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DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA

PAPER 74-1 Part A

REPORT OF ACTIVITIES
Part A. April to October 1973

1974

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BOOK REVIEW

The Geological Survey of Canada is again out with the best $5 bargain in the industry, its 400-page "Report of Activities — Part A — April to October 1973". The current issue contains 139 well-illustrated papers.

The soft-bound book contains two papers on Appalachian geology, two on coal research, 11 on Cordilleran geology, eight on geochemistry, 21 on geophysics, 18 on marine geoscience, one on mineral deposits, four on petrology, 12 on Precambrian geology, 35 on Quaternary geology, 21 on structural geology, stratigraphy and paleontology, and three general papers dealing with miscellaneous investigations and general information.

The papers range from brief half-page reports to more ambitious seven-page project descriptions such as "Physical and chemical properties of unconsolidated sediments in permanently frozen terrain, District of Keewatin" by the Terrain Sciences Division, and "Investigations on the Bear-Slave geochemical operation" by the Resource Geophysics and Geochemistry Division.

Other items include reports on geothermal studies in the Rockies, seismic refraction in Sverdrup Basin, experimental high-resolution aeromagnetic surveys, geophysical study of Mackenzie Valley permafrost; surficial and bedrock geology of the Scotian Shelf and Grand Banks, marine surveys, surficial geology and geomorphology of Melville and Ellesmere Islands, geological, geophysical and hydrographic studies in Lancaster Sound and Maxwell Bay, Quaternary sedimentology and geomorphology studies on Banks Island, southeast Melville, western Byam Martin Island, Somerset Island, and near-shore studies along east Melville Island, surficial geology of Mackenzie Valley transportation corridor, structure and stratigraphy of Ringnes and nearby, smaller Arctic Islands.

The book is available from the Geological Survey of Canada, 601 Booth St., Ottawa and Information Canada bookshops.

Among other recent publications is a catalog — Paper 73-11 — detailing all publications by GSC on the geology of the Arctic Islands.

OILWEEK March 4/74

They visited us here in Calgary! Wyn Irish has pointed this out to OILWEEK people.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

GSC PAPER 74-1 Part A

REPORT OF ACTIVITIES
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ADDENDUM

The following reports were received after October 25, the date on which final preparation for publication of this report was begun.

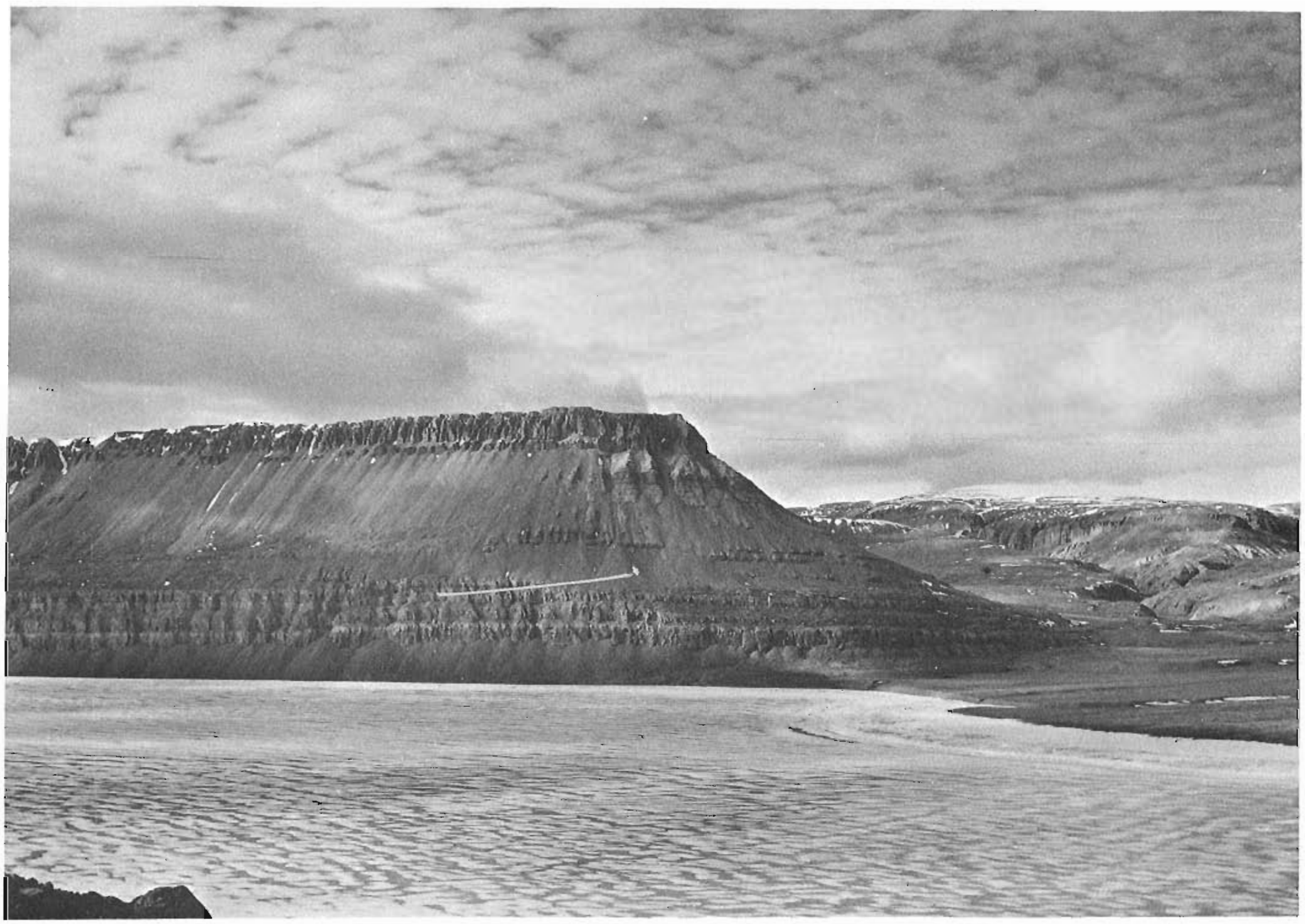
INTRODUCTION

The Geological Survey of Canada, a branch of the Department of Energy, Mines and Resources, was founded in 1842 and is the principal geological agency of the federal government. Its primary role is to provide an overview of all facets of Canadian geology as a basis for national policy, for government and industrial planning and for public information.

Studies carried out by the Geological Survey of Canada are directed to an understanding of the natural resource base, to the identification of resources, to an appraisal of the natural resource endowment and to an examination of the environment of the resources. The resources are mainly non-renewable and range from extractive mineral and fossil fuel resources to the non-extractive materials and terrain conditions that determine land utilization and conservation.

The "Report of Activities" series has grown in the past decade from short preliminary accounts of field work to the present semi-annual collection of interim reports covering a wide range of topics. With this report the Geological Survey introduces a new format, a format that will be used for all regular publications. The larger page size will allow the use of more detailed line drawings and will also result in better fossil plates and photographic illustrations.

Many of the conclusions presented in this publication are based on a preliminary assessment of the data collected and are subject to confirmation or revision in the light of more detailed office and laboratory studies. To expedite publication, illustrations are reproduced directly from material submitted by the authors and the text has been given a minimum of editorial attention. The 139 papers are arranged in broad scientific categories but these in no way reflect the administrative organization of the branch. Divisional affiliations follow each author's name and for branch use, project numbers are included. An index to geographic locations (arranged by province, territory or district) and an authors' index follows the text. Papers for inclusion in the main body of the report were received until October 29, 1973 and material for inclusion in the Addendum was accepted until November 19, 1973.



Late spring, northern Baffin Island.
116329

1.

CLEAVAGE AND OROGENY

W. H. Poole

Regional and Economic Geology Division

Axial plane cleavage within a thick conformable sequence of folded strata of sub-greenschist or lowest greenschist facies is generally assumed to have formed in one "instant" of geological time in response to stresses associated with an orogeny. Thus we presume for example that 10 to 20 thousand feet of strata deposited during 60 to 70 million years of the early Paleozoic quietly awaited the stresses associated with an orogeny 10 to 50 million years later before developing the folds and axial plane cleavage we see today. We assume that the cleavage and folds developed after the sediments had become "dry" through loss of water, lithified and relatively strong.

A recent find in Newfoundland, first brought to my attention during excursion 63, stop 3-8, of the International Geological Congress in 1972, challenges this classical view. The lesson is that cleavage in some 'unmetamorphosed' sedimentary rocks must have formed in the sediments before they became 'rocks'. The beds are early Silurian in age, and the orogeny to which the cleavage and folding are attributed is the Acadian, a Devonian event about 25 to 50 million years later.

The Botwood Formation near Bishop Falls on the Trans Canada Highway and along the first few miles of the Bay d'Espoir road consists of interbedded red and green micaceous sandstone, siltstone and shale with ripple-marks, crossbeds and worm burrows well exposed in fresh vertical highway cuts. They were deposited in a shallow water terrestrial environment during early Silurian (Llandovery-Wenlock), and represent the youngest pre-Acadian strata in most of Newfoundland. All the Botwood beds are deformed; beds dip steeply, cleavage in the shale and siltstone is generally a simple fracture cleavage, nearly vertical and undeformed by any superposed younger cleavage, and folds are tight and of large amplitude.

Some of the red shale and siltstone beds contain parallel to subparallel dykes of sandstone oriented parallel to the fracture cleavage and at marked angles to the bedding. In these particular exposures, the beds are upright, dip 55 to 75 degrees west and are cut by a vertical to near-vertical fracture cleavage. Lines of intersection of beds and cleavage parallel the axis of one observed fold, trend northeast and are horizontal or gently plunging. The dykes are several inches long, less than 2 inches wide and commonly taper at each end (Fig. 1). The tapered ends of some dykes parallel the cleavage in the shale (slaty mudstone) and the central parts of the dykes dip less steeply in a curving flattened "S" or "Z" shape as if the dykes are following a refracted cleavage. Some of the dykes in three dimensions are discoid. A few dykes in one bed are thinner

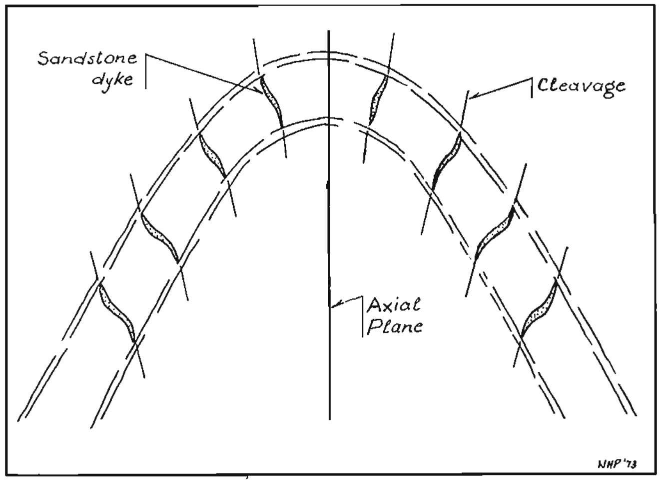


Figure 1. Sketch to illustrate relationship of sandstone dykes to axial plane fracture cleavage and 8-inch bed of red slaty shale and siltstone. Botwood Formation, early Silurian. Near Bishop Falls, Newfoundland.

and as much as 3 feet long. Many can be seen to originate in thin sandstone beds but many others appear to be "blind" and "floating" in the shale. One bed in the Trans Canada Highway exposure has dykes spaced approximately every two feet along its vertical exposure. Not all beds contain dykes; within several hundred feet of strata, only a few beds within a 20- to 40-foot section display dykes.

The dykes clearly parallel the fracture cleavage. They maintained their conformity with the cleavage on each side of the axial plane of a tight rounded fold.

It must be presumed that the sandstone of the dykes had high pore water and low strength at the time of intrusion, i. e. not long after deposition but before loss of pore water through normal compaction had reached the point where the sands had become too viscous to flow. The cleavage planes along which the dykes were intruded must have formed at this time. Since they trend northeast parallel to the regional Acadian structures, the orientation of the cleavage must have been controlled by regional orogenic stresses whatever their ultimate origin may have been.

One must conclude then that the cleavage formed soon after deposition during which the sedimentary basin or trough was being deepened and at the same time squeezed, and that the cleavage-formation "front" propagated upward in the sedimentary sequence being thickened by continued deposition. Either the cleavage is pre-Acadian, or if Acadian by definition, then that orogenic episode began well before final deposition of the sediments involved.

The curved 'refracted' shape of the dykes suggests that the cleavage and dykes when first formed were vertical and northeast-trending and the beds horizontal or within a few degrees or so. As deformation proceeded and folds formed and tightened, cleavage and dykes became rotated by intrastratal creep (slip) which varied with lithology across any one bed to produce the curved shape.

The sandstone dykes, cleavage and folds thus appear to provide a genetic link between sedimentation-diagenesis-compaction in a deepening basin, the initiation of deformationl structures, and finally the folds and refracted cleavage of the orogen at the end of the cycle. Surely we ought not to focus our attention on the "orogeny", a collective word for a group of processes (deformation, metamorphism, plutonism, uplift and erosion) which seemingly occurred in a belt of rocks during a relatively short interval of time after deposition had ceased. Better that we consider each process itself and attempt to determine its age, style, extent, origin, etc. Only then will we come to understand the character and independence and interdependence of these orogenic processes.

Project 720093

Harold Williams[1] and W.R. Smyth[2]
Regional and Economic Geology Division

The Hare Bay Allochthon to the south of Hare Bay was mapped during the 1973 field season and all of the geological boundaries, earlier mapped in more detail by Smyth (1973), were re-investigated. The extent of the Northwest Arm Formation (Cooper, 1937) was outlined in Hare Bay and critical parts of the allochthon north of Hare Bay were re-examined. All of the Hare Bay Allochthon and the Carboniferous rocks at Conche are now mapped suitable for publication at 1 inch to 2 miles.

The Hare Bay Allochthon south of Hare Bay consists of 5 distinct structural slices (Fig. 1). From structurally lowest to structurally highest these are: Northwest Arm Slice, Maiden Point Slice, Croque Head Slice, St. Julien Island Slice, and the White Hills Slice. The Northwest Arm, Maiden Point, and White Hills Slices are a continuation of the same structural slices from the north side of Hare Bay (Williams, et al., 1973). The Croque Head and St. Julien Island Slices (Smyth, 1973) occur only south of Hare Bay.

Between Canada Bay and Hare Bay the allochthon has a similar structural style to that north of Hare Bay whereby individual slices are separated by mélange that has a black and green shale matrix with blocks of sedimentary rocks like those of the Northwest Arm Formation and blocks of sandstone and volcanic rock like those of the Maiden Point Formation. The Northwest Arm Slice lies directly upon the autochthonous Goose Tickle Formation (Cooper, 1937); the Maiden Point Slice also lies directly upon the autochthonous Goose Tickle Formation at most localities; the Croque Head Slice lies upon the Maiden Point Slice; and the St. Julien Island Slice lies upon the Croque Head Slice. The White Hills Slice south of Hare Bay overlies the Maiden Point and Croque Head Slices but it is not in contact with the St. Julien Island Slice. It is interpreted as the structurally highest slice because of the relationships north of Hare Bay where the White Hills Slice structurally overlies all other slices (Williams, et al., 1973)

South of Canada Bay the Maiden Point Slice forms the highest structural slice in an imbricate zone of west-directed thrusts that involve both autochthonous carbonate rocks and their Precambrian crystalline basement. All the rocks possess a cleavage, which is interpreted to relate to thrusting and Ordovician klippe emplacement. This cleavage is folded about northeast-trending axes probably as the result of post-emplacement Acadian deformation. At Sugarloaf Cove the Maiden Point Slice is underlain by semi-pelitic, pelitic, and calcsilicate schists that are interpreted as the metamorphosed equivalents of the autochthonous Goose Tickle Formation (Smyth, 1973). These are in turn structurally underlain by cleaved Grenvillian gneisses which have undergone retrograde metamorphism and which are thrust above sandstones of the Bradore Formation. This zone of intense structural telescoping that involves even the Precambrian crystalline basement is unique to this area south of Canada Bay among the transported rocks of Western Newfoundland.

A broad area of autochthonous carbonates overlain by the Goose Tickle Formation is exposed in an anticlinal structure southwest of Whites Arm. This area is an erosional window, the Whites Arm Window (Smyth, 1973), beneath the Maiden Point Slice.

All of the transported rocks south of Hare Bay are involved in post-emplacement upright folds about northeast-trending axes. Mélange zones that separate slices and that are a direct result of klippe emplacement display a folded cleavage in most places. The first cleavage is interpreted to relate to slice emplacement and it is folded about steep northeast-trending post-emplacement folds. Early recumbent folds that either pre-date or relate to the emplacement of the Maiden Point Slice are displayed locally and their presence is inferred in many other places where bedding faces downward along the steep cleavage related to post-emplacement deformation. South of Hare Bay the early recumbent folds face northwestward (Smyth, 1973). Second phase folds that fold a schistosity in greenschists and amphibolites of the White Hills Slice are themselves folded about northeast-trending post-emplacement fold axes at Fishot Island. Pre-emplacement metamorphism there increases toward the east, and by analogy with the relationships north of Hare Bay (Williams and Smyth, 1973) implies the existence of a steep ophiolite sheet nearby and offshore toward the east. A pronounced aeromagnetic anomaly offshore supports this implication (Geol. Surv. Can., 1970).

The Carboniferous rocks at Conche are mainly brown and red sandstones, shales, conglomerates, and minor limestones that are openly folded about north-trending axes. The conglomerates are coarsest and thickest along the western margin of the outcrop belt where they are faulted against the Maiden Point Formation. Most clasts consist of Maiden Point greywacke. Plant remains are abundant throughout the finer clastic beds and indicate an age of upper Horton or late Tournaisian (Baird, 1966).

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CARBONIFEROUS COVER ROCKS

MISSISSIPPIAN

14	CAPE ROUGE FORMATION: sandstone, siltstone, shale
13	CROUSE HARBOUR FORMATION: conglomerate

ALLOCHTHONOUS ROCKS

WHITE HILLS SLICE

LOWER ORDOVICIAN OR OLDER

12	Greenschist and amphibolite

ST. JULIEN ISLAND SLICE

LOWER ORDOVICIAN OR OLDER

11	Sandy limestone, polymictic conglomerate, minor greenschist, greywacke, and gabbro

CROQUE HEAD SLICE

LOWER CAMBRIAN OR OLDER

10	MAIDEN POINT FORMATION: greywacke and minor slate

MAIDEN POINT SLICE

LOWER CAMBRIAN OR OLDER

9	MAIDEN POINT FORMATION: greywacke, pebble conglomerate, green, grey, and black slate; minor mafic volcanic rocks and limestone conglomerate

NORTHWEST ARM SLICE

LOWER ORDOVICIAN

8	NORTHWEST ARM FORMATION; black and green shale with boulders and blocks of buff-weathering limy siltstone, sandstone, and limestone

AUTOCHTHONOUS ROCKS

MIDDLE ORDOVICIAN

7	GOOSE TICKLE FORMATION: grey to dark grey greywacke siltstone and shale with local conglomerate and limestone; 7a, semi-pelitic, pelitic and calc-silicate schist, local marble
6	TABLE HEAD FORMATION: grey to dark grey limestone, minor shale

LOWER CAMBRIAN

5	DEVILS COVE FORMATION: purple to white limestone and shale
4'	BRADORE FORMATION: arkosic sandstone and pebble conglomerate

LOWER CAMBRIAN OR OLDER

3	LIGHTHOUSE COVE FORMATION: mafic green volcanic rocks and dykes
2	BATEAU FORMATION: plutonic boulder conglomerate

PRECAMBRIAN (HELIKIAN OR OLDER)

1	LONG RANGE COMPLEX: mainly granitic gneisses, granite, amphibolite and meta-gabbro

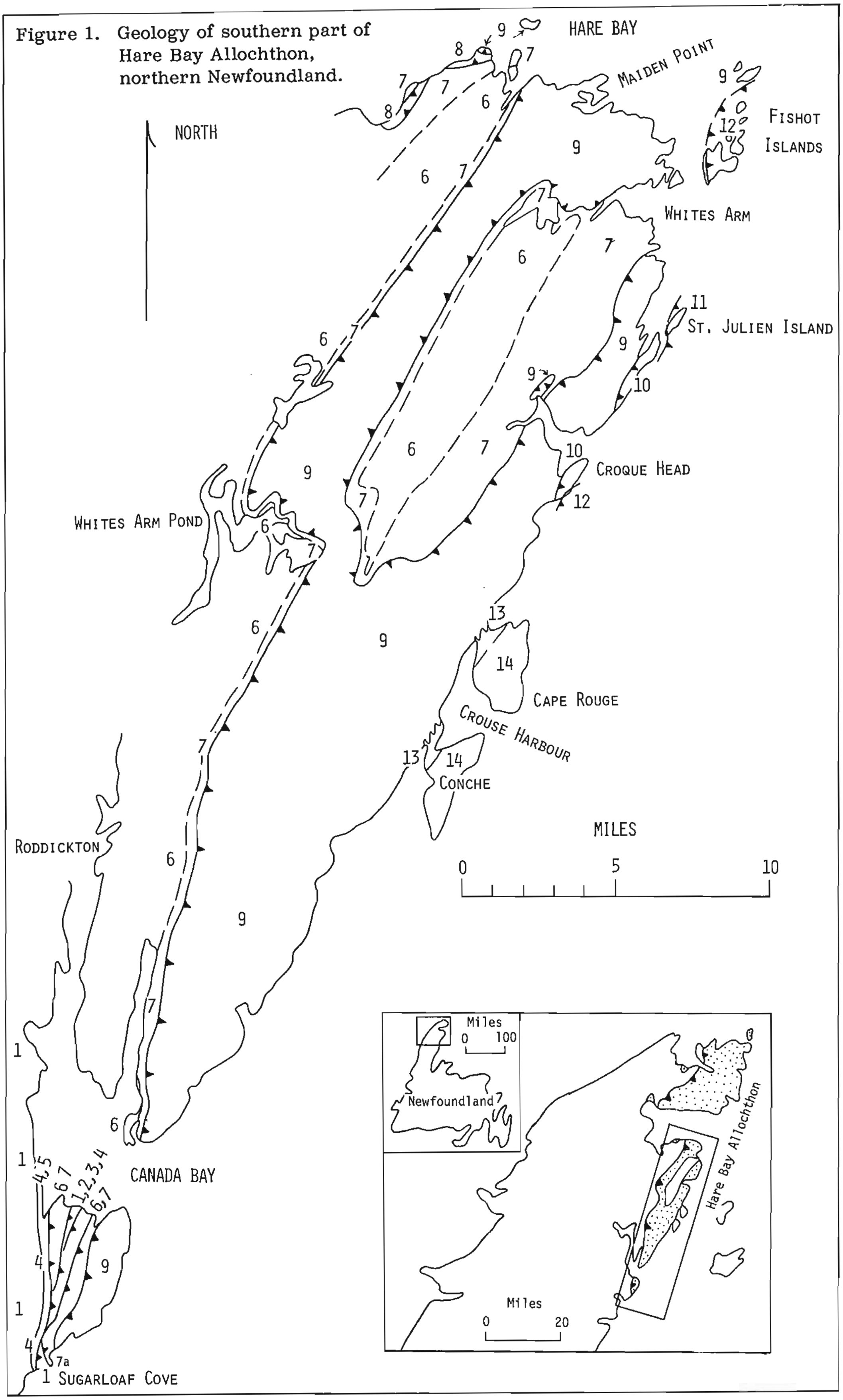

Figure 1. Geology of southern part of Hare Bay Allochthon, northern Newfoundland.

