch, attests to (renewed) Late Cretaceous uplift and tectonic activity on the south flank of Old Crow Basin.

The youngest sequence of rocks in the northern part of the Tectonic Complex in Yukon Territory occurs on Beaufort Shelf north of Barn Mountains (G.S.C. Loc. C-9784; 68° 50'N, 131° 54'W). Its lower part comprises an estimated 10,000 feet (3,000 metres) of folded and faulted, marine, grey shale (see Table 1) of Senonian age (T.P. Chamney, Interdepartmental Report, 1972) which may be temporally equivalent to the mudstones and shales described in Old Crow Basin.

Overlying these Upper Cretaceous shales with apparent conformity are an estimated 2,500 feet (800 metres) of interbedded lithic sandstone, conglomerate, shale and high volatile bituminous coal of the Moose Channel Formation at the headwaters of Conglomerate and Deep Creeks. Pollen recovered from carbonaceous shales adjacent to one of the coal seams (G.S.C. Loc. C-11263; 68° 53'N, 138° 02'W) indicates that a Senonian (Campanian – ? Maestrichtian) age seems most likely (W.W. Brideaux, Interdepartmental Report, 1972). The Moose Channel Formation outcrops in a doubly plunging syncline, the axis of which trends north. The fold is cut by a series of steeply dipping, east-trending faults, some with significant right-lateral as well as vertical separations. The Upper Cretaceous shales and the Moose Channel Formation show obvious effects of Tertiary deformation there as well as near the mouth of Fish River (68° 42'N, 136° 19'W) where coal and conglomerate beds are observed to dip vertically. By comparison with some of the major deltas of the world, the Upper Cretaceous shales would appear to represent marine, prodelta deposits shed by rivers rising in Laramide uplands to the southwest[2], and the Moose Channel clastics and coal, distributary channel fill and back-swamp organic accumulations respectively, of an early Tertiary deltaic plain.

A re-evaluation of the possible continuation of the Kaltag fault northeastward across Alaska and Yukon Territory was made because of the implications regarding the northeast-trending faults being identified beneath Tuktoyaktuk Peninsula, east of Mackenzie Delta. It has been well documented as a major right-lateral fault that has been active since Cretaceous time

Plate 1. Angular unconformity between the Precambrian? Neruokpuk Formation and the Jurassic Kingak Formation 9.5 miles (15.5 km.) northwest of IOE Spring River well, northern Yukon Territory.

in west-central Alaska[9], but its continuation into Yukon Territory is conjectural. Should it persist in its northeast trend and enter Canada along the south flank of the Brooks Range Geanticline (Fig. 1), it may have manifested itself in the near-surface rocks as the array of north and northeast-trending strike-slip faults in Rapid Depression[3]. Moreover, the remarkable curvilinear escarpment flanking southern Canada Basin[10] may well connect with it. Thus, the northwestern limit of the ancestral North American continental plate may have been the Kaltag fault, and that part of Alaska and Yukon Territory north of it is part of the Eurasian plate. The fact that the geological trends for Alaska match those for northeastern U.S.S.R. for both the Cenozoic and Paleozoic eras[11] would lend support to this hypothesis. The North American plate may have simply drifted right-laterally away from Eurasia so that there were no pivot points, no Alaska Orocline, and no Arctic Sphenochasm. Canada Basin south of Lomonosov Ridge was apparently an ancient and persistent ocean[11] and the northeast-trending faults being identified by drilling in the Tuktoyaktuk Peninsula are genetically part of a major, strike-slip fault system bounding the North American continental plate.

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[2] Norris, D.K.: Structural and stratigraphic studies, Blow River area, Yukon Territory and western District of Mackenzie; in Report of Activities, Part A: April to October, 1969; Geol. Surv. Can., Paper 70-1, Pt. A, p. 230-235 (1970).

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[10] Boberschmidt, L.J.: Arctic ocean floor; in National Geographic Magazine, v. 140, no. 4, map (1971).

[11] Churkin, M.Jr.: Paleozoic tectonic history of the Arctic Basin north of Alaska; Science, v. 165, no. 3893, p. 549-555 (1969).

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TERRAIN SCIENCES

26. SURFICIAL GEOLOGY RECONNAISSANCE, ISLAND OF NEWFOUNDLAND

2,12

Project 720028

D. R. Grant

Airphoto interpretation of terrain forms and deposits at 1:50,000 scale for much of Newfoundland has commenced in order to develop techniques of geochemical prospecting especially suited to the terrain and to locate materials that are characteristic of the Newfoundland environment. As most of the bedrock is concealed by overburden, primarily glacial till and related deposits, prospecting for mineral occurrences commonly becomes a search for trace elements in the drift which is assumed to be an indirect sample of the buried bedrock surface. In this context, concentrations of metal in stream-sediment, lake-sediment and biological materials living upon these substrates are treated as second- and third-order derivations of hypothetical bedrock sources.

The aim of the glacial geological study is to provide the surfical material sampling program with knowledge of the kind, origin, provenance, and thickness of overburden, in order to infer the source of mineral anomalies in the overburden, and to test whether negative results necessarily imply absence of sources.

A cursory examination of airphotos covering the entire island, and detailed study of airphotos in the four pilot study areas for 1972 (Springdale, South Twin Lake, Daniels Harbour, Clarenville) reveals several conditions likely to confound drift-prospecting: (1) a very wide variety of terrain types with abrupt transitions, (2) a non-systematic mosaic of disjunct, often superimposed sedimentary environments, (3) large local variations in drift thickness, (4) evidence of wholesale transport of till masses several tens of miles onto unrelated geologic terranes, (5) a zonal distribution of solifluction processes, with a surprisingly intense development of colluvial overprinting in the interior of the province, (6) widely divergent trends of glacial transport indicated by intersecting drift lineations and crossed striations attributed to migrating, separating and shrinking ice centres, (7) frequent non-parallelism of eskers and ice-flow lineations indicating that direction of ice retreat differed from direction of ice flow, and (8) end moraines are rare but ice-marginal channels abound so that, by their location, elevation and slope, the various ice centres may be located and the pattern of their retreat may be mapped.

27. POSTGLACIAL EMERGENCE OF NORTHERN NEWFOUNDLAND

2 M'
12 H, I, P

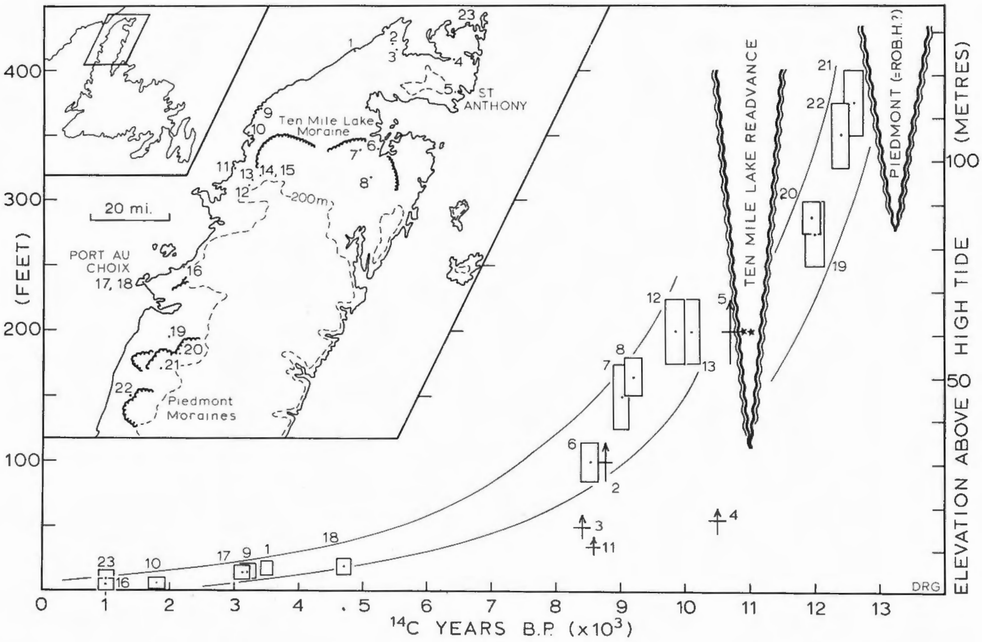
Project 690065

D. R. Grant

Surficial geological mapping of the Northern Peninsula has included documenting postglacial changes in the relative level of land and sea. This report complements previous accounts[1, 2, 3] of the surficial deposits and geomorphology of the area. In contrast to coasts that are now submerging farther south in Newfoundland and the Maritimes, most of the Northern Peninsula has been, and still is, emerging from the sea due to continuing glacio-isostatic rebound.

The trend of falling sea level, as shown in Figure 1, has been reconstructed by plotting the elevation of former strandlines against their age as measured by radiocarbon analysis of fossil shells found intact, articulated and in growth position in the gravelly beach sediment. A few shells from deep-water sediment fall below the sea level corresponding to their age, as expected. The rate of emergence has decreased exponentially from 430 cm (14 feet) per century shortly after deglaciation 11,000 to 13,000 years ago, to 14 cm (0.47 feet) per century during the last few thousand years. The maximum elevation of the former marine inundation varies from 425 feet to 225 feet above present sea level owing to differences in the time and rate of deglaciation, and to two glacial readvances that removed evidence of earlier higher sea levels.

A readvance near Ten Mile Lake, that formed a prominent end moraine 11,000 years ago, has been dated by shell fragments incorporated in the till of the moraine (GSC-1277; 1324). The fall of sea level that occurred since the sea stood at elevation 200 feet (60 m) against the moraine is traced as a smooth curve that seems to represent the emergence for the entire northern lowlands,



(Rectangles denote age and elevation errors of samples formed in beaches at or near former sea levels. Crosses with arrows are samples from deepwater sediment formed below the corresponding sea level. Stars are samples from till of end moraine. Site 23 is the Viking settlement (ca 1000 A.D.) on a raised beach berm at elevation 2.85 m (9.5 feet), L'Anse au Meadow.)

Figure 1. Emergence trends in northern Newfoundland.

with little sign of significant geographic differences. In contrast, the postglacial fall of sea level following the piedmont moraine phase on the western lowlands seems disjunct to that for the northern area. Moreover, datings of similar features in the St. George Bay area still farther south plot below both curves in the range less than 50 m and older than 10,000 years. These latitudinal differences in rate of sea-level change reflect the transition from an emerging coast on the north to a submerging coast on the south across a pivotal line of no present net change inferred to cross the Northern Peninsula in the vicinity of Bonne Bay.

[1] Grant, D. R.: Late Pleistocene readvance of piedmont glaciers in western Newfoundland; Maritime Sediments, v. 5, no. 3, p. 126-128 (1970).

[2] Grant, D. R.: Surficial deposits, geomorphic features, and late Quaternary history of the terminus of the Northern Peninsula of Newfoundland, and adjacent Quebec-Labrador; Maritime Sediments, v. 5, no. 3, p. 123-125 (1970).

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28. SITE DESCRIPTION, AGE AND SIGNIFICANCE OF A SHELL SAMPLE FROM THE MOUTH OF THE MICHAEL RIVER[1], 30 KM SOUTH OF CAPE HARRISON, LABRADOR

13I

Project 690043

D. A. Hodgson and R. J. Fulton

Of the few radiocarbon dates published for material gathered in central and southern Labrador, the oldest are 5575 ± 250 and 5400 ± 200 years B. P.[2] near Churchill Falls[3] followed by 5330 ± 170 years[4] (GSC-1135) at North West River[5]. Hence, a collection of shells dated at 8640 ± 230 years[4] (GSC-1453) merits more consideration than would normally be given to a sample from a site which cannot readily be related to a specific sea level. The sample was collected at 54° 41'N lat., 57° 49'W long., near the mouth of the Michael River (Fig. 1) in the course of reconnaissance of the surficial geology of southern Labrador[6].

Evidence of marine submergence is relatively abundant along the Labrador coast. The most conspicuous features, and the ones most readily tied to former higher sea levels, are washing limits and coarse boulder and gravel beach ridges. Also present are extensive marine terraces or deltas filling the lower ends of many river valleys with a succession of coarse sand or gravel over silt and fine-grained sand. Dateable material has not been found in the coarse marine deposits possibly because the cool wet climate and the acid nature of the rocks and vegetation promote leaching or oxidation of organic material from all permeable deposits. Shells have been found in the less permeable silt units, but collection sites are widely separated and, as the silt unit is an offshore facies, it is difficult to correlate shells with the sea level at the time of their deposition.

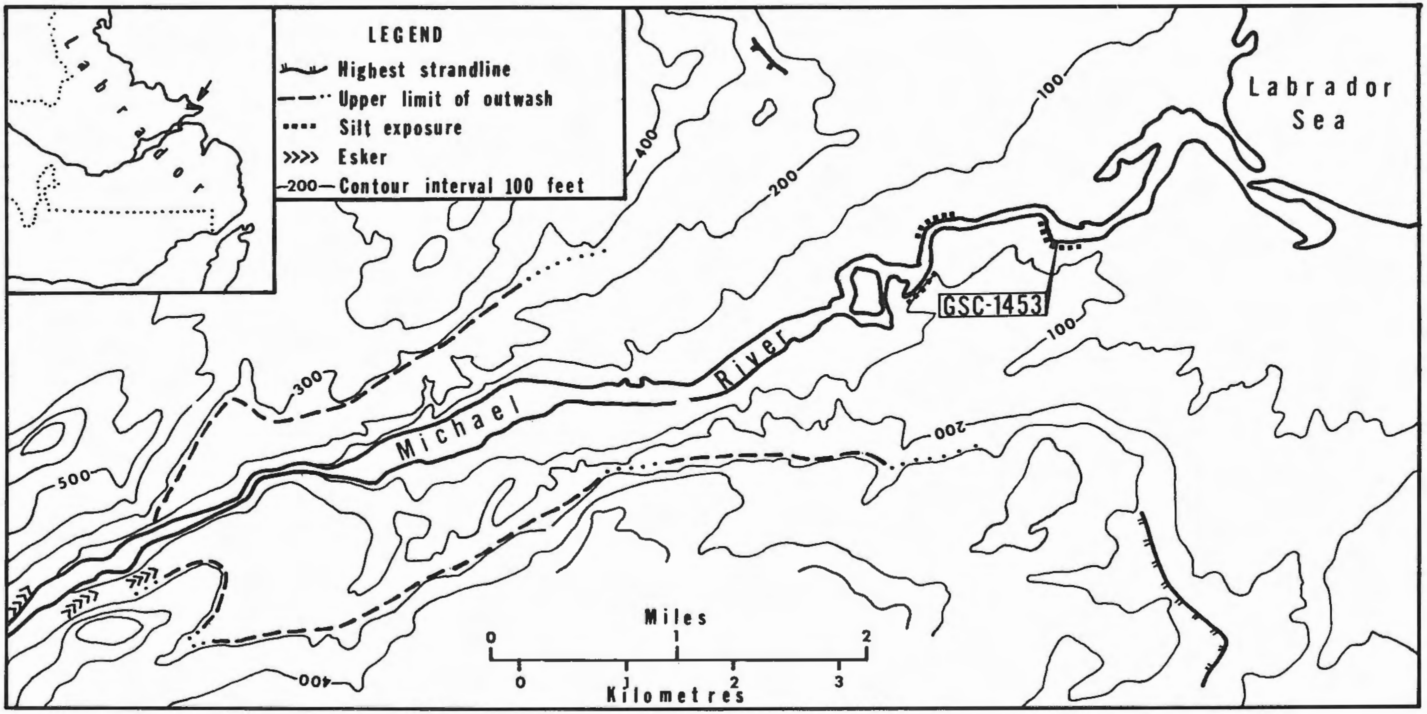

Figure 1. Lower valley of the 'Michael River', coast of Labrador.

The shells discussed here were embedded in freshly exposed silt, at or slightly below river level (2 m above m. h. w. l.); shell fragments were also present 10 m higher in the succession. Silt extended above river level for 15 m and was overlain by 10 m+ of crossbedded sand. The silt unit was traced 2 km upstream, but no further dateable material was found here, or anywhere else on the coast between Groswater Bay and Cape Harrison. The collection of marine pelecypods included *Clinocardium ciliatum* (fragments), *Macoma calcarea* (thin, some paired valves), *Mya truncata* (some whole valves), *Serripes groenlandicus* (fragments), *Yoldia arctica* (some whole valves); unidentified gastropods were also present. Only *Serripes groenlandicus* (17.7 g) were used for dating.

The collection site is in a valley with a 2-km-wide sand and silt infilling between thin till covered and boulder strewn granite uplands. The valley narrows 10 km from the sea, and depositional features become limited to a narrow floodplain and to discontinuous kettled terraces commonly bearing one or more sinuous esker ridges. At the valley constriction, the river is ca 50 m a. s. l., and the base of the esker remnants is 5 m higher in elevation. A short distance downstream, the esker merges into a braided sand outwash plain, elevation 82 ± 2 m. Remnants of this sandur are found as far as 7 km downstream. Immediately north and south of the valley mouth, the marine limit is clearly indicated at 80 to 85 m a. s. l. by a washing limit (till stripped off bedrock), or by a shingle and boulder beach ridge standing by itself or at the top of a flight of beaches.