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3. A PROPOS DE QUELQUES TONSTEINS OBSERVES DANS LES VEINES DE CHARBON DE LA FORMATION DE KOOTENAY EN COLOMBIE-BRITANNIQUE ET EN ALBERTA (CANADA)

Project No. 710089

E. Mériaux[1]
Université des Sciences et Techniques de Lille, France

En 1971, une étude préliminaire de niveaux argileux inclus dans la "veine de charbon n° 10 (Balmer) a Sparwood Ridge dans le bassin de Fernie (Colombie-Britannique)" (E. Mériaux, 1972) avait permis de montrer l'existence de véritables tonsteins décrits sous l'appellation de Graupen-tonstein.

En 1972 de nouveaux prélèvements dans la formation de Kootenay ont été effectués en Colombie-Britannique et en Alberta en particulier à:

MORRISSEY RIDGE
- veine 2

FORDING RIVER
- Eagle Mountain: vein 4
- région de Greenhills: veins B et D

KAISER RESOURCES
- Sparwood Ridge: veine D
- Natal Ridge: veines A, "Lower" C et "Upper" C

KINE CREEK
- veines 10A, 10B, 9 et 8

FLATHEAD RIVER
- veines 4A, 4B et 5

GRASSY MOUNTAIN
- 2 veines du niveau d'Adanac
- 1 veine du niveau de Mutz

ADANAC
- veine située immédiatement sous le "Cadomin conglomerate"

BYRON CREEK
- veine 2

TENT MOUNTAIN
- veine 1?, 2? et 3?

BEAVER MINES
- 2 veines

De nombreux niveaux argileux indurés inclus dans le charbon ont été trouvés. Les études microscopiques ont révélé que là encore la plupart de ces niveaux sont des Graupen-tonstein (type V de A. Bouroz, 1969). Le type V est constitué d'éléments anguleux ou plus souvent arrondis altérés et présentant des micro-vermiculations kaoliniques. La présence de kaolinite bien cristallisée a été confirmée par des études aux rayons X. Le quartz est toujours présent mais en très petite quantité. L'analyse élémentaire a montré des traces de Y, Sr. Rb, Zn, Ca, des teneurs faibles en Fe, K et Ca; les éléments dominants étant Al et Si.

Les études qualitatives ont en outre révélé l'existence d'un tonstein de type IV (A. Bouroz, 1969) caractérisé par la présence de très nombreuses biotites. Ce niveau particulier a été trouvé dans la veine n° 8 à LINE CREEK. Il s'agit probablement là d'un niveau repère intéressant. Les résultats sont donc encourageants et une étude détaillée est actuellement en cours.

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[1] L'Institut de géologie sédimentaire et pétrolière

4. JOINT FEDERAL-PROVINCIAL COAL EVALUATION PROGRAM IN SASKATCHEWAN

Project 720051

S.H. Whitaker[1], P.L. Broughton[2], J.A. Irvine,
Institute of Sedimentary and Petroleum Geology, Calgary

During 1973 field work was completed for the Saskatchewan Coal Evaluation Program. Detailed drilling on roughly one-mile spacings was carried out in areas in which promising coal occurrences were observed during the regional drilling program of 1972. Figure 1 shows the location of the areas of drilling concentration. In a few localities detailed drilling indicated no significant reserves were present and drilling was discontinued at a two- or three-mile spacing. Two drilling techniques were used during the program. Two normal rotary drilling rigs completed 345 testholes for a total of 85,759 feet and a reverse circulation rotary drilling rig completed 154 testholes for a total of 23,352 feet. The drilling pattern was designed so that reverse circulation testholes were distributed as evenly as possible throughout the areas in which lignite seams were best developed.

Samples of the lignite taken over one-foot intervals through the seam were collected from all of the testholes and shipped to Fuels Research Centre, Mines Branch, Department of Energy, Mines and Resources, for chemical analysis. Preliminary results indicate that reverse circulation rig coal cuttings provide the most consistent analytical results and consequently analyses of them will be used as standard in the evaluation of analytic results from the remainder of the testholes.

Preliminary results of the drilling program are summarized for the following regions: Estevan, Big Beaver-Gladmar-Bengough, Fife Lake-Coronach- Willow Bunch, Wood Mountain-Killdeer, and Shaunavon. Figure 2 shows typical testhole logs from several regions. References to economic mineability made below are based on the assumption that current surface mining practices in the Estevan coalfield would be used in the other regions.

The Estevan region is the only area in which lignite is being mined at the present time in Saskatchewan. The best-developed seam in the region is the Estevan seam which is mined at all three operating mines. In addition to the Estevan seam there is one major seam (Boundary) lower in the section and several seams (Souris River, Roche Percée, Short Creek) higher in the section (Fig. 2). Boundary seam appears to be parted throughout the region and the upper seams are all relatively thin (3 feet to 7 feet). Although these seams appear to be continuous over large areas, faulting of the seams is known to occur in the operating mines.

The Big Beaver-Gladmar-Bengough region contains many isolated areas in which lignite seams occur at mineable depths. Correlation of the seams in this region is not yet clear, but one or more would appear to be correlative with seams in the Fife Lake-Coronach-Willow Bunch region.

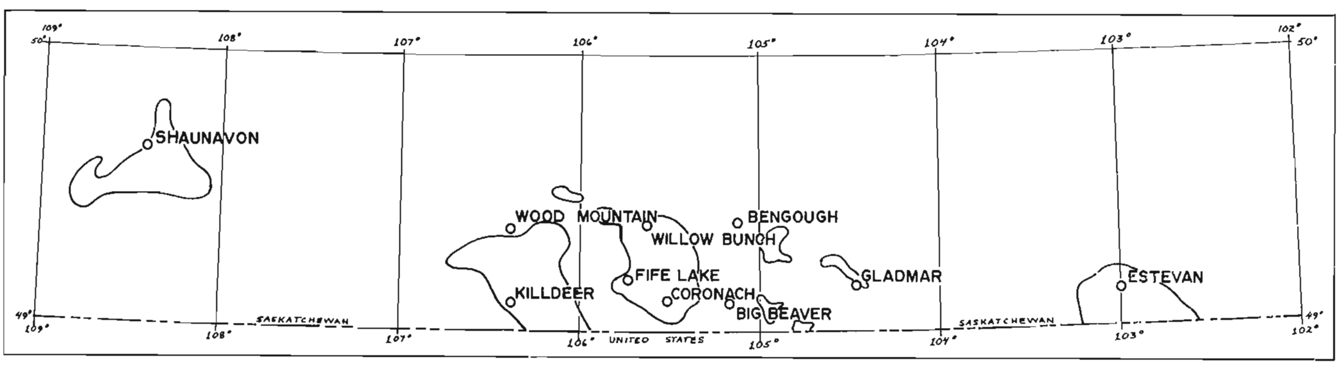

Figure 1. Location of areas of detailed drilling.

Geophysical logs were run in each testhole with a full suite comprising the following logs: spontaneous potential, single point resistance, natural gamma, gamma-gamma density, and caliper. A detailed log of natural gamma and gamma-gamma density was run over thick lignite seams. Spontaneous potential and single-point resistance logs were not run in the reverse circulation rotary testholes.

At least two major lignite seams of large areal extent occur within the Fife Lake-Coronach-Willow Bunch region. One is the Willow Bunch seam and the other is not known to be a correlative of any seams named in the literature (Fig. 2). Both seams are mineable over extensive areas of their occurrence.

Several seams occur within the Wood Mountain-Killdeer region; most are relatively thin (less than 10 feet) and high topographic relief makes mining uneconomic over much of their area of occurrence at the present time. However, at least one or two of the seams in the southern portion of the region are mineable over a significant area.

[1]Saskatchewan Research Council, Saskatoon

[2]Saskatchewan Department of Mineral Resources, Regina

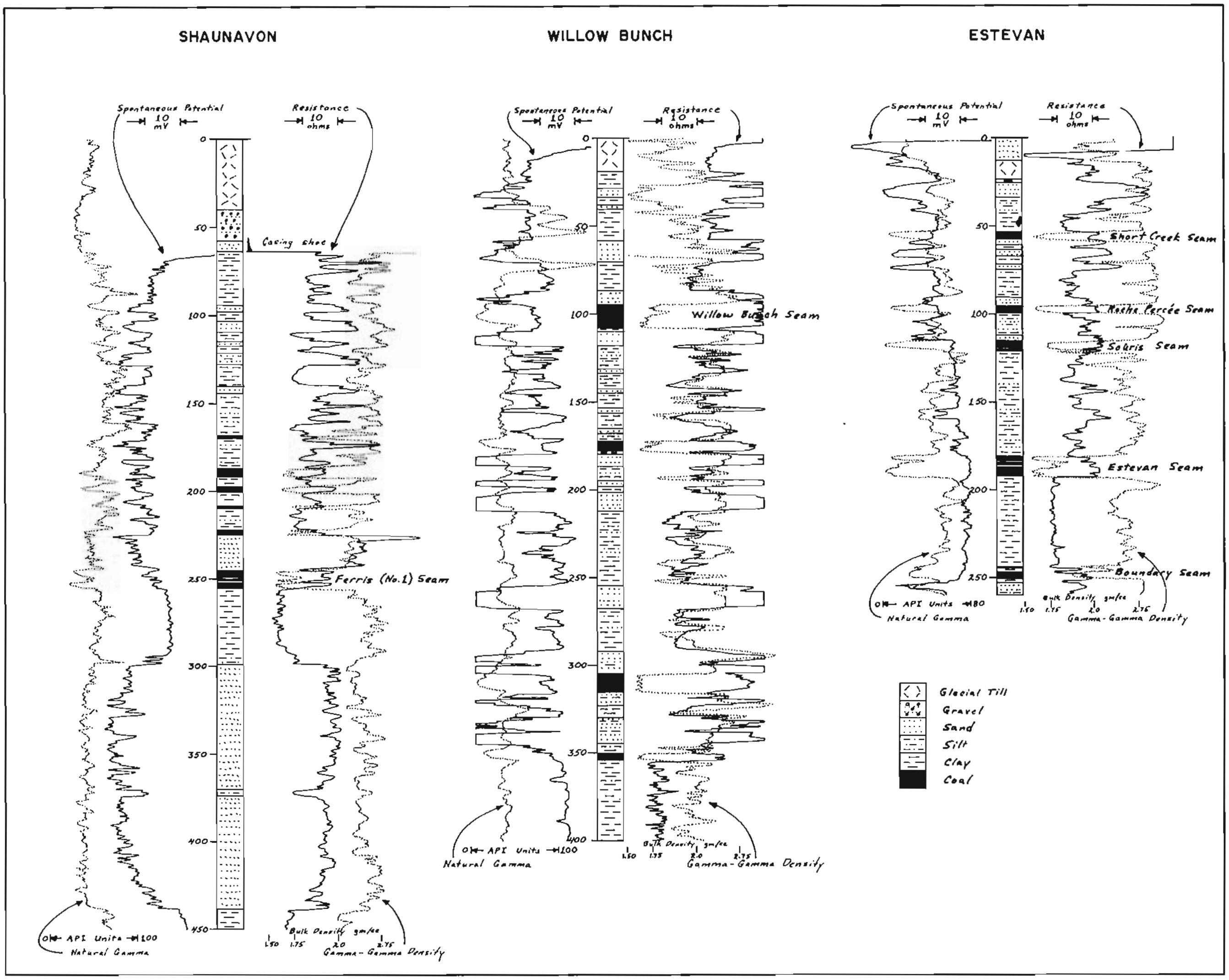

Figure 2. Representative geophysical logs.

The Ferris or No. 1 seam is the only major seam that occurs in the Shaunavon region (Fig. 2). It is mineable over an extensive area but appears to be variable in thickness and in places splits into two separate seams. Several thin seams occur higher in the section.

Correlations between regions have not yet been established with any certainty due to physical separation of regions and in most cases absence of correlative sediments in intervening areas.

5. OPERATION SAINT ELIAS

Project 730035

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

During the 1973 field season about six weeks were spent on a wide-ranging helicopter-supported reconnaissance of the Saint Elias Mountains. The objective was to gain familiarity with the region in preparation for a large, comprehensive geological program planned for 1974. The reconnaissance was primarily concerned with an assessment of geological and logistical problems to provide a basis for planning future work.

Beginning in 1974, the basic geological mapping will be augmented by stratigraphic, sedimentological, volcanological, and structural studies by various specialists. Particular attention will be devoted to investigations of aspects of the geology that are apparently related to the known mineral occurrences of the region. The program will include a study of the surficial deposits and geomorphological history.

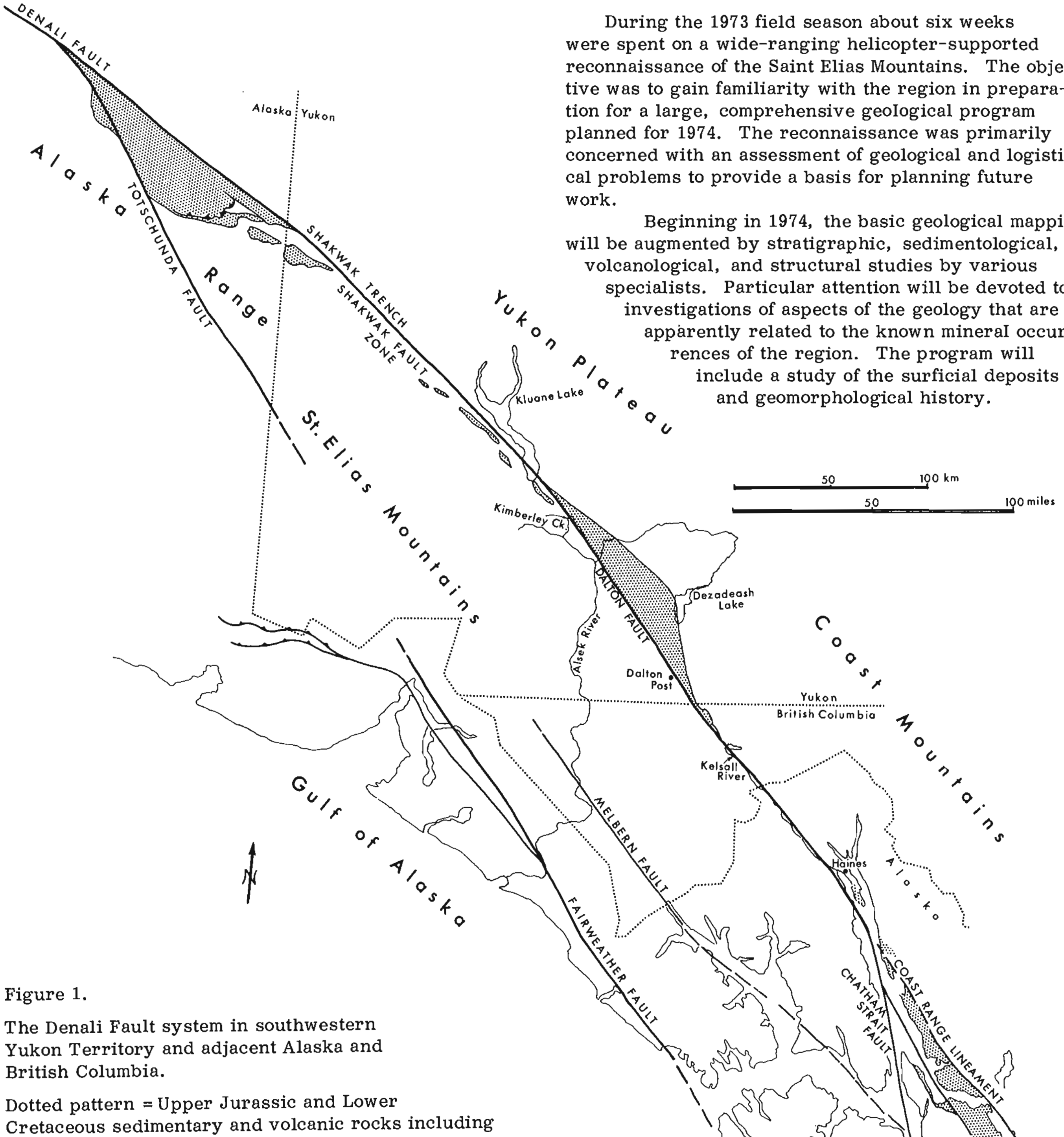

Figure 1.

The Denali Fault system in southwestern Yukon Territory and adjacent Alaska and British Columbia.

Dotted pattern = Upper Jurassic and Lower Cretaceous sedimentary and volcanic rocks including the Dezadeash Group.

During the reconnaissance in 1973, a major straight segment of the Denali Fault system, for which the name Dalton Fault is proposed, was traced through the mountains from near the south end of Kluane Lake southeastward past Dalton Post to the Kelsall River valley (Fig. 1). The existence of the fault was previously suggested by Boucher and Fitch (1969). The fault separates the Upper Jurassic - Lower Cretaceous Dezadeash Group on the northeast from Triassic and older rocks on the southwest, and is prominently marked by the bright-weathering colours of intensely fractured and altered rocks in a zone up to several miles wide. Low-grade metasedimentary rocks west of the fault near Alsek River, thought to be Cretaceous by Kindle (1953), are predominantly thin-bedded limestone, and differ from the greywacke and shale of the Dezadeash Group. They may be Upper Triassic.

Kindle interpreted the fault zone as a depositional unconformity between the Dezadeash Group on the east and older rocks on the west. Local conglomerate beds with coal, previously believed to mark the base of the Dezadeash Group, may be slices of Tertiary rocks within the fault zone. Tertiary volcanic rocks, probably Miocene and Pliocene in age, are locally involved in the faulting. Boucher and Fitch (1969) reported microearthquake activity related to the Denali Fault system in the region, hence the fault may be active at present.

Movement on the fault is probably transcurrent in a right-lateral sense, if it is consistent with known or inferred movement on subparallel faults in nearby Alaska. The amount and direction of movement cannot be determined with present information.

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Project 700047

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About three weeks of the 1973 field season were spent in completing the reconnaissance mapping of Fort Grahame (94 C, east half) map-area and southern part of Ware (94 F, west half) map-area. The remainder of the season was devoted to Toodoggone (94 E) map-area. About one month of field work is required for completion of Toodoggone and Ware (west half) map-areas. J.L. Mansy continued work on the Ingenika Group and related rocks between Ingenika and Finlay Rivers (see elsewhere in this report).

Rocks considered to be correlative with the Misinchinka Group farther south contain sheared archeocyathids in metamorphic rocks of low grade near the top of the assemblage in southeastern Ware (west half) map-area. Thus Lower Cambrian strata must be included in the metamorphic terrain that straddles Rocky Mountain Trench south from Fox Pass to and beyond Omineca River.

Graptolitic siltstones and shales in northeastern Fort Grahame map-area include many discontinuous units of dolomite breccia presumably derived from an eastern carbonate source. An excellent collection of Lower Devonian graptolites was made east of Ospika River.

The accompanying sketch map of Toodoggone map-area (see Fig. 1) shows the general distribution of the main rock units. In a regional context the stratigraphic assemblages, including related granitic rocks form several distinct tectono-stratigraphic units as follows:

1. Upper Proterozoic strata between Fox River and the granitic terrain west of Obo River and Upper Triassic rocks farther south occur in two metamorphic anticlinorial culminations coincident with Sifton and Swannell Ranges. The intervening terrain, including Lower Paleozoic rocks, comprises little metamorphosed or unmetamorphosed strata except north of Ridgeway Lake where older rocks occur. The structural style of this unit is consistent with the westerly directed structures described farther south and east (see Mansy, elsewhere in this report).

2. Rocks underlying the region west of unit 1 and the eastern boundary of Sustut Group strata and comprising a variety of volcanic, granitic, and lesser sedimentary rocks show no well defined structural style. Steep faults seem to be abundant and much of the unit may be block faulted. Foliated granitic, sedimentary, and volcanic rocks are common in the eastern part of the unit south and west of Thudaka Creek. The belt of foliated rocks swings westerly near the lower reaches of Thudaka Creek towards the area near the headwaters of Lunar Creek. The foliated granitic rocks may be related to the 'Takla' Group Upper Triassic-Lower Jurassic volcanics. Non-foliated granitic rocks south of Chukachida River, however, appear to be equivalents of the extrusive post 'Takla' and pre-Sustut Group rocks referred to informally as the 'Toodoggone' volcanic rocks (see Carter, 1971). An ultramafic body near the headwaters of Geese Creek lies within an Upper Paleozoic (?) greenstone terrain.

3. The southwestern part of the map-area is underlain by continental sediments of the Sustut Group and the mainly marine underlying sediments to the southwest (see Eisbacher, 1971). The strata are gently dipping in the northeast and tightly folded in the southwest.

Prospecting and exploration has been concentrated within tectono-stratigraphic unit 2 as described above. Takla rocks contain ubiquitous copper minerals and numerous claims have been staked in the area (see Carter, 1971). Spectacular gossans are abundant throughout the areas underlain by Takla and 'Toodoggone' volcanic rocks.

Copper and molybdenum have been noted in hypabyssal granitic rocks, presumably related to the 'Toodoggone' volcanic rocks, near Jock Creek and to the southeast across Finlay River.

Galena and minor chalcopyrite occur locally in Lower Cambrian strata of the eastern belt.

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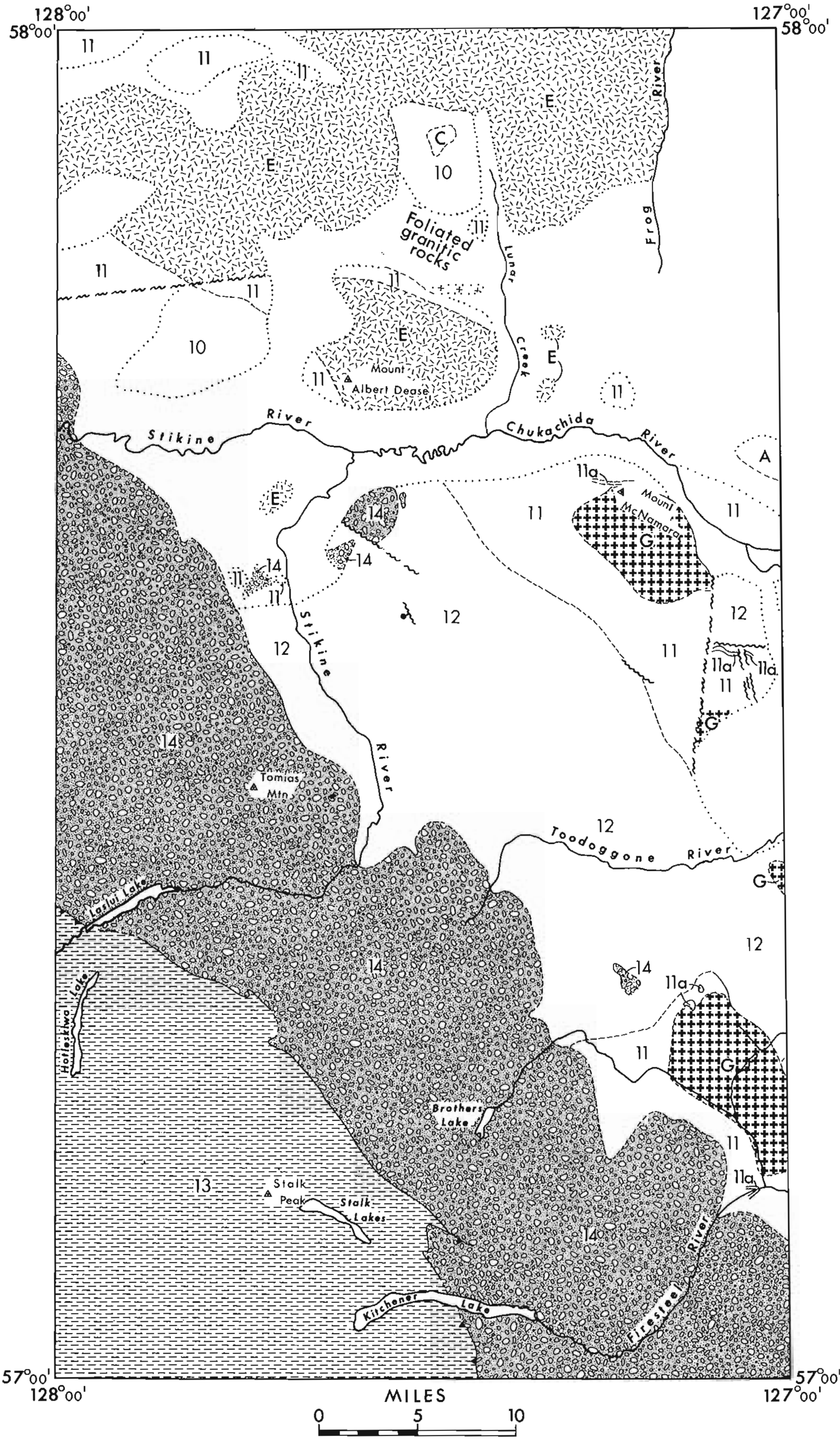
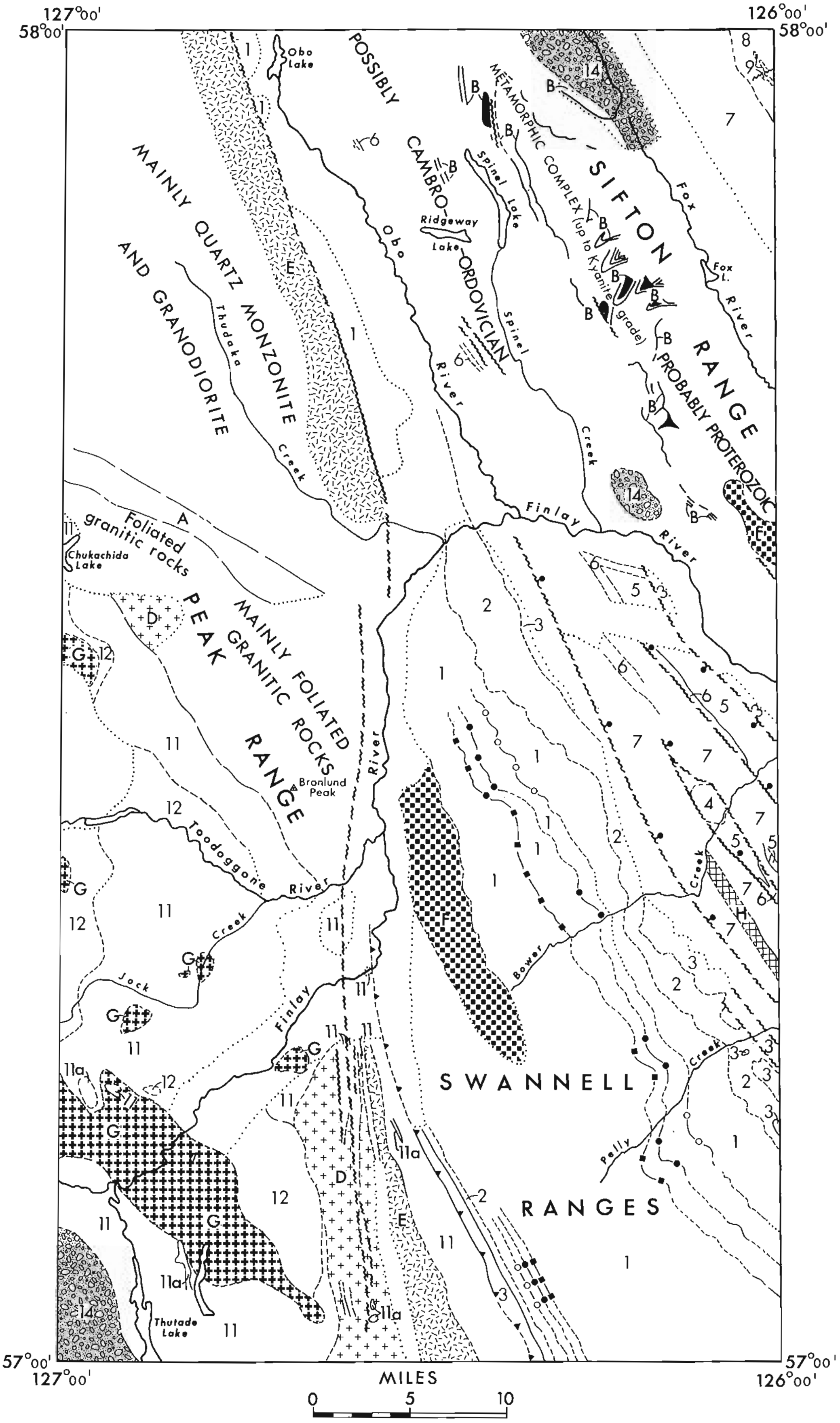
FIGURE 1


128°00'
127°00'
58°00'
58°00'
Foliated granitic rocks
Frog River
Lunar Creek
Mount Albert Dease
Stikine River
Chukachida River
Mount McNamara
Stikine River
Tomias Mtn
Toodoggone River
Laslui Lake
Hottesktwa Lake
Brothers Lake
Stalk Peak
Stalk Lakes
Kitchener Lake
Firesteel River
57°00'
57°00'
128°00'
127°00'
MILES
0
5
10


127°00'
58°00'
126°00'
58°00'
57°00'
127°00'
57°00'
126°00'
Obo Lake
POSSIBLY CAMBRO-ORDOVICIAN
METAMORPHIC COMPLEX (up to Kyanite grade)
SIFTON RANGE
PROBABLY PROTEROZOIC
MAINLY QUARTZ MONZONITE AND GRANODIORITE
Spinel Lake
Ridgeway Lake
Obo River
Thudaka Creek
Spinel Creek
Fox River
Fox L.
Finlay River
Foliated granitic rocks
Chukachida Lake
PEAK RANGE
MAINLY FOLIATED GRANITIC ROCKS
Bronlund Peak
Finlay River
Toodoggone River
Jock Creek
Bower Creek
Pelly Creek
SWANNELL RANGES
Thutade Lake
MILES
0
5
10

LEGEND FOR FIGURE 1

TERTIARY AND UPPER CRETACEOUS

14.	SUSTUT GROUP:	:Nonmarine conglomerate, shale, siltstone, tuff. Gabbroic dykes and sills.

UPPER JURASSIC

13.		:Shale, siltstone, pebble conglomerate; may include Middle Jurassic.

PRE UPPER CRETACEOUS-
POST UPPER TRIASSIC

12.	'TOODOGGONE' volcanic rocks	:Dacite, latite, tuff, breccia, flows; may be younger than 13.

UPPER TRIASSIC

11.	TAKLA GROUP	:Augite porphyry, plagioclase porphyry, tuff, breccia, flows; limestone, minor greywacke, shale; 11 a, crystalline limestone, may be in part older.

UPPER PALEOZOIC

10.		:Phyllite, slate, greenstone.

DEVONIAN AND MISSISSIPPIAN(?)

9.		:Conglomerate, grit, shale.

ORDOVICIAN, SILURIAN AND DEVONIAN

8.	CLOUDMAKER FORMATION	:Siltstone, shale.

CAMBRIAN AND ORDOVIAN

7.	KECHIKA GROUP	:Phyllitic limestone.

LOWER CAMBRIAN

6.		: Limestone, siltstone, dolomite.
5.		:Impure quartzite, shale; locally sandstone conglomerate.
4.		:Orthoquartzite.

PROTEROZOIC

3.		:Limestone (locally oolitic and pisolitic) minor dolostone.
2.		:Sericitic and calcareous phyllite.
1.		:Quartzo-feldspathic, gritty sandstone, siltstone, shale, and conglomerate; minor limestone: and metamorphic equivalents, metamorphosed to at least garnet grade.

<u>AGE UNCERTAIN</u>

H.	Acid intrusives, hypabyssal.
G.	Quartz monzonite and granodiorite; probably related to 'Toodoggone' volcanic rocks.
F.	Biotite, muscovite augen leucogranitic gneiss biotite, muscovite leucogranite.
E.	Granodiorite, quartz monzonite, diorite.
D.	Foliated granodiorite.
C.	Ultramafic complex; dunite core, pyroxenite border.
B.	Limestone, marble (in part probably correlative with map-unit 3).
A.	Leucogneiss, amphibolite, chloritic schist.

geological boundary

limit of geological mapping

fault

thrust fault

chlorite isograd

biotite isograd

garnet isograd

Project 700047

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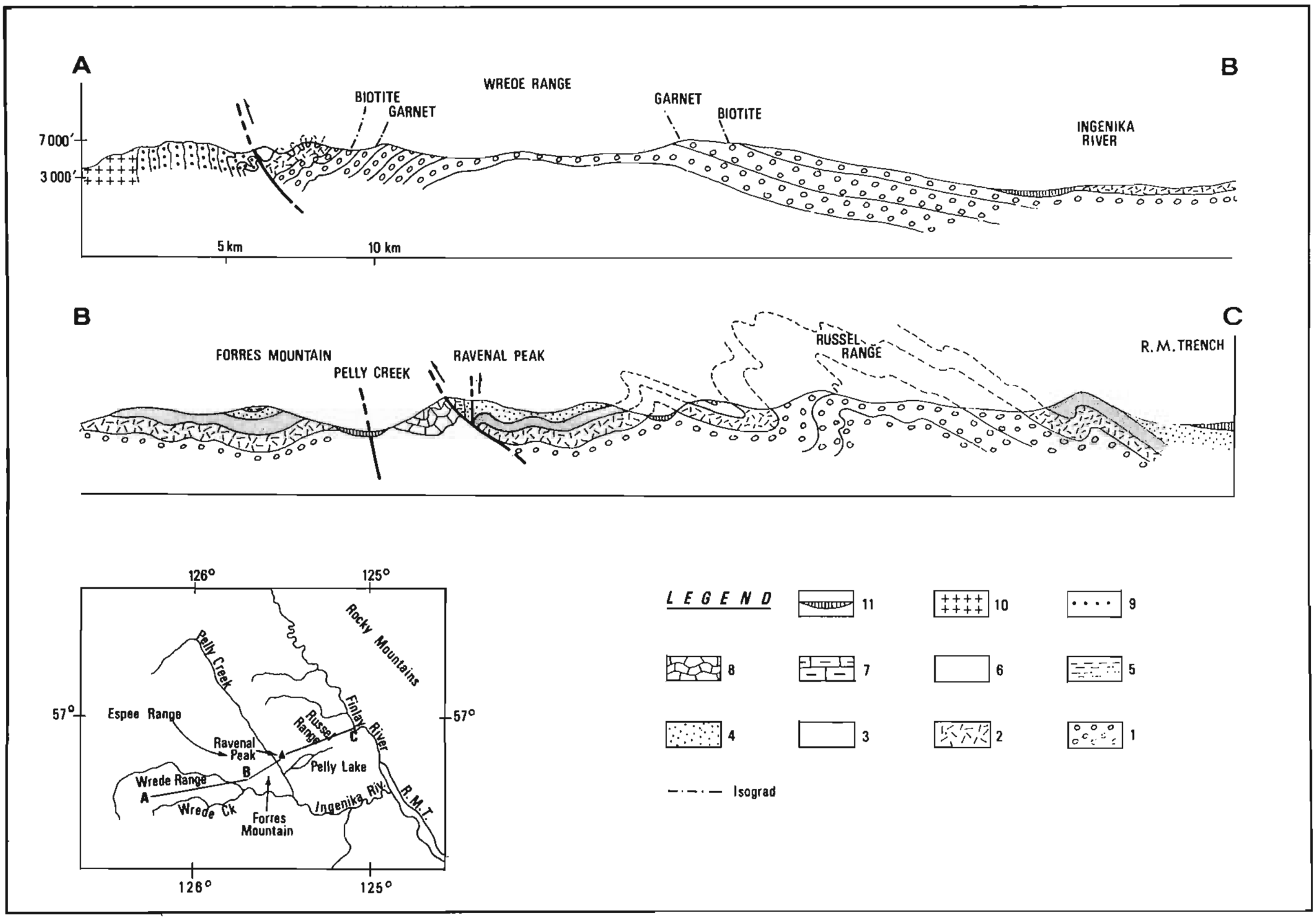
Study of the Proterozoic Ingenika Group and overlying Cambrian strata in Omineca Mountains was continued with emphasis on mapping south of Finlay River in Toodoggone (94E) and Ware (94F) map-areas, and north of Ingenika River in Fort Grahame (94C) and McConnell Creek (94D) map-areas.

The structural style of Ingenika Group rocks in the region is shown in Figure 1 which illustrates the general westerly and southwesterly directed asymmetry of major and minor folds. At least two regional, westerly directed thrust faults have been recognized. The trace of one trends northerly from near Ingenika River on the east side of Pelly Creek to north of Finlay River. Another bounds Ingenika Group strata on the west where they are in contact with upper Paleozoic and lower Mesozoic strata.

Along the cross-section line facies changes are evident in several of the map-units. In map-unit 1, the maximum size of clasts ranges from about 4 to 5 cm in Russel Range to generally less than 1 cm in Wrede Range. In addition, the abundance of pebble conglomerate is much greater in Russel Range than in Wrede



1. Shale, siltstone, pebble conglomerate
2. Calcareous phyllite
3. Limestone, dolomite, minor phyllite
4. Green and purple shale, quartzite, limestone
5. Quartzite and shale (Lower Cambrian)
6. Dark weathering shale and quartzite
7. Limestone, siltstone, shale, dolomite
8. Wavy banded silty limestone, calcareous shale, argillaceous limestone
9. Black limestone, cherty shale, green tuff, augite porphyry
10. Granodiorite
11. Alluvium

Figure 1. Diagrammatic structural section across Wrede, Espee, and Russel Ranges.

Range. Conversely, phyllites and thin beds of limestone are more important in western than in eastern outcrops.

Map-unit 3 is about 500 feet thick in Russel Range and about 1,200 feet thick near Forres Mountain. The rocks are mainly well bedded limestones on Forres Mountain but include a lower member of interbedded limestone and phyllite in western Wrede Range.

Map-unit 4 contains a lower member of sandstone and dolomite near Rocky Mountain Trench. These lithologies are not present farther west where phyllite, shale, quartzite, and limestone predominate. This assemblage is about 1,000 feet thick near Rocky Mountain Trench, and is 2,000 feet thick near Forres Mountain.

Map-unit 7 comprises three members. A lower one, 200 feet thick, consists of massive, locally oolitic, blue-grey weathering limestone containing archeocyathids and trilobites. The middle member includes light green siltstone, limestone, calcareous shale, and laminated green and buff siltstone, aggregating about 150 feet in thickness. A thin upper member of red, purple, and grey dolostone with oolites, oncoliths and poorly preserved archeocyathids was noted locally.

Map-unit 8 has been reinterpreted as being correlative with part of the Kechika Group (see Mansy, 1972), and thus stratigraphically overlying Lower Cambrian strata.

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8. UPPER PALEOZOIC AND LOWER MESOZOIC ROCKS OF THE OMINECA MOUNTAINS

Project 720041

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Stratigraphic and structural studies in the Omineca Mountains, begun in 1972 (Monger, 1973), were continued on rocks previously mapped as upper Paleozoic by Lord (1948), Armstrong (1949), and Roots (1954) in (a) the northern part of the Manson Creek Belt, (b) the Lay Range and (c) the northern part of the Stuart Lake Belt (Fig. 1). In addition, a detailed stratigraphic investigation of lower Mesozoic rocks was initiated in McConnell Creek (94C east half) and Aiken Lake (94C west half) map-areas. Paterson studied the Stuart Lake Belt and Monger the other regions.