It is probable that the upper valley was occupied by ice at the time of deposition of the 82-m sandur, and ice may have remained in the valley until sea level fell below 55 m, for the esker does not appear to have been modified by marine or fluvial processes. The absence of lower terraces indicates that the flow of meltwater was greatly reduced after the initial surface had been developed.

The maximum elevation of the top of the sediment fill overlying (and postdating) the fossiliferous silt is 25 m a. s. l.; 2 km upstream, the continuation of the silt unit is overlain by up to 50 m of sediment. Hence sea level was at least 50 m above present datum (30 m below the marine limit) when the shell bearing silts were deposited; i. e. no more than 35 per cent of postglacial uplift had been accomplished 8640 ± 230 years ago. There are no published uplift curves for the coast of Labrador to permit one to estimate, from the above data, the date of the marine incursion (which is assumed to be concurrent with the date of deglaciation). However, Matthews[7] presents a reasonably smooth uplift curve for northern Ungava, and Grant (pers. comm.) has constructed a curve for northwestern Newfoundland. Using Andrews'[8] method of predicting uplift (based on smooth uplift curves from Arctic Canada), it can be shown that for deglaciation of a site at ca. 9500 years, 33.5 per cent of postglacial uplift (which includes a eustatic sea level correction) has been accomplished by ca 8500 years ago. Løken[9] postulated transgressions prior to, at, and subsequent to 9000 ± 200 years ago in northern Labrador, but isostatic rebound in the earliest stages of postglacial uplift, with which we are concerned here, should have been great enough to overcome the effects of eustatic transgression. Thus it is suggested that, if rebound of the earth's crust in Labrador is at all similar to rebound in Arctic Canada, then 10,000 years B. P. might reasonably be the earliest date for deglaciation of the coast at Michael River.

[1] Name in local use for the river draining Lake Michael.

[2] Age determination based on a 2σ limit of error.

[3] Morrison, A.: Pollen diagrams from interior Labrador; Can. J. Bot., v. 48, no. 11, p. 1957-1975 (1970).

[4] Age determination based on a 1σ limit of error.

[5] Lowdon, J.T., Robertson, I.M., and Blake, W.Jr.: Geological Survey of Canada radiocarbon dates XI: Radiocarbon, v. 13, no. 2, p. 255-324 (1971).

[6] Fulton, R.J., Hodgson, D.A., and Minning, G.V.: Quaternary geology inventory, southern Labrador; *in* Report of Activities, Part A, April to October, 1970; Geol. Surv. Can., Paper 71-1, Pt. A, p. 160 (1971).

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[9] Løken, O.H.: The late-glacial and postglacial emergence and deglaciation of northernmost Labrador; Geog. Bull., no. 17, p. 23-56 (1962).

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29. THE RESPONSE OF TUNDRA PLANTS TO ANTHROPOGENIC HABITATS IN THE HIGH ARCTIC

Project 710042

78 F, G, H,
79 E
88 E, G, H

M. Kuc

In 1971 the Terrain Sciences Division initiated an inventory of terrain disturbance on Melville Island, N.W.T.[1] The project, headed by D.M. Barnett, included a study by the writer of changes in Arctic biota resulting from man's activity. The main object of study concerned the environmental complex of casually related phenomena: vegetation, ground disturbance, and soil erosion. Field work was aimed at: (1) gaining information about native plants which could be useful in rehabilitating disturbed environment, and (2) mapping areas disturbed by petroleum exploration.

Mapping of anthropogenic habitats and environs was carried out on Melville Island at the following localities: Drake Point, Homestead Hecla, Sherard Bay, Rea Point and Winter Harbour. Additional observations were made at Resolute, Cornwallis Island. Plant communities were mapped by ground survey and the resulting geobotanical subdivisions were plotted on black and white air photographs. The mapping was checked and improved on low level flights in a Piper Super Cub. Overland travel by means of a three-wheeled "Honda ATC 90" motorcycle greatly facilitated the mapping. Various features of plant communities were recorded by means of black and white polaroid photographs, colour slides and film. Laboratory work on vegetation maps is now in progress.

Figure 1A. Winter Harbour, disturbed ground southwest of the abandoned oil well.

Figure 1B. *Alopecurus aplinus* L. on reworked till of the Winter Harbour Moraine.

Figure 1C. *Arctagrostis latifolia* (R. Br.) Griseb. in a flooded shallow depression.

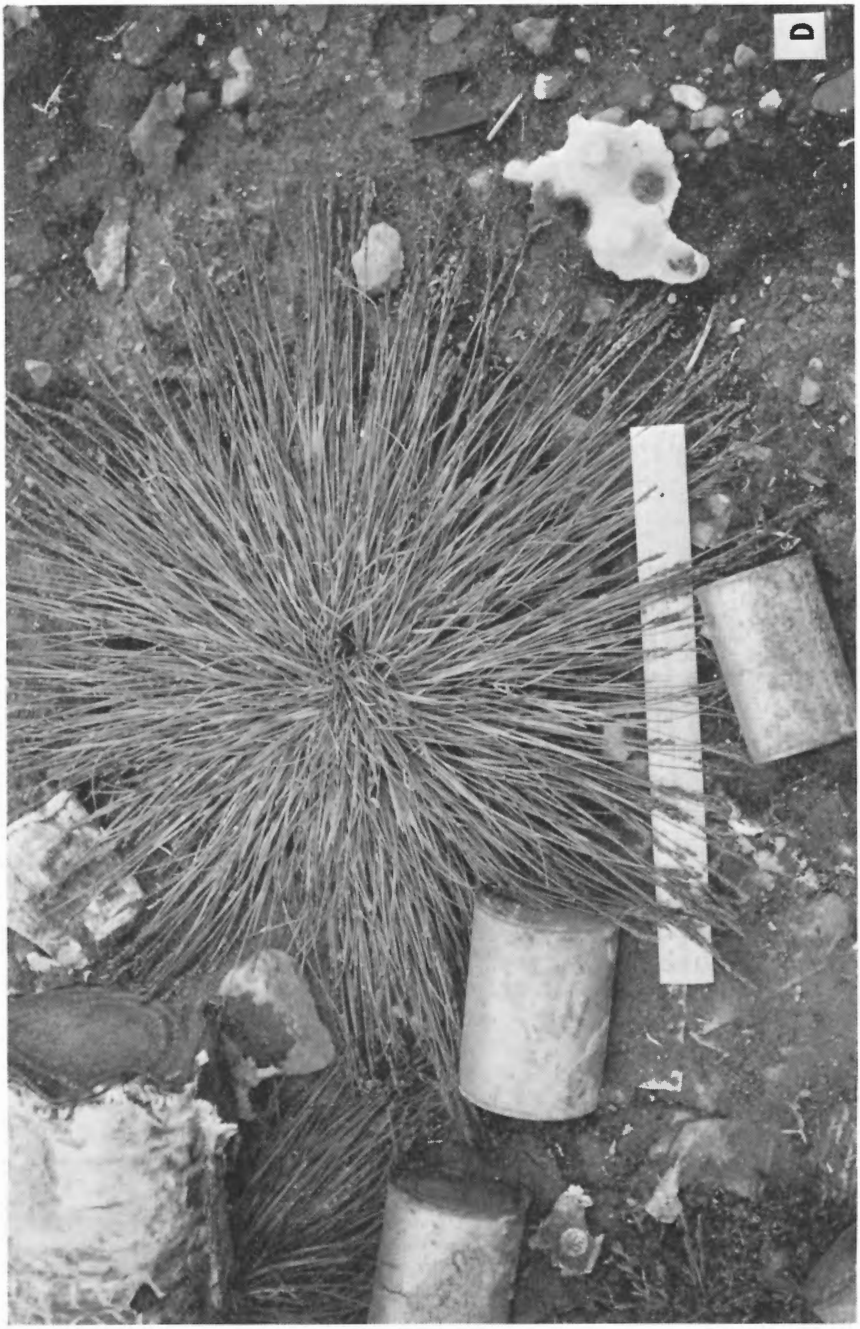

Figure 1D. Phippsia algida (Sol.) R. Br. on a garbage dump (eutrophic habitat).

TABLE 1

Bio-mass characteristics of plants invading disturbed anthropogenic habitats in the vicinity of the oil well at Winter Harbour, Melville Island.