(a) Northern end of Manson Creek Belt

In this area the strata appear to form a homoclinal succession, interrupted by faulting and local folding, that dips westwards from the high-grade metamorphic axis of the Wolverine Complex. The stratigraphic section, in order of decreasing age, and generally from east to west, consists of the following units:

1. Upper Precambrian to Lower Cambrian phyllite, quartzite, brown weathering ferruginous carbonate, and minor pods of archeocyathid-bearing limestone. These rocks are correlated with the Ingenika Group of Roots (1954).

2. Ordovician(?) and Silurian(?) to Middle Devonian carbonate and minor phyllite with an apparent thickness of at least 3,000 feet but much internal deformation. The lowest 1,000 feet of foliated, fine-grained crystalline limestone, platy argillaceous limestone and phyllite, lithologically resembles some Ordovician and Silurian carbonates in the eastern Cordillera (A. Boucot, pers. comm.). The remainder is algalaminate dolomite overlain by dolomitic limestone that in places contains round, etched quartz grains and lower Middle or upper Lower Devonian fossils.

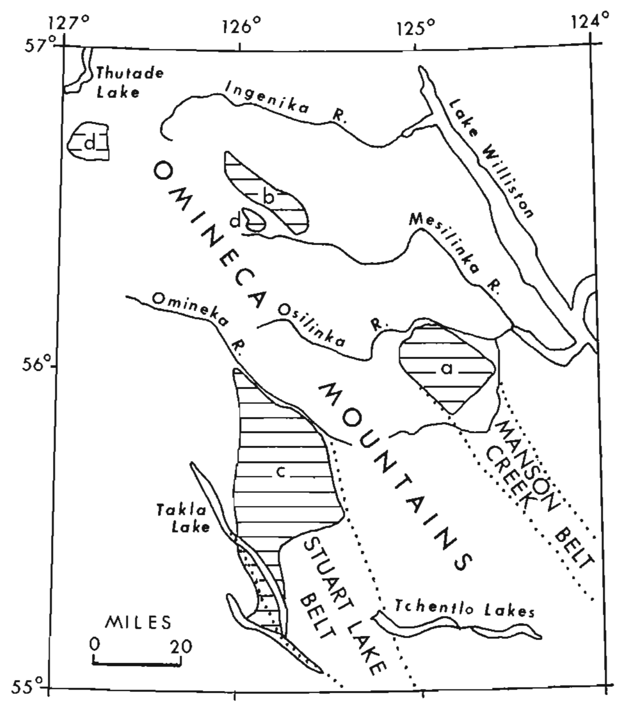

Figure 1 -INDEX MAP-
Areas studied in the Omineca Mountains

3. Late Pennsylvanian - Early Permian and (?) older, cherty pelite, pelite, and chert, minor local conglomerate containing phyllite, greywacke, limestone and quartzite clasts, and thin argillaceous limestone beds with Upper Pennsylvanian fusulinids and earliest Permian fusulinids and conodonts. Thick, intercalated diabase and gabbro sills are in the upper part. Total apparent thickness is approximately 7,000 feet, including about 3,000 feet of sills. Toward the top of the section, thin-bedded chert predominates but downward the sequence becomes less cherty and grades into slate that both overlies and is faulted against Devonian carbonate.

4. Permian(?) altered basic volcanics (Nina Creek greenstone of Armstrong, 1949, p. 39) with an apparent thickness of at least 5,000 feet. These are monotonous, typically massive, locally variolitic very fine grained flow rocks, that are rarely pillowed, but locally include aquagene tuff and volcanic breccia horizons. They are possibly the extrusive equivalent of the underlying sills.

(b) Lay Range

As described previously (Monger, 1973), the Lay Range consists of a number of northwest-trending fault slices. It seems probable that the lithic tuff, volcanic sandstone and breccia and flow rocks are Upper Triassic, rather than upper Paleozoic as suggested by Roots (1954). They closely resemble rocks in the lower part of the Takla Group in the region. Exceptions are (1) hematitic conglomerate with abundant granitic clasts, correlative with the Cretaceous Uslika Formation, and (2) the fault slice forming the crest of the Lay Range that contains fossiliferous Middle Pennsylvanian carbonate, chert, phyllite, and conformable conglomerate containing volcanic and mica schist fragments which is possibly entirely upper Paleozoic.

(c) Northern end of the Stuart Lake Belt

Three subdivisions have been made within rocks previously unmapped or mapped as part of the Cache Creek Group at the northern end of the Stuart Lake Belt. Lying immediately west of the Pinchi Fault are Upper Triassic or Lower Jurassic chert pebble conglomerate, argillite and sandstone. These are separated by a northeast-dipping fault zone containing serpentinite and greenstone from phyllite, greywacke and massive crystalline limestone locally containing mid to Upper Permian fusulinids, that comprises the Cache Creek Group. West of this is an easterly dipping thrust fault zone containing a serpentinite/greenstone melange in contact with Upper Triassic(?) volcanic breccia, lapilli tuff, rhyolite, greenstone, greywacke and argillite. Southwards the latter unit is exposed on the shores of Takla Lake, south of Takla Landing, so that the western boundary of the Cache Creek Group at this latitude lies east of Takla Lake and west of Tsayta Lake.

The eastern group of rocks appears to be metamorphosed and faulted but not folded, whereas the Cache Creek Group rocks have been metamorphosed in the lower greenschist facies with local glaucophane, and have undergone at least three deformational episodes. The oldest minor structures include a prominent foliation that generally parallels compositional layering and marks the orientation of the axial planes of mesoscopic, east-west trending, tight or isoclinal folds. Related early macroscopic structures have not been recognized, as lensoid lithological units cannot be traced for any distance. Later chevron or concentric folds trend north-south and their axial planes dip westwards at moderate angles. The youngest structures are warps and kinks probably related to late faulting, that modify the trend of the earlier structures. The Triassic(?) rocks, on the west, are of greenschist facies and contain biotite and chloritoid, but appear to have undergone only one period of intense deformation that formed a penetrative cleavage, cross-cutting compositional layering. This cleavage and metamorphism cannot be directly related so far to any phases in the Cache Creek rocks, but the presence of little deformed and metamorphosed probable Lower Jurassic rocks west of Takla Lake suggests that it is of pre-Lower Jurassic age.

(d) Lower Mesozoic rocks in McConnell Creek and Aiken Lake map-areas

Lower Mesozoic rocks were studied in detail where they are particularly well exposed and unaltered near Dewar Peak, and where the alteration is more intense, northwest of Aiken Lake. At Dewar Peak, and the area to the southwest, the rocks, including the underlying Paleozoic strata, are exposed in a series of fault blocks. The stratigraphic section, from oldest to youngest is as follows:

1. The Asitka Group comprises altered basalt, chert, and fossiliferous, tuffaceous Lower Permian limestone overlain by well-layered basic volcanics, bedded volcaniclastics, rhyolite, and, uppermost, purple, locally sheared lithic tuff, fossiliferous tuffaceous limestone of probable Early Permian age, and bedded chert. The total thickness is in excess of 5,000 feet.

2. The lower division of the Takla Group of Lord (1948) can be subdivided into six lithological units, some of which may be all or partly coeval with others. The basal unit(1) consists of dark grey argillite with siltstone laminae, local dark limestone lenticles and thin, lithic tuff beds towards the top. It contains probable late Karnian ammonites, pelecypods and belemnites and has a total thickness of about 1,000 feet. The lower contact with the upper Paleozoic is probably everywhere a fault, but the consistency of the map-pattern suggests that it is a 'sheared' stratigraphic contact rather than a major displacement. The basal unit grades upward into (2) thin- to medium-bedded, green to buff, lithic crystal tuff about 700 to 1,500 feet thick. Succeeding this is (3) massive volcanic breccia containing blocks, boulders and cobbles of augite porphyry, feldspar porphyry and tuff, interbedded with thick bedded crystal lithic lapilli tuff containing abundant pyroxene crystals, with a thickness ranging between 1,000 and 2,700 feet. Conformably above the breccia is (4) 400 to more than 1,500 feet of commonly dark grey and fresh, but locally yellow-green and epidotized, augite porphyry pillow lava that is locally overlain by (5) as much as 300 feet of distinctive, pillowed coarse tabular feldspar porphyry which forms a characteristic component of many of the breccia units. Elsewhere (6) a breccia unit as much as 1,000 feet thick, that contains red, maroon, green fine feldspar porphyry fragments but relatively little augite porphyry, lies directly above the augite porphyry pillow lava and is the uppermost unit of the lower division.

3. The upper division of the Takla Group lies disconformably (?) on the lower division. The base of this unit contains fossils possibly of Lower Jurassic age (H.W. Tipper, pers. comm.). The lowest part consists of thin-bedded, maroon, lithic tuff that grades upward into more massively bedded, maroon volcanic breccia with local limy horizons.

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VICTORIA MAP-AREA, (92B, C), PACIFIC RIM NATIONAL PARK VANCOUVER ISLAND, B.C.

Projects 730036 and 720074

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Reconnaissance mapping of Victoria map-area, Vancouver Island, was initiated in conjunction with geological investigation of Phases II (Broken Island Group) and III (Westcoast Trail) of Pacific Rim National Park. Previous work had been done by C.H. Clapp (1912, 1917), J.T. Fyles (1955) and the writer (Muller and Jeletzky, 1970; Muller 1971). "Phase I" (Long Beach area, of the park was studied in 1972 (Muller, 1973). The season's work was carried out mainly in the park-areas and the southwestern previously unmapped parts of the map-area.

The map-area is of special significance to Vancouver Island geology as it contains two distinct marginal tectonic belts: the San Juan and Metchosin blocks, possibly welded on to the main body of the island in early Tertiary time along San Juan and Leech River Faults respectively. The general stratigraphy of the three belts is illustrated in Figure 1.

Vancouver Island north of San Juan Fault consists of a late Paleozoic volcanic-sedimentary complex (Sicker Group), an early Mesozoic volcanic-sedimentary complex (Vancouver Group), the Westcoast migmatite complex, Jurassic granitic intrusions, late Mesozoic clastic sediments, early Tertiary granitic plutons, and, along the west coast, a veneer of Lower Teritary sediments.

The Westcoast Complex underlies the islands of Barkley Sound and a strip 5 miles or more wide between Bamfield and Port Renfrew. A veneer of Lower Tertiary sediments overlies it along the coast with major unconformity but no unconformable relationships with Sicker or Vancouver Group rocks have been established. The rocks exhibit a progression from angular agmatite to elongated agmatite to amphibolite-gneiss and finally to nebulitic and homogeneous (biotite) hornblende quartz diorite. Several different types of texture may occur within one outcrop and generally a light-coloured phase of medium-grained quartz diorite or granodiorite intrudes and is intimately mixed with a dark-coloured phase of fine-grained amphibolite, diorite or gabbro. No suitable material for potassium-argon age-determination has been found in the complex due to general alteration. However, an amphibolized dyke in the complex in the Tofino area, collected in 1972, yielded a potassium-argon age of 191 = 9 m.y. (R.K. Wanless, pers. comm.). This lowermost Jurassic age indicates the parent-rock was pre-Jurassic, i.e. either the Triassic part of the Vancouver Group or the Upper Paleozoic Sicker Group. The "Nitinat Limestone" (Clapp, 1912), exposed on Nitinat Lake, Carmanah and Walbran Creeks is entirely recrystallized, locally contains chert lenses, and is associated with meta-tuffs. It resembles and is tentatively correlated with Upper Paleozoic Buttle Lake limestone rather than Triassic limestone. The reconnaissance mapping indicates that it forms blocks, several miles across, within the Westcoast Complex.

Complexly folded and faulted, metamorphosed but well-bedded limestone and silty argillite exhibit gradational contact with Westcoast Complex amphibolite-gneiss on Cree, Howell, Wouwer, Benson and Clarke Islands in the southern part of the Broken Island Group. They are cut by aplitic dykes, similar to the light-coloured component of the adjacent migmatite complex. The limestone-argillite sequence is similar to and provisionally correlated with the Upper Triassic Parson Bay Formation of Alert Bay - Cape Scott map-area (Muller, et al., in preparation).

The almost total absence of Sicker and Karmutsen Volcanics, in contrast to abundant presence of Bonanza Volcanics in the map-area suggests that the older volcanics were the main parent-rocks of the migmatite complex.

Upper Triassic and minor Lower Jurassic sediments occur in an irregularly broken belt from Coleman and Spencer Creeks on Alberni Inlet via the middle part of Nitinat River to Gordon River and Harris Creek areas. Considerable detailed mapping is still needed to unravel the structural complexity that is apparent from scattered occurrences of these beds.

Bonanza Volcanics are widespread and are mainly tuff and breccia of intermediate composition, similar to those of the type region (Muller, et al., in preparation) and are considered to be also of Early Jurassic age.

San Juan Block is bounded on the north by San Juan Fault. The fault follows the north slope of San Juan River valley and probably extends westward below Tertiary sediments to the lower part of Camper and Sandstone Creeks. To the south the block is bounded by Leech River fault, following Leech River and Loss Creek. Southeastward the two faults apparently converge towards the Colwood area, just southwest of Victoria.

The block is underlain by Leech River Schist, a shear-folded metagreywacke-slate complex with, east of the head of Leech River, minor metavolcanic rocks. The complex shows progressive metamorphism southward towards Leech River Fault. The rocks grade from phyllitic greywacke and slate near San Juan Fault to garnetiferous quartz-biotite schist, and near Leech River Fault these locally contain porphyroblasts of andalusite and staurolite. The volcanic rocks have been converted to chlorite-actinolite schist with minor quartz and plagioclase.

Leech River Schist can now be correlated with some confidence with the late-Jurassic to early-Cretaceous Pacific Rim Complex (Muller, 1973).

RELATIONSHIPS OF FORMATIONS OF VANCOUVER ISLAND

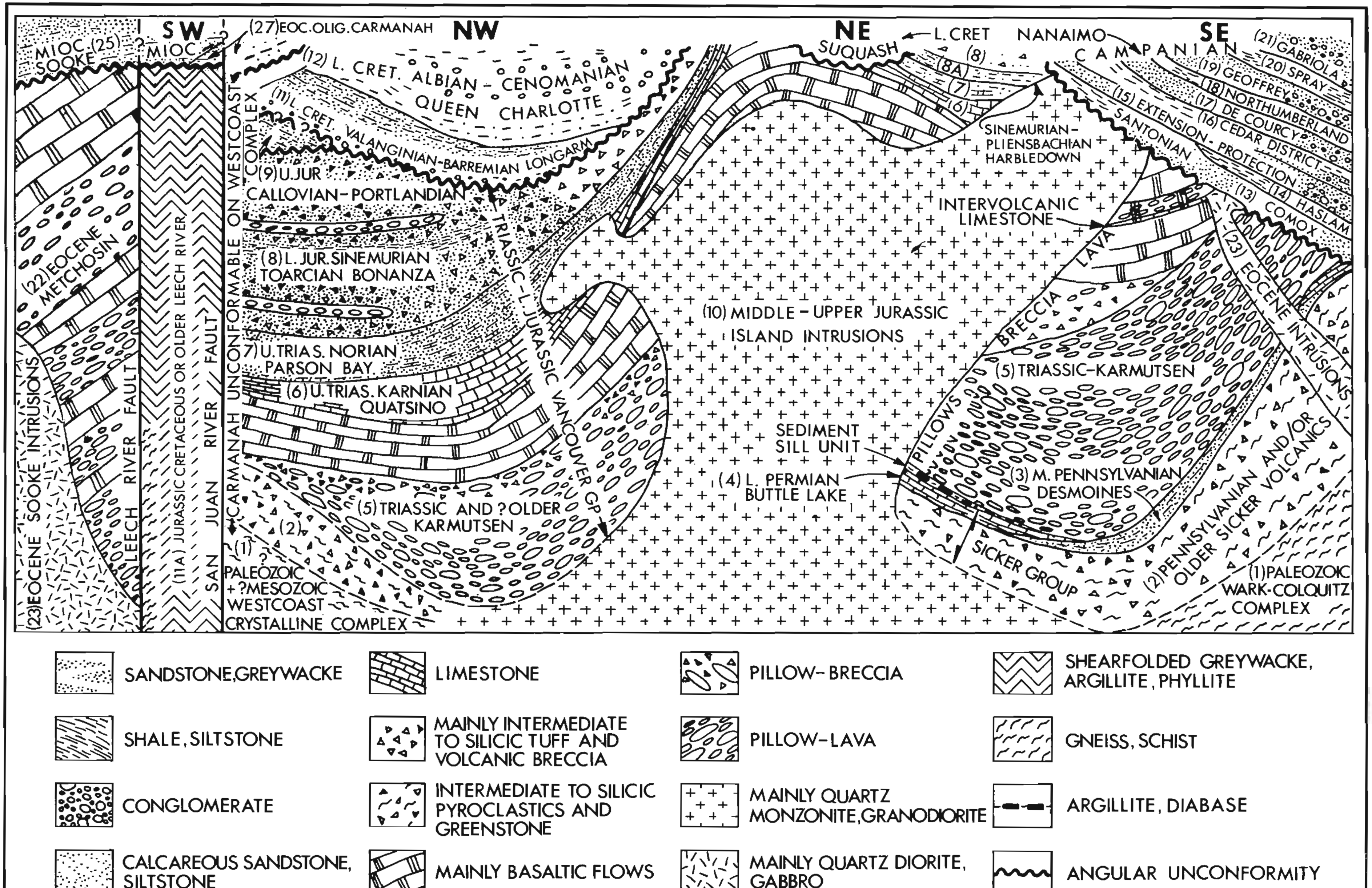

FIGURE 1

Additional evidence is the occurrence of folded ribbon-cherts on the road just south of B.C.F.P. logging camp in the Port Renfrew and in a few other places just south of San Juan Fault. In addition Tertiary basal conglomerate near Owen Point contains large blocks of chert though the underlying rock is Leech River Schist. The ribbonchert is a characteristic, though minor, component of the Pacific Rim Complex.

The Metchosin Block, joined to the San Juan Block along Leech River Fault, consists mainly of Metchosin Volcanics. They are basaltic lavas, pillow lavas and minor tuffs, intruded by dykes and sills of diabase and minor bodies of quartz diorite. On the basis of macro- and micro-fauna from tuffs near Albert Head their age is early Eocene. The volcanics are apparently correlative to the Crescent Volcanics of Olympic Peninsula and the Metchosin Block is considered to form the northern edge of that geological province.

Tertiary sediments lie in each structural block with profound unconformity on respectively Westcoast Complex, Leech River Schist, and Metchosin Volcanics. The outcrop-trace of the unconformity roughly follows the present coastline and the unconformity is exposed in many places. Thus the coastal belt of Tertiary sediments is intermittent and only between Port Renfrew and Clo-oose does it attain a width of more than one mile. The sediments continue offshore in the Tofino Basin (Shouldice, 1971, Tiffin, et al., 1972). Exposed thicknesses, not yet measured accurately, are a few thousand feet, but up to 12,000 feet have been drilled offshore. It appears that the sediments were stripped off almost completely in the land-area by Pleistocene erosion, while being preserved below sea-level. The presence of deep-water faunas in the Carmanah Formation indicates considerable additional northeastward extent of the Oligocene sea. It has not yet been established with certainty whether Tertiary sediments have been affected by movement along Leech River and San Juan Faults.

A preliminary study of the benthonic microfaunas by B.E.B. Cameron suggests that clastic sediments of the Carmanah Formation, overlying Westcoast Complex rocks north of Port Renfrew, are mainly correlative to the Refugian of the State of Washington (late Eocene to early Oligocene; Rau, 1967). Near Carmanah Point younger beds correlative to the Zemorrian (middle to late Oligocene) are present. It is hoped that a more definite age-assignment will be possible after all foraminifera including the planktonic ones, have been studied in detail. Beds immediately overlying Leech River Schist in the San Juan Block are also early to middle Refugian in outcrops near Owen Point and San Juan Point. However, one mile north of Sombrio Point, just north of a zone of highly sheared volcanics apparently representing Leech River Fault, south dipping siltstones contain a different marine fauna of probable Miocene age. In the Metchosin Block only post-Oligocene nearshore sediments Sooke Formation) overlie Metchosin Volcanics unconformably. No microfauna has been found in these but according to the microflora they are late Miocene to early Pliocene. According to the macrofauna they are Oligocene to Miocene (Shouldice, 1971).

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10. STRATIGRAPHY AND STRUCTURE OF THE MOUNT IDA GROUP, VERNON (82L), SEYMOUR ARM (82M), BONAPARTE LAKE (92P) AND KETTLE RIVER (82E) MAP-AREAS, BRITISH COLUMBIA

Project 720037

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Acknowledgments

As in the previous year, assistance to the project was given by K.L. Daughtry, geological consultant, Vernon, B.C., who continued to provide field data and stimulating discussion bearing on geologic problems of the Mount Ida Group. J.G. Bolm, pursuing a study of pegmatite genesis in the Monashee Group under the supervision of R.R. Reid of the Idaho College of Mines, generously shared data and ideas. The co-operation of J. Sluggett, working under the supervision of J.V. Ross at the University of British Columbia on radiometric age determinations of gneisses lying north of the Mount Ida Group, is greatly appreciated.