Ecological group and species	Dry bio-mass of the best developed specimens				Root systems and seed production of plants invading anthropogenic habitats (as compared to plants in natural habitats) 1 - identical habitats; 2 - distinctly improved; 3 - much better developed	
	natural habitats		anthropogenic habitats		root systems	seed production
	total weight(g)	no. of specimens	total weight(g)	no. of specimens		
HEMEROPHILES						
A. Arctagrostis latifolia (R. Br.) Griseb.	—		—		3	3
Juncus biglumis L.	0.25	21	1	21	2	1
Phippsia algida (Sol.) R. Br.	5	1	52	1	3	3
Poa abbreviata R. Br.	12	1	82	1	3	3
Puccinellia angustata (R. Br.) Rand & Redf.	41	1	360	1	3	3
B. Alopecurus alpinus L.	0.1	4	1	4	2	1
Cerastium arcticum Lge.	—		—		2	2
Cochlearia officinalis L.	0.1	1	0.3	1	1	2
Deschampsia brevifolia R. Br.	—		—		3	1
Dupontia fisheri R. Br.	0.4	4	1	4	2	1
Draba bellii Holm.	5	1	8	1	2	2
Festuca brachyphylla Schultes	0.8	5 tufts (average)	1.2	5 tufts. (average)	2	2
Poa alpigena var. colpodea (Fr.) Schol.	—		—		3	2 (viviparous)
Oxyria digyna (L.) (Hill)	15	5	6	1	1	2
Ranunculus nivalis L.	0.6	1	1	1	2	2
Saxifraga cernua L.	—		—		3	not observed
Stellaria lactea Richards	—		—		2	1
HEMERADIAPHORES						
Papaver radicatum Rottb.	1	1	1	1	1	1
Potentilla pulchella R. Br.	2	1	3	1	1	1

In 1971 no plant invaders were found on greatly disturbed ground around the airport at Resolute or at the nearby Eskimo village. Nor were plant invaders found at numerous sites on Melville Island where extensive operation of heavy transport vehicles had taken place since 1968; i.e., Rea Point base, Drake Point gas well area and camp, Homestead Hecla drilling site, Sherard Bay airstrip and camp, and Towson Point drillsite. The oldest anthropogenic habitats, such as former Eskimo camps on Cornwallis Island and sites visited by expeditions to the Winter Harbour area (Melville Island) at various times since 1819-1820, are partly covered by vegetation which does not differ from the growth on adjacent undisturbed habitats.

The extensive, muddy, completely disturbed area at Winter Harbour (Fig. 1A), abandoned since 1961, is now invaded in many places by primitive elements of vegetation. These are represented by individual flowering plants, groups of plants and patches of sporophytes (mainly mosses). Within this area plants were recorded which occupied anthropogenic habitats, and observations of their bio-mass, root systems, and seed production were made. The results are summarized in Table 1.

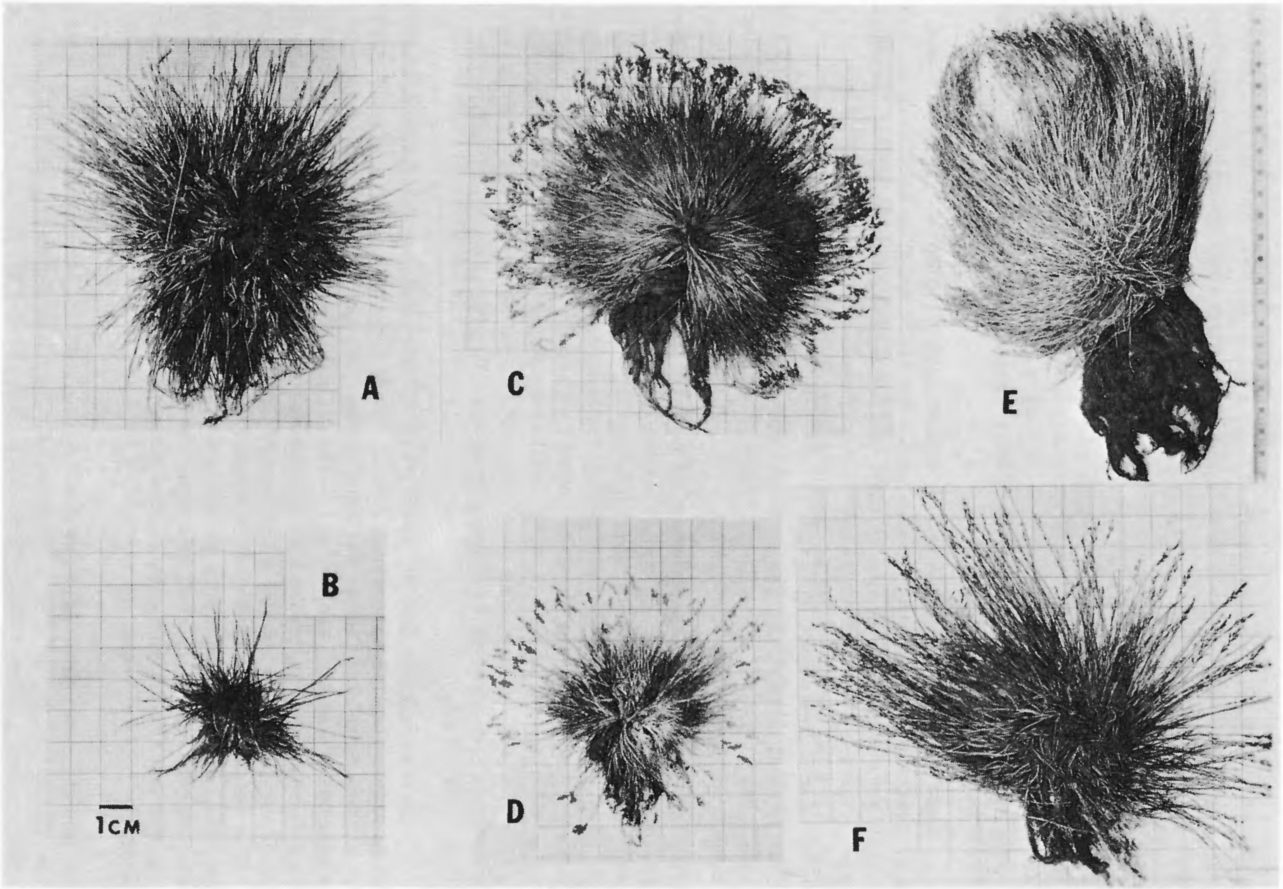

Figure 2. Comparison in general appearance between some luxuriant hemerophiles (upper row) and the best developed specimens of the same species from natural habitats (lower row): Phippsia algida (Sol.) R. Br. (A, B); Poa abbreviata R. Br. (C, D); Puccinellia angustata (R. Br.) Rand & Redf. (E, F).

A classification for the interaction between plants and disturbed ground was applied, using Linkola's[2] system as adapted for a survey of tundra environments. It consists of three major categories:

1. HEMEROPHILES; plants which occupy anthropogenic habitats relatively rapidly and exhibit better-developed life forms than on natural habitats:

   A. Luxuriant vascular plants of extensive bio-mass, strongly developed root systems, and greatly increased seed production (see Table 1). Mosses are represented only by acrocarpous and geophytic species such as Bryum sp., Desmatodon heimii (Hedw.) Lazar., Encalypta procera Bruch, Pohlia sp., and many unidentified juvenile forms. All the moss species listed are characterized by taller stems, denser mats, and considerable annual increases of bio-mass. Cup-like terrestrial fungi (Pezizales) are abundant.

   B. Specimens growing better in anthropogenic places. Their forms are distinctly larger than those of plants from natural habitats, but are much smaller in all respects than the luxuriant hemerophiles. Vascular plants occur as listed in Table 1, and mosses are represented by Polytrichum alpinum Hedw. and Timmia autriaca Hedw.

2. HEMERADIAPHORES; the general appearance of these plants is nearly identical to that of specimens occurring in natural habitats. Vascular plants are listed in Table 1.

3. HEMEROPHOBES; components of nearby plant communities which so far have not reoccupied their former habitats or else appear on them only as small, depauperate individuals: Saxifraga caespitosa L., S. nivalis L., S. oppositifolia L., Salix arctica Pall. Other common constituents of adjacent tundra areas, such as Arenaria rubella, Dryas integrifolia, and Luzula nivalis, still are completely absent in anthropogenic places. Among the mosses, which can be included in this group, are small specimens of Campylium sp. cf. polygamum. No lichens were observed.

The hemerophiles and hereadiaphores listed all seem to be suitable for cultivation under High Arctic conditions. Their expanding root systems impede erosion of the ground on flat or inclined areas and protect soft muddy ground against bombardment by rain drops. Their inflorescences abound in well developed seeds. These biological properties characterize plants which could be utilized for the rehabiliation of bare ground resulting from man's activity.

The vascular plants listed in Table 1, especially grasses, are consumed by muskoxen, caribou and birds (e.g., ptarmigan). Analysis of their droppings and stomach contents indicated that grasses - spores, leaves, inflorescences, seeds (in summer food) and straw (in winter food) - are one of the main components of their year-round diet.

[1] Barnett, D.M., and Kuc, M.: Terrain performance, Melville Island, District of Franklin; in Report of Activities, April to October, 1971; Geol. Surv. Can., Paper 72-1, Pt. A, p. 137-139 (1972).

[2] Linkola, K.: Studien über den Einfluss der Kultur auf die Flora in Gegenden nördlich vom Ladogasee. I. Allgemeiner Teil; Acta Soc. pro Fauna et Flora Fennica, v. 45, no. 1 (1916).

30. TERRAIN SENSITIVITY EVALUATION AND MAPPING, MACKENZIE VALLEY TRANSPORTATION CORRIDOR

Project 710077

96, 106

P. J. Kurfurst

During the winter 1971/72 some six weeks were spent in the field with the remaining time spent in the office.

The office work was mainly devoted to evaluation and classification of the 1971 summer field season results and preparation of the winter drilling program.

Two weeks were spent in Thompson, Manitoba in December 1971 supervising the seismic drilling operation in co-operation with the Exploration Geophysics Division of the Geological Survey. The objective of this joint program was to verify the practical application of the accoustic-wave propagation technique in the field.

Seven holes were drilled during the one week drilling operation around Fort Norman, District of Mackenzie in March 1972 to check and verify the map-units' boundaries on the 96 C sheet of the surficial geology map of the Mackenzie Valley Transportation Corridor.

Some 3 weeks in March 1972 were spent drilling in the Norman Wells area. More than 150 feet of core was recovered from ten different drill sites. These sites were located along the Canol Road, on the old and new seismic lines, and on the winter roads covering every map-unit of the area. The recovered core was stored in the freezers for further laboratory determination of the accoustic-wave propagation and for the thermo-properties tests.

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31. POLLEN STRATIGRAPHY OF A SEDIMENT CORE FROM ALPEN SIDING LAKE, ALBERTA

83 I

Project 690064

Sigrid Lichti-Federovich

The pollen stratigraphy of a ^{14}C-dated core of lake sediment from Lofty Lake in east-central Alberta at 54° 44'N and 112° 29'W has been described by Lichti-Federovich[1]. Another sediment core was recovered in approximately 1 m of water, by J. Terasmae and R. J. Mott from nearby Alpen Siding Lake, 54° 27'N and 113° 00'W, and its pollen stratigraphy (Fig. 1) has been determined in detail. In addition, marly gyttja from the base of the core (385 to 380 cm below the sediment-water interface) was submitted for ^{14}C age determination, yielding a date of 10,700 ± 170 years B.P. (GSC-1093)[2, 3].

The pollen stratigraphy is very similar to the Lofty Lake section, yielding the following pollen zones:

The lowest zone, from 390 to 380 cm depth, correlates closely with the Populus-Salix-Shepherdia-Artemisia assemblage of Zone L 1 at Lofty Lake. It is dominated by poplar (25-30%), with significant frequencies of willow, grass, sagebrush and sedge. As was pointed out in Lichti-Federovich[1], Lofty Lake is the first reported occurrence for N. America of a pollen assemblage type dominated by pollen of Populus, and this further record suggests the possibility of a regionally endemic vegetation type.

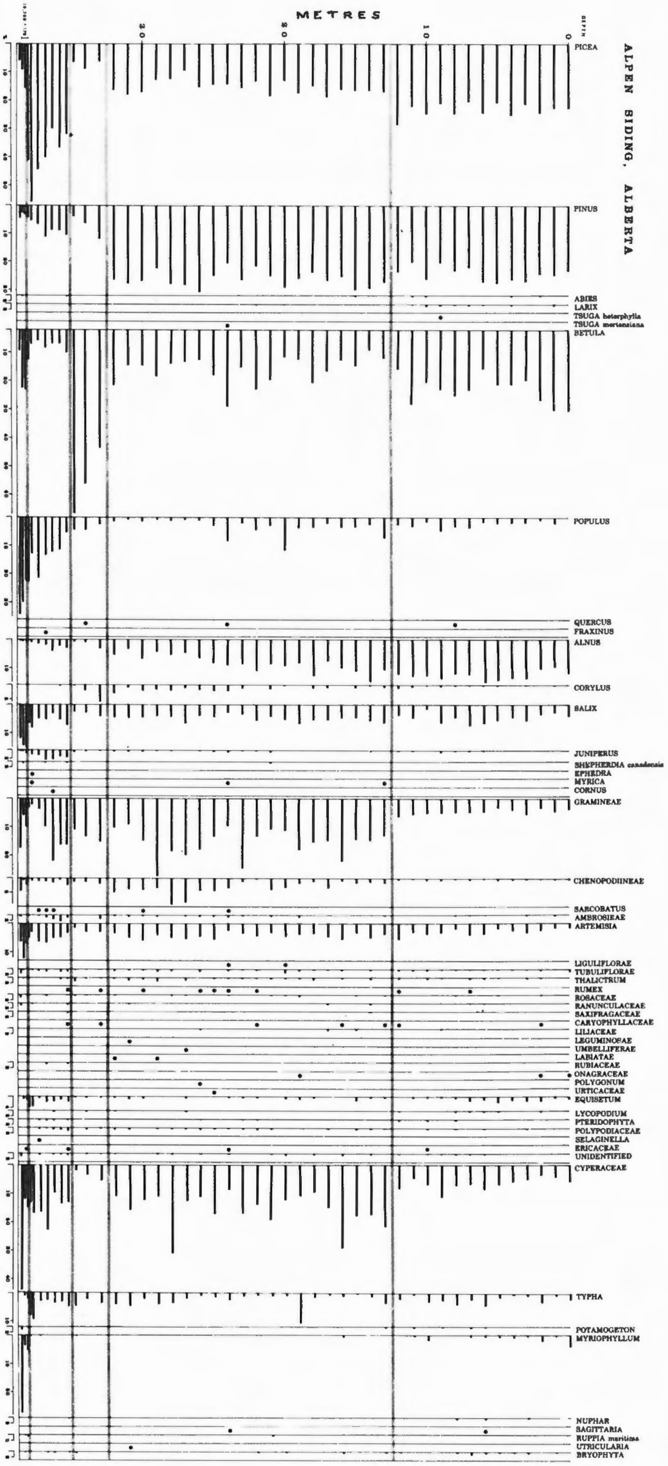

Figure 1. Pollen diagram from Alpen Siding Lake, Alberta.

From the 378 to 353 cm level the pollen stratigraphy closely resembles Zone L 2 from Lofty Lake – the dominant pollen type is Picea, with substantial frequencies of poplar, grass, sagebrush and sedge. Unlike the corresponding zone from Lofty Lake this zone shows low frequencies of Shepherdia canadensis, but the consistent occurrence of juniper matches the L 2 stratigraphy.

At the 348 cm level there is a sharp decline in spruce and a marked increase in the relative amount of birch. The assemblage, similar in most respects to Zone L 3, also includes the beginning of the Corylus curve. This zone ends at the 325 cm level, and the zone boundary displays the same changes in relative frequencies of the main pollen types as does the transition from Zone L 3 to L 4 at Lofty Lake. There are increases in the frequencies of pine, spruce and alder, whereas the birch curve declines sharply.

The uppermost stratigraphic unit, as at Lofty Lake, is dominated by the three main arboreal pollen types – spruce, pine and birch. At the same level the herb pollen types decrease sharply.

The reconstruction of the vegetation and paleoecological inferences to be drawn from this section are similar to those reported for the Lofty Lake site. A pioneer poplar-shrub community is followed, successively, by a spruce forest (the pollen assemblage being similar to those recorded widely from equivalent Late Pleistocene sediments in the Western Interior of the continent), a birch forest community with poplar and hazel, a birch-alder-herb community, and finally a mixed spruce-birch-pine forest which has persisted to the present day.

[1] Lichti-Federovich, S.: The pollen stratigraphy of a dated section of Late Pleistocene lake sediment from central Alberta; Can. J. Earth Sci., v. 7, p. 938-945 (1970).

[2] St-Onge, D. A.: Quaternary geology and geomorphology of tne Tawatina area, Alberta (83 I); in Report of Activities, Part A, April to October, 1969; Geol. Surv. Can., Paper 70-1, Pt. A, p. 183-184 (1970).

[3] Lowdon, J. A., Robertson, I. M., and Blake, W., Jr.: Geological Survey of Canada radiocarbon dates XI; Geol. Surv. Can., Paper 71-7, p. 290 (1971).

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95 H

32. DRILLING IN SURFICIAL DEPOSITS NEAR FORT SIMPSON, NORTHWEST TERRITORIES

Project 710047

Gretchen V. Minning

A three-week winter drilling program was carried out in connection with surficial geological mapping and geophysical surface resistivity and seismic surveys done in the Fort Simpson map-area (95H) during the summer of 1971.[1]

The primary objectives of drilling were:

1. to provide stratigraphic information that would show if surface resistivity and seismic surveys can be used to delineate permafrost bodies;

2. to obtain subsurface information on surficial deposits which were mapped largely by air photo interpretation and helicopter traverses.