Introduction

Continuation of field mapping of low and high grade metamorphic rocks bordering and lying within the Shuswap Metamorphic Complex was carried out over a four-month period from May to September of this year. Work began with a one-week reconnaissance in the Okanagan Valley region to gain familiarity with the western margin of the Complex. Following this, efforts were concentrated east of a line joining Sicamous and Vernon including the Shuswap and Hunters Ranges, the Silver Star area east of Armstrong and valleys east of Vernon nearly to the Pinnacles. Problem areas mapped last summer were also reinvestigated.

Preliminary conclusions and hypotheses based on two field seasons' and the intervening winter's work are reported below, but are subject to revision once paleontological and radiometric studies and analysis of data are completed.

Stratigraphy and Regional Correlation

The revised stratigraphic succession established by Campbell and Okulitch (1973) has been traced eastward into the Monashee Group of Jones (1959), where it undergoes increase in metamorphic grade and changes of structural style. The transitions, nowhere well exposed, have been mapped along the west side of Mara Lake (south of Sicamous), south of the lake on the east side of Shuswap River valley, southeast of Enderby (15 miles north-northeast of Vernon) and southeast of Sugar Lake. Essentially no aspects of the succession established previously were disproved by this work (see Fig. 1).

Stratigraphic relationships of units within the Mount Ida Group and regional stratigraphic correlations are most succinctly summarized in a correlation chart (see Fig. 2). Units are discussed from oldest to youngest and reference should also be made to the map legend.

Unit nm awaits results of lead isotope analysis of zircons (derived from granitoid gneiss sampled east of Kelowna) before it can be assigned a stratigraphic position. Mapping east and northeast of Sicamous in a complexly folded and poorly exposed terrain has not clearly delineated equivalent units of the Mount Ida Group. Indeed many lithologic types (biotite and amphibolite paragneiss and sillimanite schist of unit ns) found in this area are more probably related to older successions best exposed in eastern parts of the Shuswap Complex (Reesor and Moore, 1971). Analysis of lead isotopes in zircons from samples of granitoid gneiss from Seymour Arm (see Fig. 1) has given a minimum age of crystallization of 354±15 m.y. (R.K. Wanless, pers. comm., 1973). Tentative results of Rb/Sr analysis of the same samples indicate Proterozoic thermal event (J. Sluggett, pers. comm., 1973). These data point to a prolonged history of deformation and metamorphism of parts of the Shuswap Complex.

The Silver Creek Formation (Psc) was mapped on the basis of lithologic type and its relationship to the overlying Tsalkom Formation. In areas of high grade metamorphism it is sillimanite-garnet-quartz-mica schist, quartzite and siliceous marble. Separation from gneiss and schist of unit ns is difficult. The Cache Creek Group (PPcc) originally included much of the argillite and volcanic rocks presently assigned to Mesozoic units. As redefined by this work the Cache Creek Group is predominantly limestone with only minor greenstone and argillite. Separation from Mesozoic units in the isoclinally folded and highly faulted belt northwest and east of Vernon is difficult. Fossil localities (see Fig. 1) are those originally indicated by Jones (1959) and revisited by the writer

Although the Chapperon Group (IPc) was not extensively studied, its stratigraphic position can be better defined than formerly. Argillite which unconformably overlies it at Salmon River (30 miles east of Vernon) has yielded Upper Triassic conodonts (B.E.B. Cameron, pers. comm., 1972). The possible age of the group has been discussed by the writer in a recent paper (1973).

The Tsalkom Formation has been traced into amphibolite and marble of the Shuswap Metamorphic Complex in two localities. The assemblage is quite distinctive and is similar in many respects to the greenstone/limestone assemblage of the Cache Creek Group. The Tsalkom Formation and the Cache Creek Group are unconformably overlain by the Upper Triassic Sicamous Formation. Unconformable relationships are suggested by fossil evidence, particularly from localities east of

GEOLOGY OF THE MOUNT IDA GROUP

TERTIARY

EOCENE

Tv	Kamloops Group. Basalt flows and breccia, shale, sandstone, conglomerate.

MESOZOIC

Mg	Granitic intrusive rocks predominantly of Jurassic and Cretaceous age.

TRIASSIC AND JURASSIC

ɌJv	Augite andesite flows and breccia, siltstone, andesitic arenite. Includes uɌN and possibly some ℙPcc northwest and east of Vernon.

UPPER TRIASSIC

uɌN	Nicola Group. Augite andesite flows and breccia, argillite, shale, limestone.
	Sicamous Formation. Argillaceous limestone, argillite, shale, graphitic phyllite. May include some ℙPcc northwest and east of Vernon.

PALEOZOIC AND MESOZOIC

ℙMEB	Eagle Bay Formation. Chloritic and sericitic phyllite, limestone, quartzite, mica schist, argillite, minor conglomerate. Includes uɌN, Sicamous Formation, Middle Mississippian limestone (shown in black), as well as gneisses of possible Proterozoic age (dashed pattern).
	Tsalkom Formation. Greenstone, agglomerate, chlorite schist, minor limestone and argillite. Includes amphibolite, marble and dioritic gneiss in areas of high grade metamorphism. Limestone shown in white, ultramafic bodies in lined pattern.

PALEOZOIC

PRE-UPPER TRIASSIC (possibly PRE-PERMIAN)

ℙC	Chapperon Group. Argillite, chlorite schist, quartzite, limestone.

PENNSYLVANIAN AND PERMIAN

ℙPCC	Cache Creek Group. Limestone, some greenstone, minor argillite. May include Sicamous Formation and ɌJv northwest and east of Vernon. May include uɌN west of Kelowna.

PALEOZOIC (possibly MISSISSIPPIAN)

PSC	Silver Creek Formation (includes Mara and Chase Formations of Jones, 1959). Sericite schist, garnetiferous quartz mica schist, quartzite, calcareous quartzite. Includes granitoid gneiss of uncertain age (dash pattern).

DEVONIAN

Dns	Granitoid gneiss and schist.

PALEOZOIC AND/OR PROTEROZOIC

ns	Paragneiss (dashed pattern), sillimanite, garnet, mica schist, amphibolitic gneiss. May include younger successions of the Mount Ida Group.
qc	Marble and quartzite unit east of Sugar Lake. A possible correlative of the Chase Formation or the Hamill-Badshot assemblage (see Reesor and Moore, 1971).

AGE UNCERTAIN

nm	Amphibolitic and granitoid gneisses, minor schist and marble. No equivalents within the Mount Ida or Monashee (Jones, 1959) Groups, hence possibly the oldest unit present.
	Serpentinite found along Sicamous/Eagle Bay contact west of Adams Lake; possibly related to Eagle Bay thrusting (?).

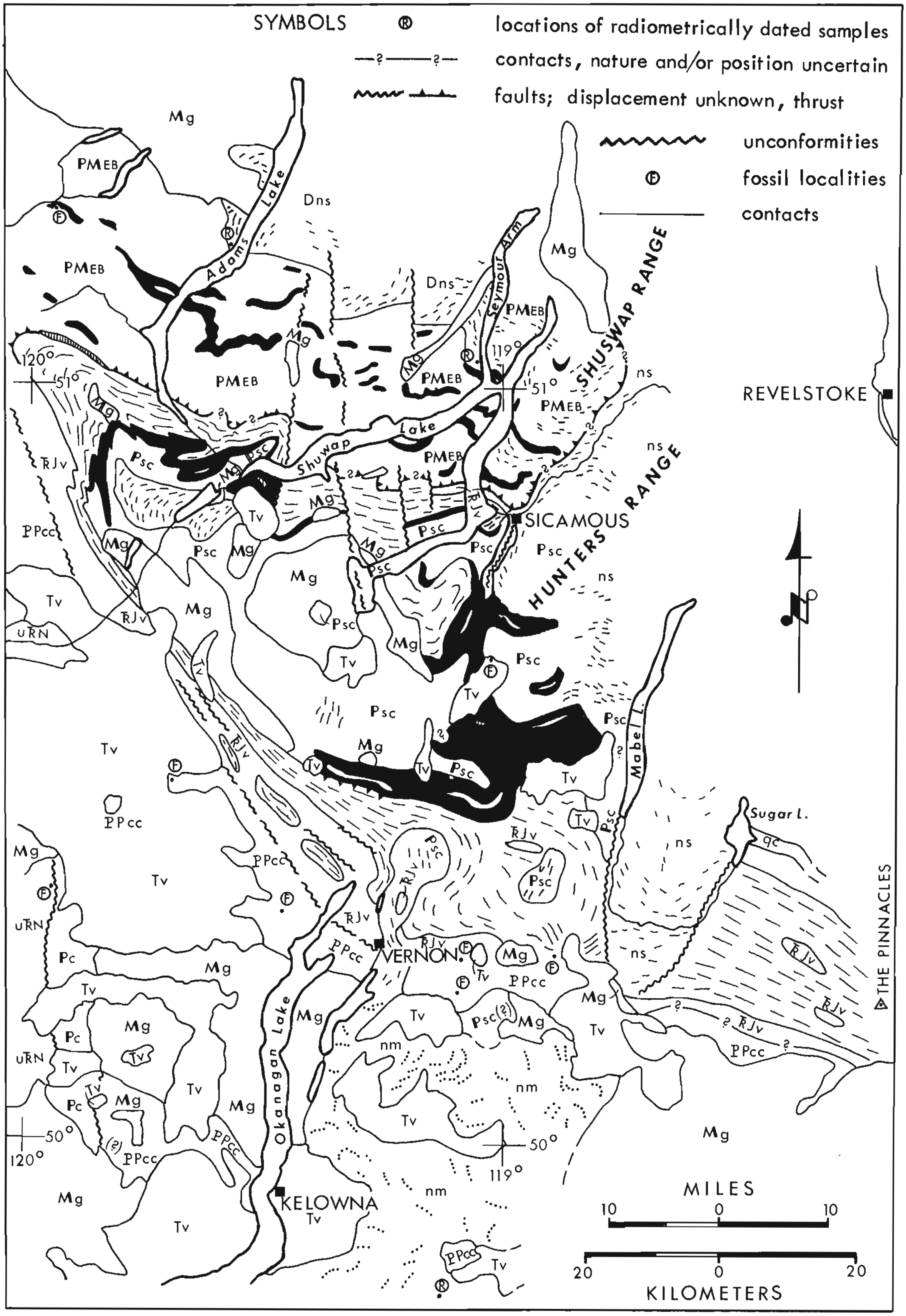
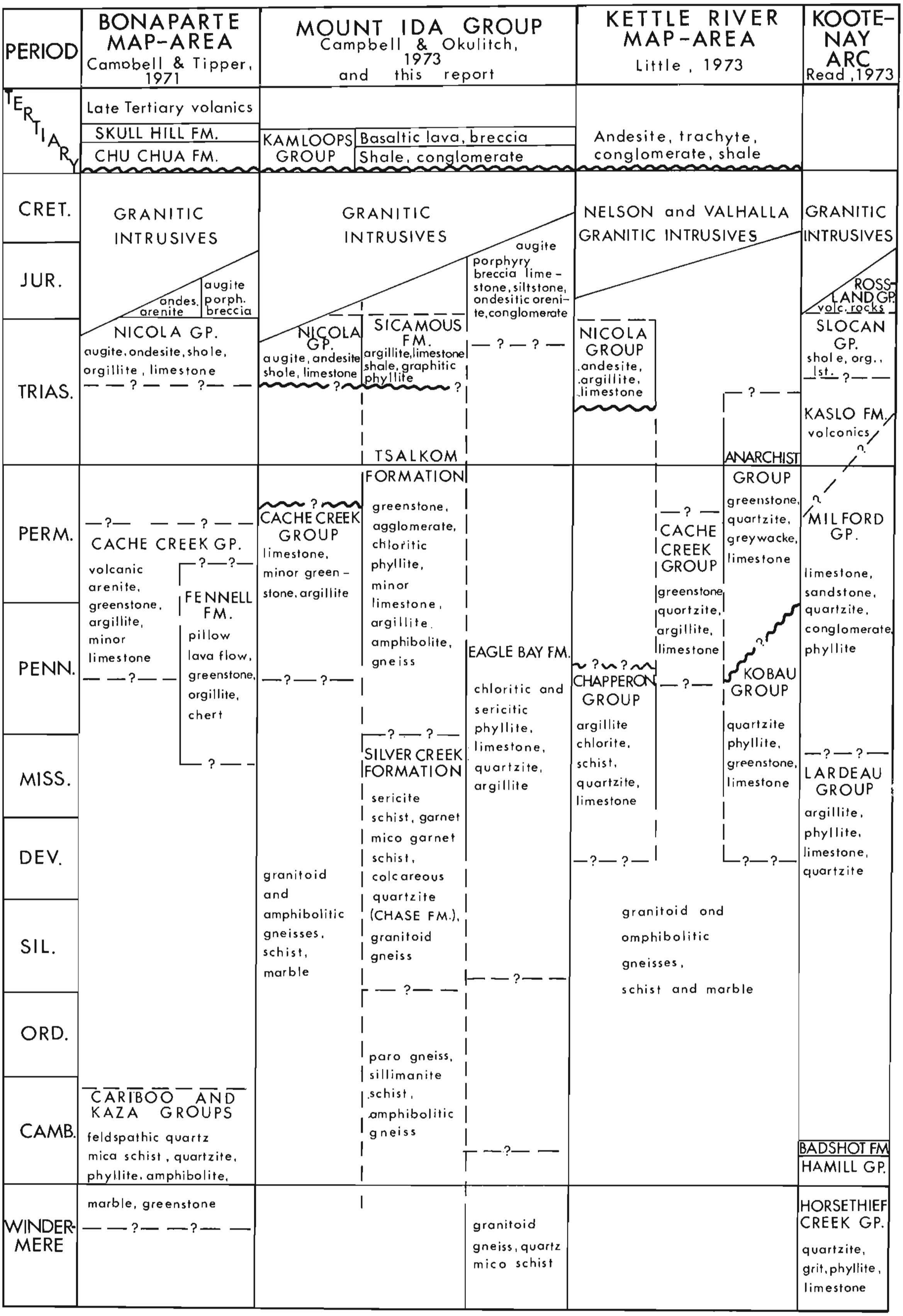

SYMBOLS
locations of radiometrically dated samples
contacts, nature and/or position uncertain
faults; displacement unknown, thrust
unconformities
fossil localities
contacts
Adams Lake
Seymour Arm
Shuswap Lake
SHUSWAP RANGE
HUNTERS RANGE
REVELSTOKE
SICAMOUS
VERNON
KELOWNA
Okanagan Lake
Mabel L.
Sugar L.
THE PINNACLES
MILES
10
0
10
20
0
20
KILOMETERS
Mg
PMEB
Dns
Psc
Tv
PPcc
Pc
ns
nm
qc
120°
51°
119°
50°

Figure 2.


PERIOD
BONAPARTE MAP-AREA
Campbell & Tipper, 1971
MOUNT IDA GROUP
Campbell & Okulitch, 1973
and this report
KETTLE RIVER MAP-AREA
Little, 1973
KOOTENAY ARC
Read, 1973
TERTIARY
Late Tertiary volanics
SKULL HILL FM.
CHU CHUA FM.
KAMLOOPS GROUP
Basaltic lava, breccia
Shale, conglomerate
Andesite, trachyte, conglomerate, shale
CRET.
JUR.
TRIAS.
PERM.
PENN.
MISS.
DEV.
SIL.
ORD.
CAMB.
WINDERMERE
GRANITIC INTRUSIVES
augite porph. breccia
andes. arenite
NICOLA GP.
augite, andesite, shale, argillite, limestone
CACHE CREEK GP.
volcanic arenite, greenstone, argillite, minor limestone
FENNELL FM.
pillow lava flow, greenstone, argillite, chert
CARIBOO AND KAZA GROUPS
feldspathic quartz mica schist, quartzite, phyllite, amphibolite, marble, greenstone
GRANITIC INTRUSIVES
augite porphyry breccia lime-stone, siltstone, andesitic arenite, conglomerate
NICOLA GP.
augite, andesite shale, limestone
SICAMOUS FM.
argillite, limestone shale, graphitic phyllite
TSALKOM FORMATION
greenstone, agglomerate, chloritic phyllite, minor limestone, argillite, amphibolite, gneiss
CACHE CREEK GROUP
limestone, minor green-stone, argillite
EAGLE BAY FM.
chloritic and sericitic phyllite, limestone, quartzite, argillite
SILVER CREEK FORMATION
sericite schist, garnet mica garnet schist, calcareous quartzite (CHASE FM.), granitoid gneiss
granitoid and amphibolitic gneisses, schist, marble
para gneiss, sillimanite schist, amphibolitic gneiss
granitoid gneiss, quartz mica schist
NELSON and VALHALLA GRANITIC INTRUSIVES
NICOLA GROUP
andesite, argillite, limestone
CACHE CREEK GROUP
greenstone, quartzite, argillite, limestone
ANARCHIST GROUP
greenstone, quartzite, greywacke, limestone
CHAPPERON GROUP
argillite chlorite, schist, quartzite, limestone
KOBAU GROUP
quartzite phyllite, greenstone, limestone
granitoid and amphibolitic gneisses, schist and marble
GRANITIC INTRUSIVES
ROSSLAND GP. volc. rocks
SLOCAN GP.
shale, arg., lst.
KASLO FM.
volcanics
MILFORD GP.
limestone, sandstone, quartzite, conglomerate, phyllite
LARDEAU GROUP
argillite, phyllite, limestone, quartzite
BADSHOT FM
HAMILL GP.
HORSETHIEF CREEK GP.
quartzite, grit, phyllite, limestone

Vernon, by unconformities noted by Jones (1959) at Keefer Gulch and Glenamma (where correlation is based on lithology only), and, in the case of much of the Tsalkom Formation, a highly variable thickness. Lithologic similarities and stratigraphic relationships thus strongly suggest correlation of the Tsalkom Formation with the Cache Creek Group.

The Eagle Bay Formation (PMEB) is a stratigraphically complex unit that should be raised to group status. As presently delineated it likely includes volcanic units correlative with the Nicola Group (a fact supported by numerous copper showings in the succession immediately overlying the Sicamous Formation — K. L. Daughtry, pers. comm., 1972), units lithologically similar to the Sicamous, Tsalkom and Silver Creek Formations, a limestone unit(s) of mid-Mississippian age (Camero, unpubl. report, 1972) and, particularly in the Shuswap Range, gneiss and schist of Paleozoic and possibly Proterozoic age.

The Upper Triassic Sicamous Formation described in a previous report (Campbell and Okulitch, 1973) has been traced south and east from fossiliferous localities in the Bonaparte Lake map-area (Campbell and Tipper, 1971) through a facies change from argillite to limestone west of Adams Lake to a crystalline limestone on the west side of Mara Lake. The limestone facies was not recognized east of this lake. An extension of the argillite facies was traced southeast to Vernon by Campbell and confirmed by the writer. This tightly folded and faulted belt, including coeval and younger volcanic rocks (unit TRJv) was followed east from Vernon to the west flank of the Pinnacles gneiss dome (Reesor and Froese, 1968). Upper Triassic conodonts were obtained from this unit 17 miles east of Vernon (B. E. B. Cameron, pers. comm., 1972).

The Nicola Group (uTRN) has not been studied except where equivalent units are included with unit TRJv. At Salmon River, as noted above, argillite formerly of the Cache Creek Group (Jones, 1959) is now assigned to the Nicola Group. The stratigraphic position of unit TRJv is assigned on lithologic grounds based on comparison with units in the Bonaparte map-area (Campbell and Tipper, 1971), and the Kootenay Arc.

Unit Tv is believed a correlative of the Eocene to Oligocene Kamloops Group (Campbell and Tipper, 1971). Plant fossils collected from shales underlying basalt flows 13 miles south of Sicamous may confirm this. Northerly trending basalt dykes found throughout the Shuswap Complex testify to a widespread and deeply rooted source for the flows and may explain the ubiquitous radiometric ages (circa 50 m.y.) obtained from the Complex.

Structure

Four phases of mesoscopic structures described in the Mount Ida Group (Campbell and Okulitch, 1973; Fyson, 1970) have been observed in high grade metamorphic rocks to the east of the group, although, as pointed out by Fyson, early phases are better developed in high grade rocks in contrast to the low grade successions where late phases are best seen. Earliest recognized, nearly isoclinal folds trending east-west are folded by closely related yet temporally distinct, tight north-south trending folds. These two fold sets share a common recumbent axial surface and are refolded by open, upright east-west trending folds and are finally fractured and warped by gentle northerly trending folds. These four phases, affecting all formations of the Mount Ida Group were presumably initiated in post-late Triassic time.

Three independent lines of evidence point to a phase of deformation prior to the late Triassic. In gneiss east and southeast of Sicamous, phase one isoclines deform and partially recrystallize biotite foliation presumably formed by shear prior to "earliest" east-west folding. At Salmon River, isoclinally folded chlorite schist of the Chapperon Group is unconformably overlain by cleaved but only gently folded Upper Triassic argillite. In the Shuswap Range, gneiss found within the Eagle Bay Formation is cut by greenstone dykes believed to be feeders to Upper Triassic or possibly Paleozoic volcanic rocks. Gneissic foliation predates intrusion.

Thrusting of the Eagle Bay Formation over the Sicamous Formation (Campbell and Okulitch, 1973) is supported by fossil evidence noted above; however the position of the fault is in doubt. In the Shuswap Range, immediately north of Sicamous, greenstone lies conformably above and interfingers with limestone of the Sicamous Formation and is therefore assigned to unit TRJv. Structurally above this unit are siliceous schist, argillite, greenstone and limestone typical of the Eagle Bay Formation as mapped to the west, as well as gneiss of possible Paleozoic or Proterozoic age. The Eagle Bay Formation is therefore interpreted as a complexly folded and thrust faulted mass incorporating a broad range of units. The northeastern contact cannot be clearly defined in the Shuswap Range.

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11. LOWER JURASSIC SEDIMENTARY AND VOLCANIC ROCKS, BAIT RANGE, HAZELTON MAP-AREA (93M E½)

Project 710015

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A faulted and synclinorially folded horst in the Bait Range (Skeena Mountains) contains Lower Jurassic marine sedimentary and marine and nonmarine volcanic rocks assigned to the Hazelton Group (Fig. 1). Marine fossils and some stratigraphically restricted lithologies allow delineation of four major stratigraphic units (Fig. 2). The succession contains rich faunas and shows relatively straightforward stratigraphic relationships. Preliminary identifications of ammonites indicate Pliensbachian, Toarcian, and possibly Sinemurian ages.

Subdivision of the four units can be achieved using lithological assemblages. Both the units and their subdivisions are informally named for characteristic types of rocks, which are not necessarily dominant in or exclusive to a particular division or subdivision.

No rocks have been observed immediately overlying or underlying the Lower Jurassic rocks in the area. The upper sedimentary division may include some early Bajocian; the lower part of the lower volcanic division is equivalent to rocks elsewhere referred to the Takla Group (Lord, 1948) and thus may be in part Triassic. Lower Jurassic volcanic rocks are widespread in west-central British Columbia but detailed correlation of the rocks of the Bait Range is not yet possible.

Most of the volcanic rocks are intermediate in composition but basic and acidic types are found. Dominant weathering colours are associated with composition and allow rough differentiation and mapping of the various types of volcanics. The sedimentary rocks conspicuously lack nonvolcanic clasts, although such material could be present and undetected in the argillites. The succession involves two major episodes of volcanic activity within an otherwise totally marine environment far from source areas of nonvolcanic detritus.

Lower volcanic division

In northwestern Bait Range and Driftwood Range, three units can be recognized but these cannot be confidently applied in central and southeastern Bait Range. In these regions, the map symbols in Figure 1 indicate dominant lithologic types without necessarily implying stratigraphic relationships.

The greenstone subdivision consists of extremely altered volcanic rocks ("greenstones") in northern Driftwood Range and Driftwood River canyon that appear to underlie the red volcanic subdivision. The greenstones extend northward into McConnell Creek map-area where Lord (1948) mapped them as the Takla Group.

The red volcanic subdivision consists of more than 3,000 feet of mainly massive red, purple, and grey tuffs, volcanic breccias, flow rocks, and ?ignimbrites. Rare bedded rocks, waterlain volcaniclastic rocks, and fossiliferous calcareous units occur; green volcanic rocks are present in minor amounts.

The green volcanic subdivision varies from about 300 to 400 feet thick in Driftwood Range, to about 1,000 feet thick in northwestern Bait Range. It is dominantly green flow rocks, volcanic breccias, tuffs, and greywackes, with minor amounts of red volcanic rocks and calcareous beds and lenses. The upper parts are characterized by bedded, fossiliferous, calcite-cemented volcanic breccias and limestones.

Rare limy pods in the lower volcanic division contain a rich and varied shelly fauna characterized by *Weyla* spp. and abundant corals. Some argillite and siltstone interbeds contain ammonites similar to those of the middle sedimentary division. The fauna of the latter includes *Arieticeras, Prodactylioceras, ?Crucilobiceras, ?Uptonia, ?Leptaleoceras, ?harpoceratids*, and oxynoticeratids (tentative field identifications by the author). While plant fragments occur in sedimentary rocks throughout the succession, they are particularly common in the lower two divisions.

Middle sedimentary division

The division outcrops throughout the Bait Range, probably exceeds 3,000 feet in thickness, and consists of laminated and massive siltstones, greywackes, tuffs, breccias, and minor volcanic rocks. It is characterized by rusty weathering banded outcrops, abundant calcareous concretions, and abundant concretionary or disseminated pyrite.

The laminated siltstone subdivision is dominated by siltstone with sand grade feldspar crystals and lithic tuff and greywacke laminae which show rare graded bedding, occasional flame and loadcast structures, rip-up argillite clasts, and minor flow rolls, the last directed to the northeast wherever observed. A few rhyolite flow rocks, ?ignimbrites, felsic tuffs, locally thick diabasic volcanic rocks, and volcaniclastic greywacke interbeds occur.

The ?ignimbrite-breccia subdivision contains hard and massive, lenticular, thick beds of black, feldspathic, poorly sorted breccias consisting mainly of angular fragments of rhyolite, generally less than ½ inch in diameter, but with minor clasts as large as a foot across. The breccias appear to be strongly lenticular, certainly were rapidly deposited and are tentatively interpreted to be ignimbrites. Both of the upper subdivisions are strongly variable laterally in lithologies and thicknesses, and in places they cannot be recognized. A thick, dominantly siltstone and greywacke assemblage, which appears to thicken northward, may form a regionally extensive unit at the

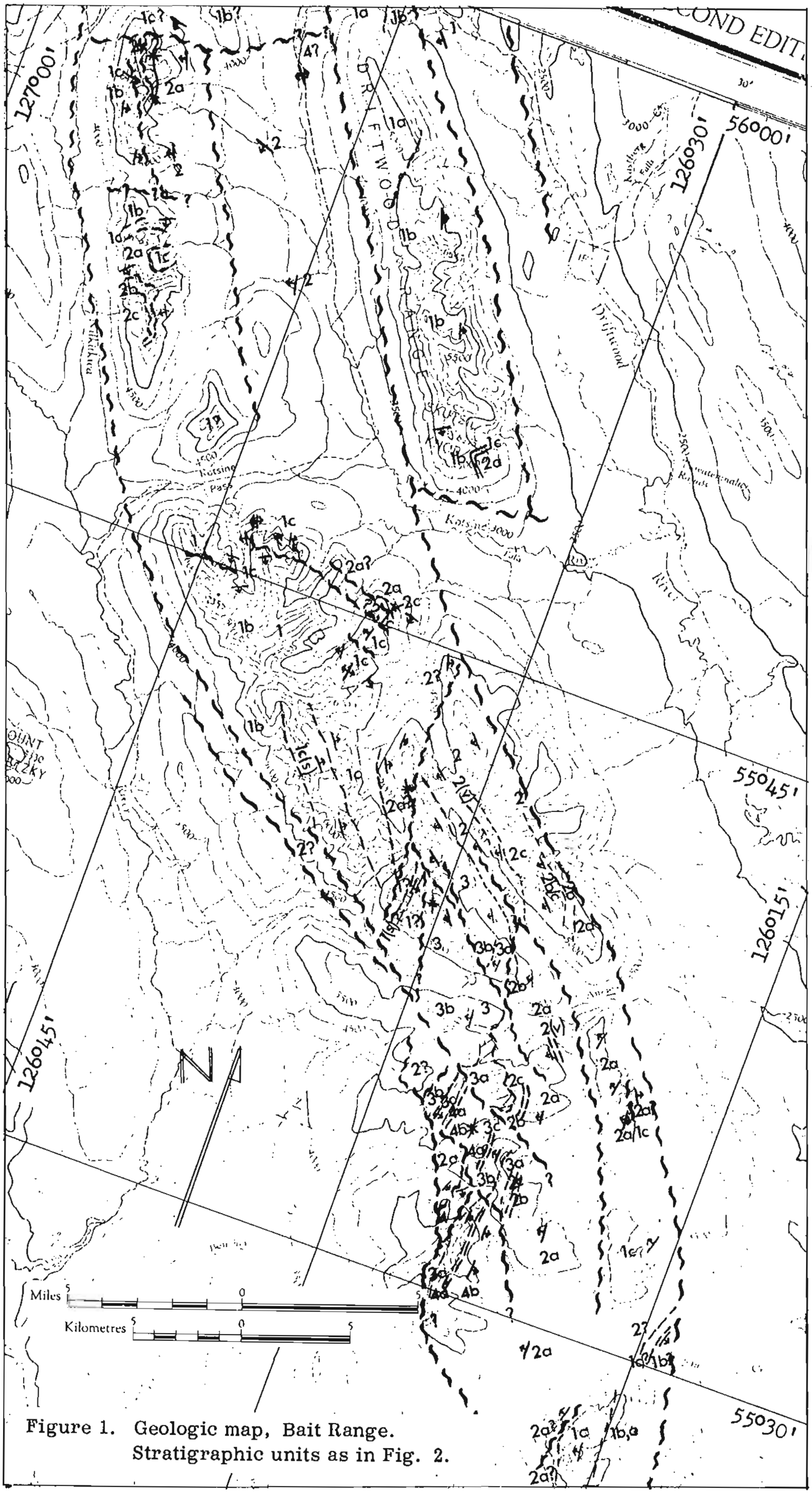

Figure 1. Geologic map, Bait Range. Stratigraphic units as in Fig. 2.

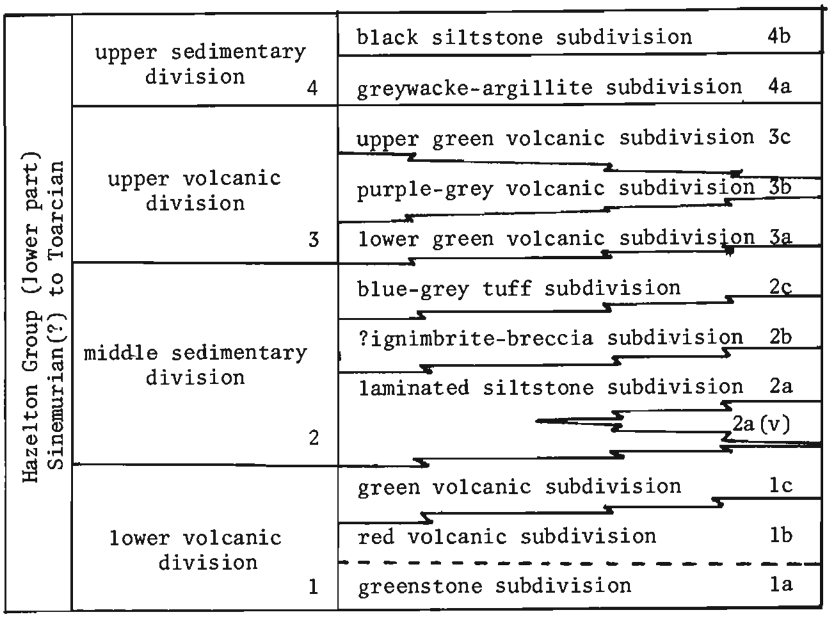

Figure 2. Stratigraphic units, Bait Range. Numbers designate informal map-units of Figure 1.

top of the middle sedimentary division. The blue-grey tuff subdivision appears to thin southward, and it, as well as the ?ignimbrite-breccia subdivision to the south, may be replaced by a unit dominated by rhyolite flows and felsic tuffs.

The blue-grey tuff subdivision contains abundant massive and laminated interbedded khaki-green-weathering blue-grey tuffs, dark brown weathering ?tuffs which are dark grey on fresh surfaces, cream-white felsic tuffs and rhyolite flows.

Upper volcanic division

The division underlies much of the southern Bait Range. Its total thickness may exceed 4,000 feet. The upper and lower contacts are gradational with marine sedimentary divisions.

The upper and lower green volcanic subdivisions mainly consist of green breccias, greywackes, tuffs, and flow rocks with some limestone pods; the last commonly contains rich and varied marine shelly faunas. Grey, purple, and red volcanic rocks are scarce. Rusty orange weathering colours, and intertonguing massive and well-bedded waterlain subunits are characteristic features. These subdivisions represent volcanic activity in marine environments with considerable reworking of the volcanic material.

The purple-grey volcanic subdivision is mainly massive tuffs, breccias, and flow rocks, mainly purple and grey in colour, but with subordinate red and green components. Waterlain volcaniclastic rocks with rare limestone pods occur locally. The subdivision may represent development of one or more volcanic centres above sea level. It appears to thicken to the north and west at the expense of the upper and lower subdivisions. In these directions, the upper green volcanic subdivision becomes entirely waterlain volcaniclastic rocks.

Faunas of the upper sedimentary and volcanic divisions include *Phymatoceras* and *Peronoceras* of Toarcian age (identified by H. Frebold). In contrast with the lower divisions, the shelly faunas characteristically contain *Myophorella, Trigonia,* and abundant belemnites, but lack *Weyla.*

Upper sedimentary division

The division is best exposed in southwestern Bait Range. It lacks the diabase-gabbro intrusions that are common in the underlying units, some of these thus may be related to extrusion of rocks of the upper volcanic division.

The greywacke-argillite subdivision consists of massive to laminated volcaniclastic greywackes, waterlain tuffs, and argillites, with sparse ammonite faunas. Its contacts are gradational with overlying and underlying units; the subdivision is about 200 feet thick.

The black siltstone subdivision is mainly black carbonaceous siltstone to fine-grained greywacke with minor medium- to coarse-grained greywacke interbeds. Laminated, platy, buff-weathering waterlain tuff of fine greywacke is locally prevalent. Ammonites are common locally and there are some beds with more varied faunas. Hard, banded, black and grey argillites form bluffy outcrops in some intervals and in places contain a rich and varied shelly fauna. At least one thick, massive, poorly sorted ?sediment-flow breccia occurs. The subdivision exceeds 1,600 feet in thickness; its top is not exposed.

Acknowledgment

T. Richards established the geological framework of the region and discussed with the author many of the ideas here presented.

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Project 720038

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Four-mile mapping of the Hazelton East-Half was completed in 1973. Sedimentary and volcanic rocks in the map-area range from Late Paleozoic to mid-Tertiary in age. Upper Paleozoic Cache Creek and Upper Triassic Takla Groups underlie small areas in the northeast corner of the map-sheet. Rocks of the Jurassic Hazelton and Lower Cretaceous Skeena groups are widespread. Volcanics of the Ootsa Lake Group are confined to the southern part of the map-area and the Takla Lake valley. The Sustut Group occurs in fault blocks in the western part of the area and underlies most of the broad Takla Lake valley.

Strata of the Cache Creek Group (map-unit 1) comprise interbedded phyllite, limestone, grit and pebble conglomerate. Serpentinite locally forms elongate masses in part conformable with enclosing strata. Rocks of the Cache Creek Group contain a penetrative foliation that is absent in all other rock groups in the area. In their most western exposures, adjacent to a major fault along the Ominicetla valley, the grade of metamorphism is in the biotite-epidote sub-amphibolite facies.

Upper Triassic rocks of the Takla Group (map-unit 2) underlie small discontinuous areas in the region of Nankai Peak and along the south border of the map-area. These rocks are mainly green, submarine, tuffs, breccias and flows with subordinate limestone, argillite and greywacke. Augite porphyry is abundant in the northern exposures.

The Hazelton Group (map-units 3 to 7) encompasses a wide variety of rock types of mid-Early Jurassic to earliest Late Jurassic age. The various units reported herein include different facies, that for convenience are shown as single time stratigraphic units.

Four units of variable thickness can be recognized in the Lower Jurassic continental and subordinate marine volcanics (map-unit 3). These are mid-Lower Jurassic continental and marine volcanics and upper Lower Jurassic continental and marine volcanics. Marine volcanics are scarce west of Morrison Lake. The great bulk of the volcanics are pyroclastics. The base of the lower continental facies is nowhere exposed, but its thickness is in excess of 5, 000 feet and perhaps as much as 10, 000 feet. The lower marine volcanics rest conformably on the lower continental volcanics and locally range up to 2, 000 feet thick. Combined thicknesses of the upper volcanic assemblages range from 500 to 5, 000 feet, with the continental facies predominant. In the western part of the area the upper and lower continental facies are indistinguishable and are probably conformable. East of Morrison Lake, they are separated by marine sediments and tuffs of map-unit 4. The volcanics show calc-alkaline affinities ranging from basalt to rhyolite and are correlative with the Sinemurian volcanics of the Smithers map-area (Tipper, 1972).

Map-unit 4 represents Lower Jurassic clastic and fine-grained pyroclastic rocks that are interbedded with and overlie the volcanic assemblages of map-unit 3. From west to east, the rocks display numerous facies variations. Immediately east of Morrison Lake, the rocks are well-bedded, shallow-water marine greywackes and tuffs. The main exposures of map-unit 4 occur along the length of the Bait Range. There, three facies are present. A lower, well-bedded, black argillite assemblage, about 500 feet thick, of late Sinemurian to Early Pliensbachian age, rests conformably on marine, early Lower Jurassic volcanics. Conformable above this unit is approximately 3, 000 feet of rusty weathering blue grey tuffs, argillite, limestone, minor grits and volcanics. Overlying conformalby and in part interfingering with the upper volcanic facies of map-unit 3, are 1, 000 to 2, 000 feet of mid-Toarcian black argillite, greywacke, minor limestone and feldspathic grits. South of Mount Netalzul, the rocks thin to about 50 feet, and the lower sedimentary facies were not recognized. These upper clastics are conformable with map-unit 5. Map-unit 4, east of Takla Lake, is represented by 2, 000 to 3, 000 feet of interbedded green sandstone, red gritty mudstone, red pyroclasts and conglomerate. Conglomeratic rocks are over 500 feet thick and clasts, to two feet in diameter, include large bladed plagioclase porphyries, augite porphyries, hypabyssal porphyritic granodiorite, vein quartz, minor limestone, and rip-up clasts from the interbedded sediments. The source of these clasts was probably the Takla Group to the east. The section appears continental in origin, except for minor, thin-bedded, well-winnowed marine sandstone and mudstone of probable Early Jurassic age.

Map-unit 5 is sandstone, greywacke and argillite of Upper Toarcian to Middle Bajocian age. The lower part is dominantly feldspathic, lithic arkose and subgreywacke with a green "glauconitic" matrix. South of Mount Netalzul, 500 feet of sandstone overlie the upper argillite of map-unit 4. East of Babine Lake, green marine sandstones are interbedded with red tuffs and overlie the continental volcanics of map-unit 3. East of Nakinilerak Lake they are absent. Conformable with the sandstone facies are 500 to 1, 500 feet of well-indurated, well-bedded, feldspathic greywackes, gritty argillites, volcanic grits and minor tuffs with locally abundant fossils.

Map-unit 6 comprises 2, 000 to 3, 000 feet of well-bedded, well-indurated silty greywacke, feldspathic grit with minor conglomerate near the base and gritty argillite near the top. Overlying the argillite is about 500 feet of well-bedded, well-winnowed, shallow water marine sandstone and siltstone that grades upwards into nonmarine sandstone, mudstone and conglomerate with minor coaly horizons. A middle Jurassic

(Bathonian) disconformity separates map-units 5 and 6.

Map-unit 7 comprises about 1,000 feet of volcanics that underlie the region immediately east and south of Mount Netalzul. These are green and maroon, epidotized and zeolitized, intermediate feldspathic tuffs, breccia and flows conformable and interbedded with the upper part of map-unit 6. Interbedded conglomerate, coaly mudstone and sandstone occurs locally.

The Skeena Group (map-units 8 and 9) includes a wide variety of sedimentary and volcanic rocks of mainly Early Cretaceous age. Lower Cretaceous volcanic rocks (map-unit 8) occur as several disconnected volcanic piles in the Babine and Takla valleys that range in composition from basic augite-plagioclase porphyry to rhyolite. Four centres of volcanism are recognized. From French Peak northwards, red, maroon, purple and green, massive feldspathic augitic porphyry breccias and flows immediately overlie conglomerate of the lower part of map-unit 9. In the upper Suskwa River valley, volcanics that range from augite porphyry to rhyolite overlie muscovite-bearing nonmarine conglomerate, sandstone and mudstone, and marine black shales of late Lower Cretaceous (Albian) age. Basic augite porphyry agglomerate, breccia and flows along the Babine River and west of the north end of Babine Lake are interlayered with Lower to Upper Cretaceous continental sandstone, red gritty mudstone and marine black shales and greywackes. To the east in the Takla Valley, unaltered, coarse-bladed plagioclase porphyry and augite porphyry overlie Middle Jurassic clastic map-units 5 and 6 and underlie Upper Cretaceous Tertiary rhyolite of map-unit 10.