Secondary objectives included development of techniques for sampling and coring of frozen unconsolidated materials, and installation of multithermistors for A. L. Judge, Earth Physics Branch.

Kenting-Big Indian drilling company provided drilling and electric logging services. A truck mounted Mayhew 1000 rotary drill rig was used for drilling and coring and a water truck was on hand for wet drilling. A panel truck with probe, cable, and photographic equipment was used for electric logging in deeper holes.

Seventy-two holes, ranging in depth from 15 to 130 feet, were drilled along two existing seismic lines and in roadside ditches where surface resistivity and seismic surveys had been run during the summer. Chip samples of bedrock and frozen and unfrozen unconsolidated materials were collected. Electric logs were run in 34 holes.

Drilling showed that resistivity surveys had predicted permafrost zones in some areas. Elsewhere, variations along resistivity curves indicated other geological phenomena such as changes in bedrock. Seismic velocity variations were fairly accurate in determining thickness and types of frozen and unfrozen unconsolidated materials.

Drilling added subsurface details on unconsolidated materials mapped over the area during the summer.[2] This study provided information on thickness and compositional variations of till, peat, deltaic, and aeolian deposits and showed that unconsolidated materials over most of the area are frozen only seasonally to a shallow depth. Thick permafrost occurred only in poorly drained areas, i.e., those mapped as peat-organic with till or lake plain with fen and peat.

A variety of core barrels was required to core frozen materials. Experimentation was necessary with each sediment cored.

Multithermistors installed in three drill holes have been successful in providing information for the Earth Physics Branch study of thermal regime in unconsolidated materials and bedrock.

[1] Rutter, N.W., and Minning, Gretchen V.: Surficial geology and land classification Mackenzie Valley transportation corridor; in Report of Activities, Part A, April to October, 1971; Geol. Surv. Can., Paper 72-1, Pt. A, p. 178 (1972).

[2] Rutter, N.W., Minning, Gretchen V., and Netterville, J.A.: Surficial geology and geomorphology of Fort Simpson 95H; Geol. Surv. Can., open file map (1972).

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33. PALYNOLOGY OF THE "KANSAN" CARBONACEOUS CLAY UNIT NEAR MEDICINE HAT, ALBERTA

Project 650027

72E

R. J. Mott and A. MacS. Stalker

Stalker[1] and Stalker and Churcher[2] have described the general surficial section near Medicine Hat, Alberta. The surficial deposits are exposed in the various bluffs along the South Saskatchewan River from about 7 miles west of Medicine Hat to approximately 8 miles north of the city. At most of the exposures 100 to 200 feet of glacial and interglacial deposits, chiefly till, sand, and silt, overlie 50 or so feet of "preglacial" gravel, sand, silt, and clay. These latter deposits are characterized by the absence of stones brought from the Precambrian Shield by ice. The carbonaceous unit from which the samples were taken for pollen analysis lies towards the base of the section within the "preglacial" deposits, directly above the basal gravel and generally not far above river level. It is a dark, greyish blue clay with minor sand and, though only 1 to 5 feet thick, it is extensive and has been found in exposures along a 6-mile stretch of the river. Wherever observed, it contains many sticks and much peaty muck.

Both the carbonaceous unit and the underlying basal gravel, with which it has a gradational contact, contain numerous bones that indicate these units are of mid-Kansan age according to the vertebrate paleontology chronology. Taxa recognized from them to date include: Castor canadensis (beaver); Paramylodon harlani (Harlan's ground sloth); Nothrotherium sp. (ground sloth); Canis cf. etruscus (wolf); Mammuthus imperator haroldcooki (Cook's mammoth); Equus scotti (Scott's horse); Equus calobatus (stilt-legged ass); Camelops minidokae (Irvingtonian camel); Tanupolama? hollomani (Holloman's long-legged llama); Antilocapridae indet, (prongbuck). The fauna does not give much information about climate, which could well have been similar to the present one, with general prairie conditions and trees growing along the river. Interestingly, the carbonaceous unit with its abundant pieces of wood is the only one near Medicine Hat in which beaver has been found.

Samples for palynological study and wood identification were taken at four different bluffs and the location and results are shown in Table 1. The samples from Island and Mitchell Bluffs contained enough pollen to warrant percentage calculations based on total pollen present equalling one hundred while the other two contain too little and numbers only are listed. All assemblages included some pre-Pleistocene palynomorphs, especially Cretaceous spores, but these are not shown in the results. Pollen preservation is variable; good in the Island and Mitchell Bluff samples, poor in the Scout's Falls and very poor in the Bain Bluff samples.

Pinus (pine) and Picea (spruce) pollen are not abundant enough to indicate the presence of these trees in the immediate area but rather transport from a short distance. Their occurrence in the Cypress Hills area would account for their pollen abundance. Numerous herb pollen types, especially Artemisia, Chenopodiineae and Gramineae (grasses), denote prairie conditions[3].

Wood is abundant in the clay unit at all sites. It is usually strongly compressed and poorly preserved making identification difficult. However, the following identifications have been made: at Island Bluff, Salix (willow), the road skirts bedrock that has had multiple gravel-veneered benches (glacial Lake Champagne beaches) developed on it: the beach gravels are generally very thin. At Champagne a large interlobate kame(?) lies transverse to the main valley trend. In Section CD the highway is still crossing glaciolacustrine deposits. However, immediately north of the highway and at the mouth of the Aishihik Valley, gravels are present: lateral moraines and kame terraces can also be traced along the southern flank of the Takhini Valley here. The gravelly and morainic deposits were presumably deposited when a glacier, retreating to the southwest, still occupied the centre of the valley in this section.

Section DE is underlain by till, frequently capped by glaciolacustrine clays and silts of late glacial and Neoglacial age. Irregular pockets of gravels (beaches or glaciofluvial in origin) are scattered throughout the area. In Section EF the highway runs along late glacial and postglacial gravel terraces and alluvial fans. Section FG is similar to DE in that the road crosses mainly till, but patches of glaciofluvial gravel, and possibly beach gravels near Kloo Lake, are common. In Section GH the highway follows along late glacial and postglacial gravel deposits.

In Section HI Kluane Lake forces the highway against the base of glacially oversteepened cliffs, except where the Slims River delta (locality 4) is crossed. Landslides have been a common phenomenon in postglacial time and still are a major threat to man's activities in this area.

In Section IJ the highway crosses glaciofluvial gravel terraces and postglacial alluvial fans. Stream channels are constantly shifting on the fans and pose a problem to road maintenance. Till underlies some of the topographic highs in the valley bottom. Section JK is underlain mainly by fluted till: however the highway does cross large gravel alluvial fans (localities 5 and 6) and follows along the gravel terraces of the Kluane River. Organic accumulations are becoming more abundant in this section and probably indicate perched water-tables due to the shallow occurrence of permafrost. Section KL is underlain by till with spotty patches of gravel: local exposures suggest that the upper till in this area is relatively thin. Thermokarst lakes have developed in fine-textured deposits within Section KL and indicate ice lensing in these materials. The Donjek River has formed a broad braided gravel floodplain.

In Section LM the highway follows along the northern edge of the Shakwak Valley where ice-rich fine-textured alluvium and pond deposits in the centre of the valley impinge on slopes underlain by bouldery colluvium and till. Only near locality 7 are coarse-textured fluvial deposits encountered. Thick volcanic ash, thermokarst lakes and, in the eastern part, sand dunes, are common features along this section: the southwestern half of the valley appears to be mainly underlain by till.

In Section MN the highway crosses the postglacial White River gravel terraces. In Section NO the highway follows along a large meltwater channel whose bottom is filled with ice-rich fine-grained sediments: however glaciofluvial gravels are common along the upper edge of this channel. The highway crosses a large postglacial gravel fan at locality 8.

In Section OP the highway crosses disintegration moraines, composed of sandy till and dirty gravels, and glaciofluvial terraces and channels. The disintegration moraines in the southern part of the section have much more relief than those near Beaver Creek where most depressions are filled with silt and organic deposits. At localities 9 and 10 the highway crosses meltwater channels where thick ice-rich organic deposits have accumulated.

Acer negundo (Manitoba maple) and *Populus* (aspen or cottonwood); at Mitchell Bluff, *Fraxinus* (ash), *Populus* and *Picea* (spruce); at Scout's Falls Bluff, *Salix*. *Populus* and *Salix* occur along the South Saskatchewan River near Medicine Hat at present and *Picea*, *Fraxinus* and *Acer negundo* would only require slight extensions beyond their present ranges to account for their presence in the area. No change in the paleoecological interpretation based on pollen is needed to accommodate the wood taxa.