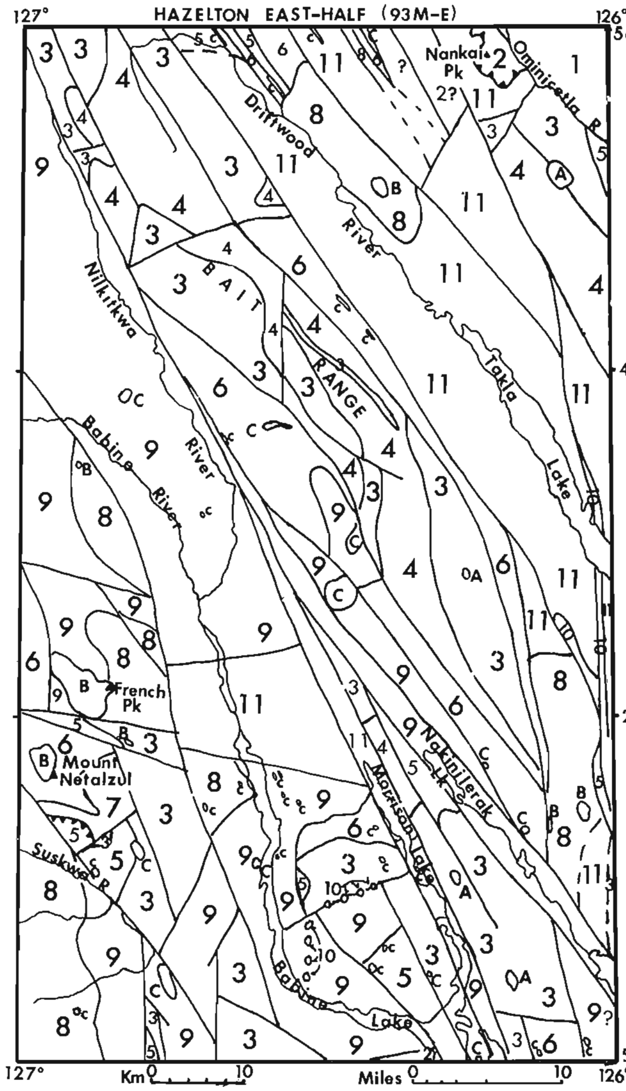
Lower Cretaceous clastics of map-unit 9 range from marine black shale to thick chert-pebble conglomerate. Most of the sediments are continental in origin except in the southern part of the map-area. They are generally well-winnowed, well-bedded, chert-feldspar-lithic-quartz arenites. Polymictic and chert-pebble conglomerates are common. One conglomerate 500 feet thick, at the head of Boucher Creek, contains abundant clasts apparently derived from the Lower Jurassic volcanics. This conglomerate rests on Oxfordian sediments of map-unit 6, but resembles other, much thinner conglomerates that have been included with the Lower Cretaceous clastic units. Lower Cretaceous clastics were not found east of the Bait Range.

Rhyolite of the Ootsa Lake Group (map-unit 10) with subordinate basic and intermediate volcanics outcrop as small intrusive - extrusive centres in the southern part of the area and underlie much of the Sustut Group in the Takla Valley.

Continental alluvium of the Sustut Group (map-unit 11) underlies part of the broad Babine Valley and most of the Takla Valley. These sediments are mainly quartz-feldspar-chert sandstones with interbedded mudstone and conglomeratic lenses. In the northeast corner of the map-area, gritty sandstone, mudstone and chert-pebble conglomerate with broad leaf flora in part underlie rhyolite tuffs (map-unit 10) and may represent the lower part of the Sustut Group.

Intrusive rocks outcrop mainly in the southern part of the map-area. None are of batholithic size and most are small plug-like bodies less than a square mile in area. Their number and great variety preclude separation on the accompanying map. Three age groups are tentatively distinguished; Early Jurassic (map-unit A), Cretaceous (map-unit B), and early to mid-Tertiary (map-unit C).

Lower Jurassic intrusions (map-unit A) include diorite, tonalite, syenodiorite and diabase. Most, in the southeast part of the map-area, intrude early Lower Jurassic volcanics. A plug of diorite-tonalite intrudes volcanics and sediments of map-units 3 and 4 east of Takla Lake. Diabase dykes and sills are common in the Lower Jurassic assemblages throughout the Bait Range. One diabase sill, east of the upper Nilkitkwa River, locally attains a thickness in excess of 500 feet. Cretaceous intrusions (map-unit B) in the western part of the area are granodiorite-tonalite around Netalzul Peak and biotite-quartz-feldspar porphyries around French Peak. Syenodiorite, syenite and granite (map-unit C) in the southeast part of the area are probable intrusive equivalents of map-unit 8. Many small stocks, plugs and dyke-like bodies of dior-



ite, gabbro, tonalite, granophyric granodiorite and rhyolite occur in the southern third of the map-area; many are rhyolite-diorite complexes related to the Ootsa Lake acidic volcanic centres. Their age is tentatively suggested to be Early Tertiary. Mid-Tertiary, fault-controlled, biotite-feldspar porphyry intrusions occur in the extreme north-central and southern sections of the area. The northern bodies are related to the Kastberg Intrusions and the southern bodies are related to the Babine Intrusions.

Long, north-northwest trending lineaments and faults divide the area into distinctive geologic and geomorphologic belts. Major east-west cross faults and a vast array of minor block faults greatly modify the general linear pattern of the major north-northwest trending structures. Thrust faulting is directed in an east to northeast direction in the western part of the map-area, but in the northeast corner, is directed to the west-southwest. In the latter region, augite porphyries of the Takla Group are thrust over sandstones of the Upper Cretaceous Sustut Group. Folds are prevalent throughout the region and are probably related to the more dominant faults. Compressional structures probably developed in mid-Cretaceous times and extensive block faults, similar to a basin and range structure, developed during mid-Tertiary time.

Most rock units are devoid of obvious mineralization. Minor copper occurrences are scattered throughout the Lower Jurassic volcanics and in the Lower Jurassic clastics east of Takla Lake. The most important mineralization is related to the mid-Tertiary Babine Intrusions in the vicinity of Babine, Morrison and Nakinilerak lakes. These bodies are most common along the major north-northwest faults. Their locus seems to be concentrated on or near the crest of a northerly trending structural arch, that exposes Upper Triassic and Lower Jurassic strata in the vicinity of Babine Lake, and plunges under the Cretaceous and Tertiary sedimentary and volcanic rocks to the north and to the south into the Smithers map-area.

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LEGEND

SUSTUT GROUP

11 : Upper Cretaceous - Lower Tertiary, sandstone, siltstone, mudstone, conglomerate.

OOTSA LAKE GROUP

10 : Upper Cretaceous - Lower Tertiary, rhyolite, dacite, basalt flows tuffs and breccia.

SKEENA GROUP

9 : Lower Cretaceous, sandstone, shale, conglomerate, mudstone, minor volcanics and coal.

8 : Lower Cretaceous, flows, tuffs and breccias, augite porphyry, bladed plagioclase porphyry, rhyolite tuffs, biotite-hornblende - feldspar porphyry.

HAZELTON GROUP

7 : Oxfordian; green, red, purple intermediate breccia, flow and tuff.

6 : Callovian-Oxfordian; sandstone, greywacke, conglomerate, argillite, mudstone, minor coal.

5 : Upper Toarcian-Middle Bajocian; greywacke, sandstone, argillite, red tuff, conglomerate.

4 : Upper Sinemurian - Middle Toarcian; argillite, greywacke, tuff, limestone.

3 : Upper Sinemurian - Middle Toarcian; rhyolite to basalt flow, tuff and breccia.

TAKLA GROUP

2 : Upper Triassic; augite porphyry flow, tuff, breccia, limestone, argillite and greywacke.

1 : Upper Paleozoic; phyllite, limestone, conglomerate, serpentinite.

INTRUSIVE ROCKS

C : Lower Tertiary; rhyolite, diorite, gabbro, granodiorite, biotite-feldspar porphyry.

B : Cretaceous; biotite-quartz-feldspar porphyry, tonalite, syenodiorite, syenite.

A : Lower Jurassic; tonalite, diorite, syenodiorite.

Project 700026

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Spectrum Range

Mapping of the late Tertiary and Quaternary Spectrum Range volcanic complex (57°20'N, 130°45'W) was completed to a scale of 1:25,000. The five principal stages of volcanic activity, described in a previous report (Souther, 1973) were recognized throughout the area. In addition, several eruptive centres were identified. Two of these, the Armadillo centre and the Spectrum centre, are associated with subvolcanic intrusions and peripheral haloes of hydrothermal alteration.

The deeply dissected Armadillo centre is near the apex of a broad lava dome comprising more than 3,500 feet of light grey sodic rhyolite and green peralkaline trachyte flows and pyroclastic rocks. Several individual vents are confined to a circular area about two miles in diameter within which the lavas and associated explosion breccias are silicified and bleached to a white, rusty weathering rock containing disseminated pyrite. Breccias in the upper part of the volcanic edifice contain a stockwork of hydrous iron oxides and, less commonly, of sulphides. The lowermost exposures of altered rock are cut by fresh dykes and large irregular masses of fine- to medium-grained aegirine syenite that is clearly an intrusive equivalent of the trachyte lavas. Contacts with the syenite are commonly sharp and the adjacent rock shows only minor contact effects. The pervasive hydrothermal alteration of rocks in the vent area thus followed extrusion of the trachyte lava but preceded the rise of subvolcanic syenite magma to its present level of exposure.

The Spectrum centre is a well defined volcanic neck comprising a dark grey, moderately welded, trachytic vent breccia about 1,000 feet in diameter. It pierces at least 2,000 feet of sodic rhyolite, trachyte and basalt that underlie the central Spectrum Range, and it is believed to be the source of a dark grey peralkaline trachyte that caps the higher mountains of the range. Rocks in a zone up to one quarter mile wide adjacent to the neck have undergone intense silicification, bleaching and minor pyritization, whereas the vent breccia and porphyritic intrusive phases near the base of the neck are unaltered.

The absence of contact effects around subvolcanic intrusions related to the centres suggests that direct effusion of volatiles from the magma was not an important factor in formation of the alteration haloes. Instead, the pervasive silicification and pyritization appear to be the result of a convecting hydrothermal system that lay above a source of heat in the central parts of the volcanoes. In the Armadillo centre hydrothermal alteration was mostly post eruptive whereas alteration around the Spectrum centre preceded eruption of the vent breccia and associated trachyte flows.

Collections from both centres were made with the aim of studying the net gain and loss of major and trace elements in the hydrothermally altered zones.

Tahltan Syenite Stock

A program of detailed mapping and systematic sampling was started on the Tahltan Syenite Stock. The stock is exposed in Stikine Canyon near Tahltan River where it intrudes Triassic augite andesite breccias and is overlain unconformably by late Tertiary intracanyon basalt. It has a north-south diameter of about 2.5 miles, is roughly circular in plan, and exhibits a pronounced concentric zonation.

Four principal zones were recognized in the field:

1. A marginal zone (0.4 to 0.6 mile wide) of coarse grained, lustrous black pyroxenite containing up to 40% magnetite, 5 to 10% apatite and sparse crystals of biotite up to 3 cm across.

2. A mixed zone (0.1 to 0.3 mile wide) of veined pyroxenite and agmatite in which the pyroxenite is cut by a stockwork of, or occurs as, angular blocks within fine grained pink syenite.

3. A zone of pink, medium grained pyroxene syenite (or monzonite?).

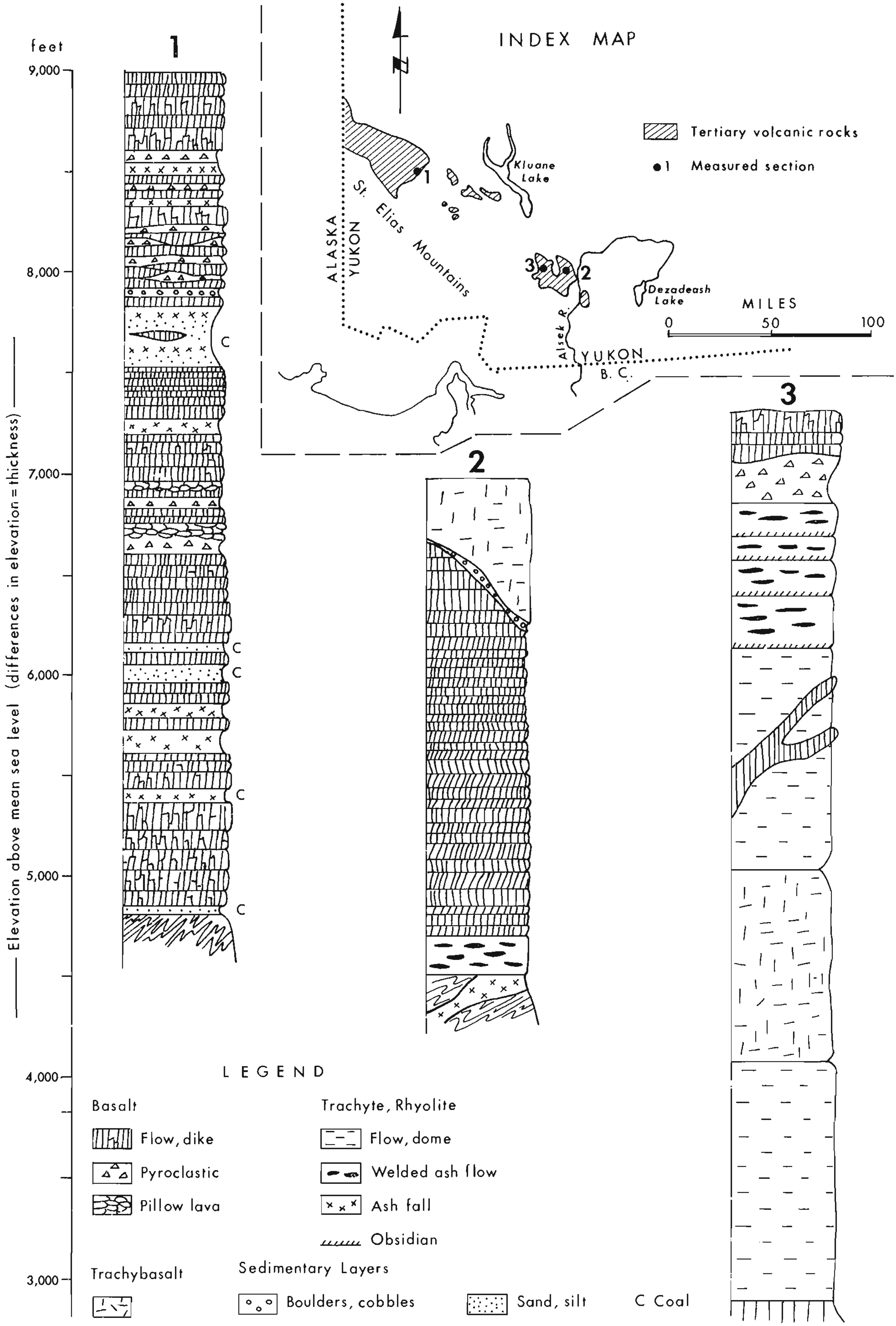
4. A core zone of leucocratic, porphyritic syenite in which the feldspars have undergone intense deuteric alteration.

The two inner zones contain traces of disseminated sulphides including chalcopyrite and in addition, the central zone contains small local concentrations of cupriferous sulphides along fractures.

Although the Tahltan body has little or no economic potential, it is petrologically and structurally similar to other cupriferous alkaline bodies, some of which contain proven deposits, that lie along a north-south belt through the Stikine region. Its study should thus have a direct influence on regional metallogenic concepts. Age dating and study of trace element geochemistry of minerals from the stock and from adjacent volcanic rocks is being undertaken in an effort to establish whether or not the stock is coeval with and genetically related to the enclosing Triassic volcanic rocks.

Tertiary Volcanic Rocks of St. Elias Mountains

A brief reconnaissance was made of Tertiary volcanic rocks in St. Elias Mountains. Previous mapping by Kindle (1953), Muller (1967), and Wheeler (1963) established the distribution and late Tertiary age of the rocks which comprise more than 4,000 feet


feet
9,000
8,000
7,000
6,000
5,000
4,000
3,000
Elevation above mean sea level (differences in elevation = thickness)
1
2
3
C
INDEX MAP
N
Tertiary volcanic rocks
1 Measured section
Kluane Lake
St. Elias Mountains
ALASKA
YUKON
Dezadeash Lake
Alsek R.
YUKON
B. C.
MILES
0
50
100
LEGEND
Basalt
Flow, dike
Pyroclastic
Pillow lava
Trachyte, Rhyolite
Flow, dome
Welded ash flow
Ash fall
Obsidian
Trachybasalt
Sedimentary Layers
Boulders, cobbles
Sand, silt
C Coal

of volcanic flows and pyroclastics. They are confined to the eastern ranges of the St. Elias where they form a discontinuous belt that trends northwesterly into the region underlain by Wrangell Lava in southern Alaska. Throughout most of the area the lavas are flat lying or gently tilted. They have, however, been involved in Neogene faulting, and particularly near the Shakwak fault zone, they are intensely shattered and folded.

Three stratigraphic sections were measured (Fig. 1). These reveal a complex alternation of acid, intermediate and basic lavas from many separate vents. Section 3, on Felsite Creek, is near the centre of an enormous pile of light coloured trachyte (?) that includes individual lava domes more than 1,000 feet thick as well as numerous welded ash flows having a composite thickness of nearly 4,000 feet. Six miles east of Felsite Creek, section 2 includes only one ash flow, 200 feet thick, which rests directly on pre-Tertiary basement and is overlain by more than 2,000 feet of uniform basalt flows. Section 1, facing the north side of Steele Glacier, is predominantly basalt but the succession is interrupted by many layers of siliceous air-fall pumice. This material commonly shows evidence of reworking and mixing with fine fluvial or lacustrine silt and sand. Most of these sedimentary layers contain coalified plant debris, broad leaf plant impressions and, locally, coal seams up to 14 inches thick.

In each of the measured sections there is a conspicuous absence of coarse clastic material intercalated with the flows. Rare layers of pebbles and cobbles include only clasts derived from Tertiary lavas whereas clasts of older rocks, which should be present if the central ranges were being uplifted, are absent. This suggests that the volcanic activity took place during a period of tectonic quiescence. The lavas appear to have poured out onto a gently sloping surface traversed by stagnant rivers and dotted with shallow lakes and peat bogs. The profound uplift that raised the St. Elias Mountains to their present elevation must post date eruption of the Tertiary lavas.

The Wrangell Lava of southern Alaska is described as predominantly andesite and basaltic andesite with minor basalt, dacite and rhyodacite (MacKevett, 1971). A preliminary scan of thin sections from rocks of the eastern St. Elias Mountains suggests that basalt is predominant and that all of the lavas are alkaline. Most of the basalt contains abundant olivine and strongly pigmented aphitic plates of titanaugite. The felsic rocks are commonly altered but two sections contain remnants of aegirine-augite. On this basis, the rocks are tentatively assigned to the alkali-olivine basalt, trachybasalt, trachyte, sodic rhyolite succession. If this is borne out by further work, it constitutes an important transition between contemporaneous calc-alkaline volcanism in the Aleutian chain and alkaline to peralkaline volcanism in northern British Columbia.

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14. GEOTHERMAL PROJECT

Project 730067

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This project was initiated in response to increasing interest in the use of geothermal energy to supplement diminishing reserves of fossil fuel. The geothermal potential of western Canada is impossible to assess on the basis of existing data. Several Quaternary volcanoes in British Columbia have produced lavas of an age and type commonly associated with hydrothermal fields elsewhere but no active fumeroles or boiling springs are known in Canada. This does not rule out the possibility that high temperature hydrothermal systems may exist at depth. Water leaking from such a system may be cooled and diluted as it rises and emerges at the surface as a warm spring. The chemistry of such water may reflect equilibrium with the enclosing rock at depth and hence may be used as a guide in estimating subsurface temperature.

During the 1973 field season approximately 50 thermal springs were sampled in British Columbia. Analyses for major trace elements as well as dissolved gasses are being made by the Geochemistry Section of the

Table 1

Element	Low Value	High Value	No. of Analyses
Na	2ppm	1100ppm	49
K	<5ppm	52ppm	49
Ca	<10ppm	370ppm	49
Mg	<1ppm	235ppm	49
As	<1ppb	38ppb	53
U	<0.02ppb	13ppb	53
Li	<10ppb	1280ppb	49
Mn	<5ppb	1900ppb	49
F	60ppb	8000ppb	45
Cl	<1.0ppb	1678ppb	49
CO_2	0.0ppm	59.6ppm	49
HCO_3	12.3ppm	2860ppm	49
SO_4	11ppm	480ppm	20
SiO_2	17ppm	424ppm	49

ppm - parts per million
ppb - parts per billion

Geological Survey of Canada. Preliminary data indicate a wide range of values for both major and trace elements (see Table 1). Carbon dioxide and nitrogen are the principal dissolved gasses in all springs. Nine springs contain significant H_2S, two of them more than 10,000 ppm. Of particular interest are several springs with more than 400 ppm dissolved SiO_2 which may indicate high subsurface temperature.

Project 730037

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Study of lower Paleozoic rocks in the Pelly Mountains was initiated as a follow-up to earlier reconnaissance geological mapping. Work was aimed at comparing and contrasting the stratigraphic and structural relations of Cambro-Ordovician phyllite at four widely separated localities with similar possible correlative rocks found in Anvil Range where they are host to stratabound zinc-lead mineralization.