Therefore, open grassland conditions on upland sites with trees and shrubs occurring along the rivers and on other suitable sites and possibly forests of pine and spruce in the Cypress Hills is envisaged for the area. The climate at the time was probably similar to the present or slightly cooler and more moist.

[1] Stalker, A. MacS.: Quaternary stratigraphy in southern Alberta; Report II: Sections near Medicine Hat; Geol. Surv. Can., Paper 69-26, 28 p. (1969).

[2] Stalker, A. MacS. and Churcher, C.S.: Deposits near Medicine Hat, Alberta; Geol. Surv. Can., Display chart with marginal notes (1970).

[3] Mott, R.J.: Palynological studies in central Saskatchewan. Contemporary pollen spectra from surface samples; Geol. Surv. Can., Paper 69-32, 13 p. (1969).

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34. SURFICIAL DEPOSITS: ALASKA HIGHWAY, WHITEHORSE TO ALASKA-YUKON BOUNDARY

Project 650131

115 A, F, G, J, K

V.N. Rampton

During the summer of 1971 the surficial geology of the area adjacent to the Alaska Highway between Whitehorse and the Alaskan Boundary was reviewed as the first leg of the International Geological Congress Field Trip A-11 follows this route. The route of Alaska Highway follows the Takhini and Shakwak Valleys and Wellesley Basin (Fig. 1), physiographic units which form a natural transportation corridor through this part of the Yukon. A synthesis of the surficial geology has been prepared to aid in any general evaluation of future possible development (pipelines, etc.) along the corridor. In order to facilitate the discussion, the route has been divided into sections.

In Section AB (Fig. 1) the highway crosses a complex of bedrock and surficial materials. The bedrock everywhere is fairly near the surface. Gravel glaciofluvial fans occur at the mouths of meltwater channels, and a thin proglacial cap of sandy outwash frequently covers glaciolacustrine silty clays at lower elevations. The central part of the valley is underlain by glaciolacustrine materials, often capped by sand dunes.

In Section BC the highway crosses glaciolacustrine silts and clays in which shallow thermokarst depressions of up to 15 feet have formed: tilted and drowned trees in some depressions indicate that some recent melting has occurred. Between localities 1 and 2, and in the vicinity of locality 3 (Fig. 1)

Figure 1. Index map showing sections (capital letters) and localities (numbers) discussed in text.
"." indicates possible source of surface gravel. Figure 1b is the northern extension of 1a.

TABLE 1

Site location and pollen content

Site (1). Island Bluff. (50° 08'50"N, 110° 39'20"W) (NW 1/4 sec. 5, tp. 14, rge. 5, W. 4th mer.)

Site (2). Mitchell Bluff. (50° 07'40"N, 110° 37'30"W) (NE 1/4 sec. 33, tp. 13, rge. 5, W. 4th mer.)

Site (3). Bain Bluff. (50° 08'00"N, 110° 34'40"W) (NE 1/4 sec. 35, tp. 13, rge. 5, W. 4th mer.)

Site (4). Scout's Falls Bluff. (50° 05'20"N, 110° 40'30"W) (NW 1/4 sec. 18, tp. 13, rge. 5, W. 4th mer.)

	Per cent		Numbers counted	
	Site (1)	Site (2)	Site (3)	Site (4)
Trees				
Picea	-	7.5	10	1
Pinus	27.6	18.1	2	13
Shrubs				
Alnus	0.5	0.8	-	-
Salix	0.5	3.0	-	-
Elaeagnus	-	0.8	-	-
Herbs				
Gramineae	5.4	0.8	2	7
Tubuliflorae	2.2	2.3	-	1
Liguliflorae	-	-	1	-
Ambrosieae	2.2	-	-	-
Artemisia	28.1	45.9	-	1
Chenopodiineae	23.8	6.0	-	19
Sarcobatus	1.1	-	-	-
Rosaceae	-	0.8	-	-
Ranunculaceae type	-	0.8	-	-
Saxifragaceae type	-	-	1	-
Umbelliferae type	-	5.3	-	-
Lycopodium	0.5	-	-	-
Pteridophyta	1.1	0.8	-	-
Osmunda	-	0.8	-	-
Polypodiaceae	1.6	0.8	2	-
Cyperaceae	-	-	1	-
Sphagnum	0.5	-	2	-
Unidentified	5.4	6.0	2	-

Section PQ consists of a flat gravelly outwash plain: the northern end, however, is covered by ice-rich organic deposits containing many thermokarst lakes.

In Section QR the highway follows along bedrock slopes having a veneer of colluvium and, in the southern part, glacial deposits. The broad valley-bottoms in this area are filled with icy silts and peats, often in excess of 30 feet thick.

Bostock, H.S.: Kluane Lake, Yukon Territory, its drainage and allied problems; Geol. Surv. Can., Paper 69-28, 19 p. (1969).

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Day, J.H.: Reconnaissance soil survey of the Takhini and Dezadeash Valleys in the Yukon Territory; Ottawa, Queen's Printer, 78 p. (1962).

Denton, G.H. and Minze Stuiver: Late Pleistocene glacial stratigraphy and chronology, northeastern St. Elias Mountains, Yukon Territory, Canada; Geol. Soc. Am. Bull., v. 78, p. 485-510 (1967).

Kindle, E.D.: Dezadeash map-area, Yukon Territory; Geol. Surv. Can., Mem. 286, 68 p. (1953).

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Rampton, V.N.: Late Pleistocene glaciations of the Snag-Klutlan area, Yukon Territory; Arctic, v. 24, p. 277-300 (1971).

Wheeler, J.O.: Whitehorse map-area, Yukon Territory; Geol. Surv. Can., Mem. 312, 156 p. (1961).

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35. OVERBURDEN DRILLING AND SAMPLING AND GEOLOGICAL DATA COMPILATION TIMMINS - VAL D'OR AREA

Project 710100

R.G. Skinner

A drilling and data-compilation program was initiated in November under provisions of the Winter Special Employment Plan. The objective included testing and applying drilling techniques on both detailed and regional scales and compiling assessment data filed in Provincial Resident Geologists' offices. The following is a breakdown of the project.

1. As of March 31, 1972, some 250 holes totalling over 22,000 feet have been drilled using both dual-wall and percussion drills.

2. Frequently, when drilling compact lodgement till, chunks of till are returned and can be caught on a screen. These have been processed and analyzed and compared with results from the rest of the sample that passed through the screen as a slurry. The < 250 mesh fraction and the heavy mineral fraction, (<60 and >250 mesh; S. G. >3.3; minus magnetic grains) are being analyzed routinely for six elements. Other fractions will be analyzed in a few cases; otherwise, they will be stored for future reference.

3. Detailed drilling has been carried out in the vicinity of Kamiskotia-Jameland to test and compare both sampling and analytical techniques. Cobra and Pionjar percussion drills and dual-wall rotary drills were compared at the same sites.

4. Several sample-sequences through varves, sand and gravel, till and bedrock have been analyzed for mercury as well as base metals.

5. Thin sections made from drill chips of bedrock are proving very useful in areas of little or no bedrock exposure.

6. Some 70 data compilation maps for townships and quarter townships will be completed by the end of June, 1972.

7. Geochemical results in the form of raw trace element data will be placed on Open File as they become available for each phase. Evaluation of the results will be carried out over the next several months and will be published when completed.

GENERAL

General

36. A METHOD FOR THE DETERMINATION OF GEOGRAPHIC POSITION

D.K. Norris

With the increasing number of geological observations being made in Canada, it is more important than ever that their geographic position be specified in a manner that they can be relocated accurately and that duplicate observations can be recognized. In regions of simple stratigraphy and structure, exact positions may not be critical because of lateral continuity of fossil or mineral horizons. In geologically complex regions, however, they are of utmost importance because of rapid and commonly unpredictable changes in rock types or in their structural configurations.

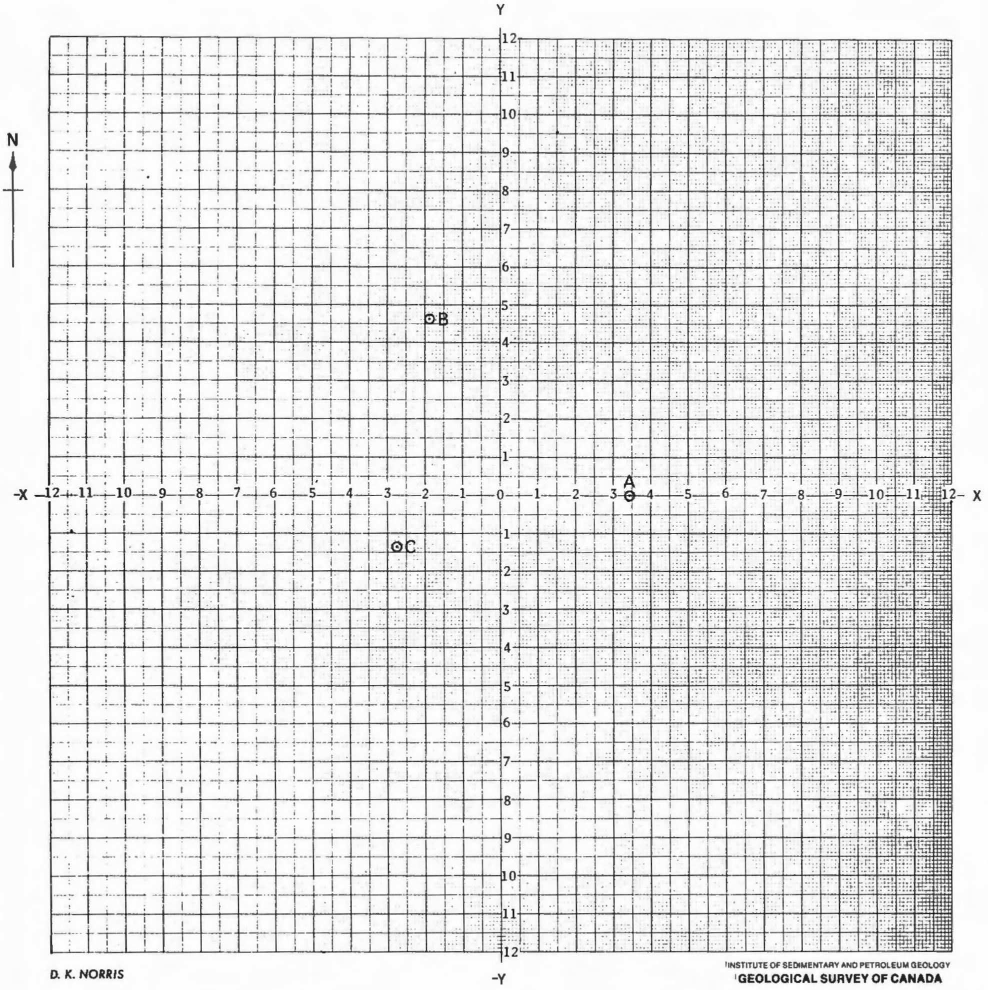

Figure 1. Replica of millimetre grid. Numbers are distances in centimetres from origin.

Locations of observations are presently expressed in two ways: 1. by latitude and longitude, and 2. by Universal Transverse Mercator Grid co-ordinates. Both methods, if applied with care by the geologist, can allow the reader to relocate a point at best within a few hundred metres. Unfortunately, its position is lost relative to a prominent tree, boulder or other minor feature on the ground.

A more exact method suggested to the reader some years ago by W.J. Hennessey and rapidly coming into use by Survey geologists[1] is that of expressing geographic position by means of a co-ordinate system on vertical (or oblique) air photographs. With this system in mind, the writer devised a transparent, millimetre grid overlay (Fig. 1) which can be placed on top of the photograph and the exact position read from the photo to the nearest fifth of a millimetre and estimated to the nearest tenth. If this method is applied carefully, any point so designated on the photo can be recognized without ambiguity on the ground within a few metres.

This grid utilizes the conventional X-Y co-ordinate system and is placed with its X- and Y-axes coinciding with or oriented by the fiducial marks on the photo. On National Air Photo Library (NAPL) photographs, these marks may be centred along the edges of the picture or positioned at its corners, and may or may not include a centre mark. Because most (vertical) photos are taken so that their sides are parallel to the north and east directions respectively, the grid is oriented by convention so that its positive Y-direction coincides with north on vertical photos and with the up direction on obliques. The positive X-directions is east. When correctly positioned, the intersection of the X- and Y-axes will coincide with the centre of the photograph and a given point must fall in one of the four quadrants or on the co-ordinate axes. Thus a point falling in the northeast quadrant will have both its X- and Y- co-ordinates positive; in the northwest quadrant a negative X- and a positive Y-co-ordinate; in the southwest quadrant both negative X- and Y-co-ordinates; and in the southeast quadrant a positive X- and a negative Y-co-ordinate. The three points included in Figure 1 are assumed to have been visible through the overlay and will illustrate how co-ordinates are read:

Air Photo		X cm	Y cm
A12664-79	Point A	+3.42	0.00
	B	-1.89	+4.63
	C	-2.75	-1.36

There is only one air photo with a given NAPL number, and this number in conjunction with a given set of photo co-ordinates identifies a unique position on the ground. The reader can readily plot the point on his own photograph and see it in relation to its immediate geological and physiographic setting. Once recorded in this manner, moreover, the exact location can be resurrected even if an original photograph is lost or destroyed. Useful supplementary information includes the appropriate map-area designated according to the National Topographic System (e.g. 95N).

In addition to the location of single positions, the method can be used to define exact ground stations at the beginning, end, and at any number of intermediate points of a traverse, stratigraphic section, or of the surface trace of any geological or cultural feature. It can, of course, be applied to horizontal photographs as well in order to convey accurate information about the exact location of position on structures, in stratigraphic sequences, and so forth, in publication.

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[1] Bamber, E.W.: Description of Carboniferous and Permian stratigraphic sections in northern Yukon Territory; Geol. Surv. Can., Paper, in preparation (1972).

ADDENDUM

(May 24, 1972)

37. WINTER WORKS LAKE BOTTOM SEDIMENT SAMPLING PROGRAM FOR THE TIMMINS - VAL D'OR REGION

Project 710099

32D542A

E.H.W. Hornbrook

A lake bottom sediment and till sampling project was performed under the Special Employment Plan of the Federal Winter Works Program. Field work was carried out in the Timmins–Val d'Or region of northern Ontario and northwestern Quebec from December, 1971 to early April, 1972. The project was planned and supervised by E.H.W. Hornbrook and conducted, under contract, by C.F. Gleeson and Associates Ltd., Ottawa. The total project provided 95 man-months of employment.

Objectives of the project were to provide winter employment and to evaluate the following aspects of geochemical exploration in the clay belt environment of the region.

1) The effectiveness of regional lake bottom sediment sampling in the clay belt to detect meaningful metal dispersion halos.
2) The effectiveness of bottom till sampling by overburden drilling to detect anomalous dispersion halos in till.
3) The comparison of the element content in lake bottom sediment and till at the same sample site to determine their relative suitability as a sample medium. This includes inspection of the geochemical dispersion halos of the two materials to determine their relationship to each other and to known mineral occurrences.
4) The suitability of various selected mesh sizes of lake bottom sediment and till prepared for analysis to enhance the contrast of anomalous metal values.

In the regional lake bottom sediment sampling program: 1327 samples were collected from 6580 square miles in the Val d'Or–Noranda, Quebec area and 1400 samples were collected from 6952 square miles in the Kirkland Lake-Timmins, Ontario area.

The overburden drilling program was carried out on lake ice as follows: Pelletier Lake - 30 sample sites; Macamic Lake - 77 sample sites; Abitibi Lake - 54 sample sites and Night Hawk Lake - 60 sample sites. Calculated footage required to collect the bottom till samples would be 12,124 feet; however, actual footage, including drilling to determine bedrock depth prior to sampling and occassional multiple attempts to collect a sample, was 30,370 feet. These samples were processed to obtain a heavy mineral separate and a -230 mesh sample. All samples have been analyzed for Cu, Pb, Zn, Mo, Ni, Mn, As and Ag and these results, together with appropriate field data, have undergone key punching, compiling, listing, digitizing and simpler statistical treatment.

Limited access and poor ground mobility combined with adverse winter weather and snow conditions made it impossible to obtain the desired uniform distribution of sample sites throughout the region. Access to sample sites was by vehicles on ploughed secondary roads, Snowmobile travel, and snowshoe traversing where necessary. There was no fixed or rotary wing air support. Thus, there are some areas with little or no samples within the region and other areas that appear, relatively, to be oversampled.

Contamination of sample sites by mining and other industrial activity and the resulting high metal concentrations creates a problem in the evaluation and interpretation of the data. At many sample sites, contamination was observed and the type recorded on field cards. However, contamination is not necessarily recognized in winter. Thus, there are possibly many high element concentrations listed for sample sites where contamination was present but not recorded. At all sites samples were collected through holes chipped, cut or augered through ice.

Careful examination of the data showed several areas of interest aside from the obvious ones closely associated with the mining camps of Kirkland Lake, Noranda, etc.

Variable sample density and the contamination mentioned above stress the necessity for a careful consideration of the data. Follow-up work, with resampling as a prerequisite, is recommended before serious exploration in any interesting area is undertaken.

AUTHOR INDEX