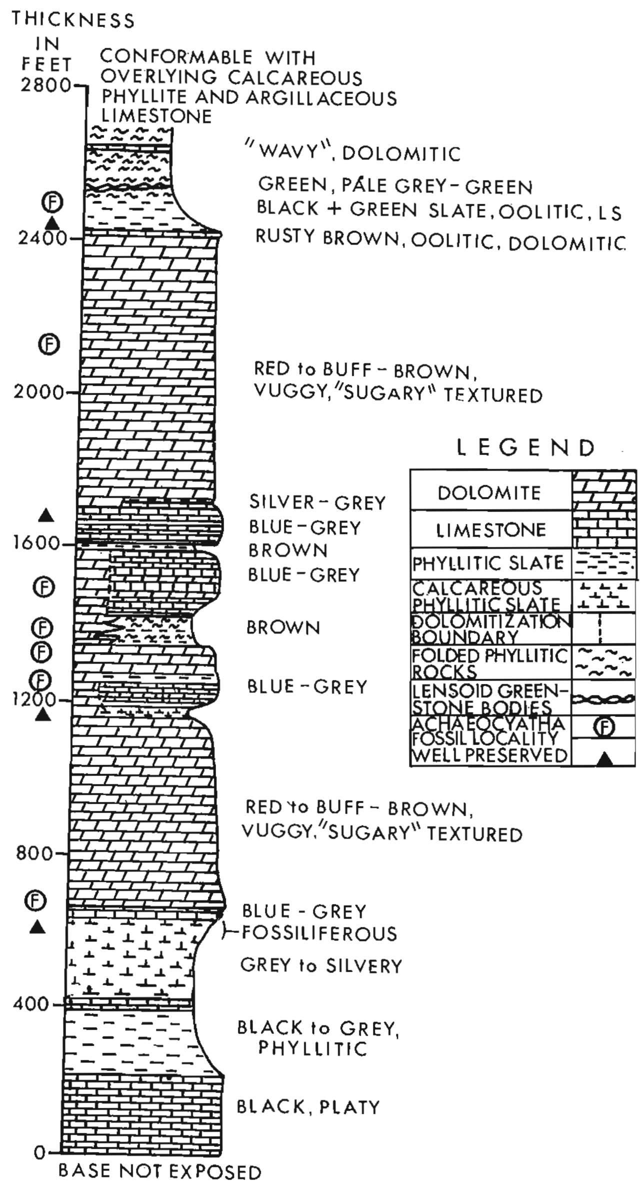
A part of Quiet Lake map-area (105F) south of Ross River (N 61°35' to N 62°00' and W 132°15' to W 133°00') where extensive areas of phyllite have been mapped (i.e. unit 2 of Wheeler, et al., 1960a) was examined by Tempelman-Kluit. There the belt of phyllite mapped along the southwest side of Tintina Trench is a zone in which northwest trending normal faults expose a variety of rock units. Phyllite, from which trilobites of probable Upper Cambrian age (W.H. Fritz, pers. comm.) were recovered at two localities, underlie only a small part of this zone. Other rocks include a prominent black slate and argillite unit found in fault blocks near Tintina Trench. Middle Devonian crinoid columnals were discovered in some of these rocks and they may be a facies equivalent of the Silurian and Devonian massive carbonate unit of Wheeler, et al. (1960a), which contains the same fossils. A prominent bright orange weathering cherty tuff unit with large lenses of sandy grey limestone several hundred feet thick is also found in this faulted belt. A well preserved and diverse conodont fauna of probable Middle Upper Triassic age (B.E.B. Cameron, pers. comm.) was recovered from the limestone.

These Triassic rocks differ markedly from strata of the Lewes River Group, but resemble those found in and north of Tintina Trench elsewhere in Yukon. The limestone is equivalent to unit 8 of Wheeler, et al. (1960a), but unit 8 as mapped by them may include older rocks. A resistant, red-brown weathering thin-bedded siltstone and limestone unit whose stratigraphic relations are unknown also occurs in blocks in this faulted belt. The Devonian and Mississippian unit 5 (black clastic and volcanic) of Wheeler, et al. (1960a) is probably equivalent to their unit 6 (volcanic) and the two map-units are apparently time equivalents. Phyllite mapped as unit 2 (Wheeler, et al., 1960a) around Lapie Lakes differs from that found nearer Tintina Trench (also included in unit 2). The former contains prominent flows and tuffs of intermediate to basic composition and strikingly resembles the lead-zinc host rocks of the Anvil district. The latter does not contain volcanic rocks.

The style of deformation in the faulted belt along Tintina Trench is characterized by northeasterly directed thrust faults involving rocks at least as young as Upper Devonian cut by younger steeply dipping normal faults that are Cretaceous or Tertiary. The significance of the important structural discordance defined by the difference in internal structure between the Siluro-Devonian and older rocks is unknown.

B. Read studied Lower Cambrian rocks near Ketza River in detail and paid particular attention to the relations between these rocks and the overlying phyllite (unit 2 of Wheeler, et al., 1960a). In the area examined the contact appears conformable. A section measured

LOWER CAMBRIAN SECTION 5 MILES S.W. OF THE KETZA RIVER 61°34'06"N, 122° 23' 36" W



in the Lower Cambrian rocks is summarized in columnar form in Figure 1.

G. Abbott examined the phyllite at two localities (Mount Hundere, N 60°32', W 128°54' in Watson Lake map-area and near McEvoy Lake, N 61°48', W 130°13' in Finlayson Lake map-area) to compare its lithology and structural relationships with that of possible equivalent strata in Anvil Range.

The phyllitic rocks at both localities include a wide variety of lithologies but have some similarities to one another and to those in Anvil District. At Mount Hundere the phyllite (unit 4 of Gabrielse, 1967) commonly includes tuffaceous or volcanogenic phyllite and small greenstone lenses like those of unit 3 in Anvil Range (Tempelman-Kluit, 1972). Near McEvoy Lake the phyllite (unit 2 of Wheeler, et al., 1960b) includes gritty quartzite like that of the Proterozic "Grit Unit" as well as dark spotted hornfels and phyllitic argillite. Light coloured, thinly banded, calc-silicate skarn and hornfels, also included in this unit, closely resembles unit 2 of Tempelman-Kluit (1972), and apparently overlies the gritty rocks.

At Mount Hundere the phyllite is characterized by highly irregular small scale folds outlined by bedding. The foliation related to these folds is itself tightly folded, and this folding has led to development of a new axial plane foliation. A strong foliation cuts bedding in the phyllite at McEvoy Lake, but is not itself folded.

The internal structure of the phyllite differs markedly from that of the overlying Siluro-Devonian rocks at both localities because these younger rocks are not internally deformed. Whether this difference is evidence of unconformable relations, as suggested in the Anvil district, or whether it is the expression of differences in competency of the rocks is not resolved.

The area southwest of Tintina Trench has been considered unfavourable for occurrences of large stratabound base metal showings, and has been neglected in exploration for such deposits. Considering the general similarity between the lower Paleozoic succession of this region and that of Selwyn basin, and considering that carbonate-shale facies boundaries, so prominent in this area, are targets for mineral exploration in more northeasterly parts of Yukon, this neglect seems unwarranted.

An occurrence of finely disseminated galena and sphalerite in light coloured banded skarn was found about six miles south-southeast of the eastern tip of McEvoy Lake.

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16. EXPLORATION GEOCHEMISTRY IN THE SOVIET UNION

Project 700046

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During July and August, 1973, R. J. Allan spent six weeks in the USSR, visiting institutes involved in aspects of geochemical exploration. The institutes seen were: The Institute of Mineralogy and Geochemistry of Ore Deposits (I. G. E. M.) and the Institute of Mineralogy and Geochemistry of Rare Elements (I. M. G. R. E.), in Moscow; the Institute of Geochemistry in Irkutsk; the Permafrost Institute in Yakutsk; the All Union Geological Research Institute (V. S. E. G. E. I.) and the Institute of Arctic Geology (N. I. I. G. A.) in Leningrad. The three main institutes involved in geochemical exploration are I. G. E. M. ; the Institute of Geochemistry in Irkutsk; and I. M. G. R. E. The former two, along with the Permafrost Institute are within the Department of Geology, Geophysics and Geochemistry of the Academy of Sciences, USSR. The latter along with V. S. E. G. E. I. and N. I. I. G. A. are within the Ministry of Geology.

I. G. E. M. , in a large, old building, has a staff of 800. About 150 are scientists, the remainder are scientific technicians and helpers. The laboratories are well equipped with at least 10 emission spectrographs, 3 electron microscopes, 2 electron microprobes, 1 laser microprobe, two atomic absorption spectrophotometers, several X-ray diffractometers and several wet chemical laboratories. Geochemical and mineralogical characterization of all Soviet ore deposit types, is the main work. Workers such as Drs. Perel'man, Bugelski and Ozerova are well-known experts on surficial metal migration.

The Institute of Geochemistry in Irkutsk (Fig. 1) is the main centre for development of geochemical exploration methods in Siberia and probably in the USSR. There is a staff of 350, including 110 scientists. The remainder are again technicians and helpers. Bedrock geochemistry and the geochemistry of primary dispersion halos are the main topics of research

Figure 1. Geochemical Institute, Irkutsk, Siberia.

Figure 2. Dr. S. Shvartsev with Emission Spectrograph for gold analysis, Irkutsk.

Figure 3. Dr. B. Shmakin, Deputy Director, Institute of Geochemistry, Irkutsk, with X-ray fluorescence quantometer.

Studies of surficial geochemical problems are of secondary importance but are conducted under Dr. V. Polikarpocthkin, perhaps the Soviet Union's leading expert in this field. Dr. Shvartsev of Tomsk Polytechnical Institute arrived at Irkutsk for joint discussions. Dr. S. Shvartsev is one of the leading exploration hydrogeochemists in the USSR. The analytical facilities at the institute are considerable and include: at least 20 emission spectrographs (Fig. 2); 2 X-ray fluorescence quantometers (Fig. 3); 6 mass-spectrometers; X-ray diffraction equipment; 2 atomic absorption spectrophotometers; and several wet-chemical laboratories. There is also a large machine-shop and a laboratory for high temperature-pressure experiments.

The third main geochemical exploration institute in the USSR is I. M. G. R. E. As part of the Ministry of the Geology, the staff under the direction of Dr. S. Grigoryan, supervise all of the routine surficial geochemical surveys conducted in the USSR; and all of the primary dispersion halo drilling programs. Dr. Grigoryan is the leading Soviet expert on the interpretation of primary dispersion halos. The Ministry field parties involved in geochemical sampling, number about 1, 000 men. Samples are analyzed at Mineral Resource Laboratories in each administrative region of the USSR.

At all three institutes, 10 million samples per year were said to be analyzed in the USSR. Nearly all analyses are done by emission spectrograph for 10 or more elements. Considering the number of emission spectrographs seen in the research institutes alone, there is no reason to doubt this figure. Two major problems in geochemistry are faced in the USSR: (1) the interpretation of the results from analyses of samples, collected mainly over the last 15 years; and (2) the detection of blind ore deposits down to the present economical limit of 3, 000 feet. These two are related in that it is predominantly the interpretation of the former in terms of the latter that is considered the present and future direction of geochemical exploration. The main approach to the problem is the systematic geochemical characterization of primary dispersion halos for all ore types.

The other institutes visited were not considered to be directly involved in geochemical exploration. However, they are well up in the list of institutes indirectly involved in this field. The Permafrost Institute, Hydrogeology Division, under Dr. V. Klimochkin, analyzes water, drainage sediment and glacial drift and interprets the results in terms of blind ore occurrences. They are presently expanding this work. N. I. I. G. A. has at least five geochemists working on research problems of hydro- and bio-geochemistry in Arctic regions. At V. S. E. G. E. I., the regional geochemical program and the laboratories are under the direction of Dr. A. Smyslov. The analytical equipment includes: at least 7 emission spectrographs, 2 atomic absorption spectrophotometers, 2 X-ray fluorescence quantometers, 2 laser microprobes, and several wet chemical laboratories. Their research is orientated towards regional metallogeny. Geochemically, this consists of the detection of geochemical provinces. This is done by routine rock analyses. Dr. Smyslov expects to have a complete geochemical province map of the USSR ready by 1978.

In summary, the total professional staff and analytical equipment involved in direct and indirect aspects of geochemical exploration, substantiates that this field is considered of major importance in natural resource assessment and mineral deposit exploration in the USSR. There is no attempt to devise quick solutions to geochemical problems, for example by advocating certain sample types, or densities or elements to be used. The maxim in the USSR is that complete geochemical characterization of ore, primary dispersion halos, geochemical provinces, secondary dispersion halos, surficial materials, and surficial dispersion processes will result in the successful use of geochemistry in locating both surface and blind ore deposits.

Project 730002

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Organic debris in drainage systems may be a sample medium for geochemical exploration and environmental pollution surveys in the southern, forested, non-permafrost Canadian Shield. Organic material from stream beds has been proved a superior sample media to inorganic, stream bed, sediment in the similar geochemical landscape of northern Sweden (Brundin and Nairis, 1972). In the disrupted drainage systems of the southern Shield, the most easily accessible organic debris is found at the bottom of lakes (Fig. 1). Because of this, the study began in late 1972, with the collection of organic-rich, gyttja from lakes in the Red Lake-Uchi area of northwestern Ontario (Timperley et al., 1973).

During 1973, laboratory studies were conducted on the chemical binding of elements in these gyttja samples. Several significant conclusions, in terms of interpretation of analytical results from gyttja surveys, came from this work (Timperley and Allan, 1973) and these are summarized as follows. The existence of free sulphide ion was confirmed. It was calculated that copper would accumulate in gyttjas as a sulphide precipitate and that zinc would be present as both a sulphide precipitate and as organic complexes. Background levels of these elements were shown to increase with an increase of organic matter content of the sediment on a dry matter basis. Interstitial water was shown to be linearily related to organic content which, for all sample types, is dispersed in this water in the same concentration. Because dispersed or colloidal copper sulphide would be present in the interstitial water, it is suggested that copper content of gyttjas should be expressed as μg/g interstitial water, for meaningful interpretation. Zinc should be expressed relative to organic content. The mode of accumulation of two metals has been determined. Whether one or other of the interpretation procedures is used for a particular element depends on its relative tendency to form a metal sulphide or an organic complex. These procedures and interpretations are fully discussed for the Red Lake samples.

Several aspects remain for investigation. Those most relevant to exploration are: (1) Is sufficient metal moved into lake gyttjas from natural or man-made sources, to cause anomalous concentrations to form? (2) depending on the purpose of the survey, what lake sample density is best used? (3) how many samples per lake are required? In known areas of high potential

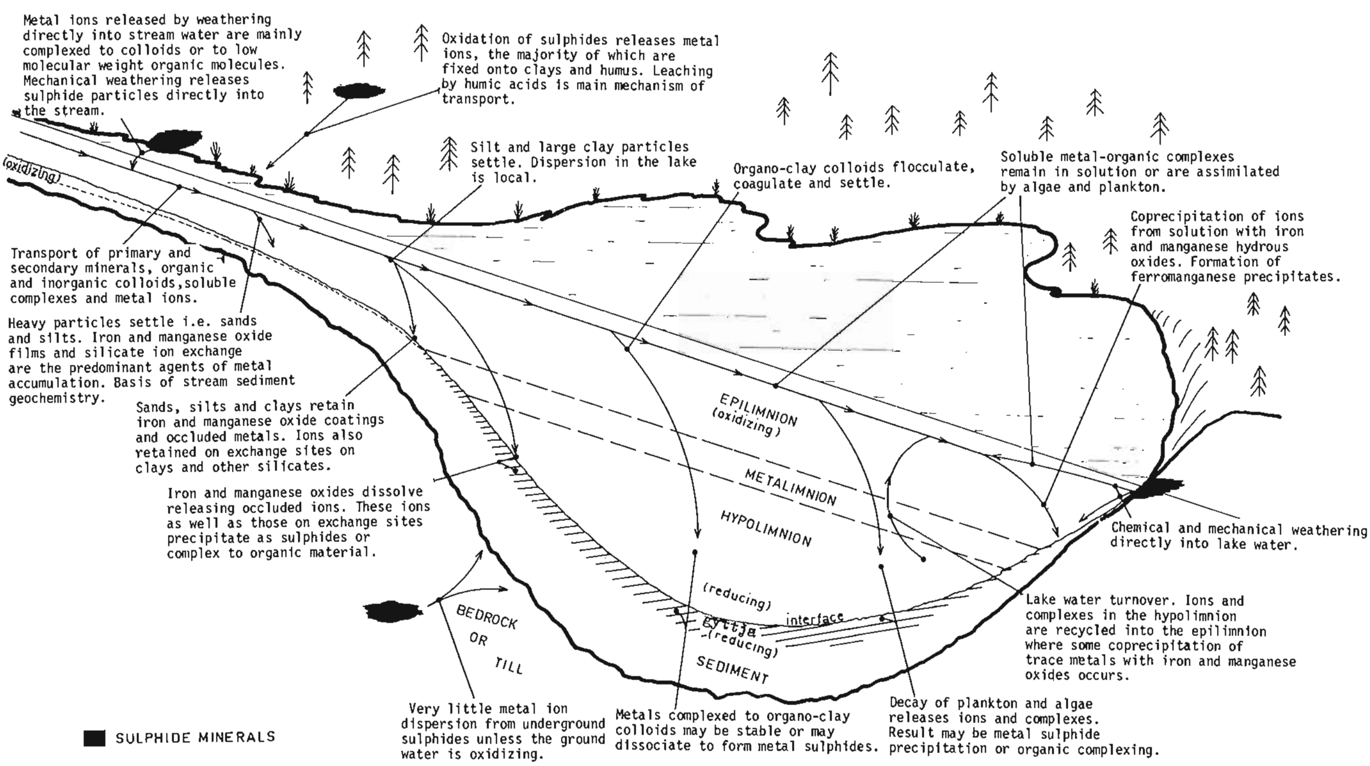

Figure 1. Typical lake in the southern, forested, non-permafrost, Canadian Shield.

in the southern Shield, geochemical methods based on overburden drilling have been proven successful. This is, however, a very expensive procedure. Collection of gyttjas is relatively inexpensive. One problem which can preclude the use of drainage system surveys in known mining areas, is contamination. With materials accumulated on lake bottoms, this aspect may possibly be overcome by collecting sediment cores. Accumulation of sediment in lakes of the southern Shield is on the average at a rate of a few centimetres or less per hundred years. One aspect of core collection, is that providing that downward leaching of metals is insignificant, then a core sample may provide an original non-contaminated sample. Alternatively, a complicating factor could be upward movement of metals from lower sediment layers. This could be a chemical movement or due to benthic insects. Sikes and Drain (1973) say that this effect can produce higher Hg concentrations in the surface sediment layers of lakes. Collection of cores in lakes with background metal levels where there is no anomalous inflow of metals from either natural or man-made sources, could clarify this situation. In many ways, lake sediments can be considered as subaqueous soils, with associated chemical complexity. It may be that contamination is insignificant in most cases. Another aspect, is that a regional level of environmental contamination may be rapidly assessed. This may be significant in interpretation of geochemical results from other surficial sample media. Significant surficial geochemical results in or near known mining operations may be discarded erroneously, due to lack of knowledge of the degree and nature of contamination levels.

Because mining in the southern Shield is seldom older than one hundred years, a core of 4 to 8 inches should pass well into pre-mining activity sediment. Such cores were collected during 1973, from a number of lakes in the Red Lake, Sudbury and Chibougamau areas. Samples in each case came from over an area of some 200 square miles from lakes over various rock types and from near natural metal occurrences and mining operations. Some cores were completely gyttja, others inorganic sediment, and others a combination of organic above inorganic sediment. Analyses of these cores should provide data of use in conducting surficial geochemical surveys in high-potential areas of mining activity in the southern Shield.

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DETERMINATION OF MAJOR ELEMENTS IN ROCKS

Project 580175

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Major element analysis in the Geochemistry laboratories is being carried out this year by atomic absorption spectrophotometry, using the Varian Techtron AA5, rather than by emission spectrometry, using the tape machine, as has been the case in previous years. The sample preparation is much the same — a lithium tetraborate/strontium tetraborate flux is used, the resulting bead is ground for 5 sec. and a 210 mg weight of this product is dissolved in nitric acid to give a final solution containing 0.1 M nitric acid, 1700 $\mu g\ ml^{-1}$ strontium and with a final dilution factor of 10,000. Standards are prepared in a similar manner. Table I gives an indication of the overall precision and accuracy of the method. The precision data is based on 10 separate major element determinations of the control, G-G, a granite. Accuracy was tested by analyzing the seven U.S.G.S. standard rocks by this technique; G-2 is cited here as an example. The production rate is 100 analyses every 4 man days.

Work is being done on silicon analysis at the present time but a less dilute solution is required in this case. In the near future, a burner capable of supporting a *separated* nitrous oxide/acetylene flame will be introduced to this laboratory. This should improve markedly the determination of elements such as barium, strontium, aluminium and silicon as the error introduced by flame noise and background absorption will be almost completely eliminated.

TABLE I

Element	Type of Flame	% Element in G-G	Coefficient of Variation %	% Element in G-2
Na	air/acetylene	2.82	2.3	3.06 (3.01)*
K	air/acetylene	2.85	3.5	3.70 (3.75)*
Fe	air/acetylene	2.12	5.2	1.88 (1.87)*
Ca	nitrous oxide/acetylene	2.13	3.5	1.37 (1.42)*
Mg	air/acetylene	1.11	1.3	0.44 (0.46)*
Al	nitrous oxide/acetylene	8.93	5.1	8.07 (8.12)*

* Abbey

Fluoride Analysis

There is now a wide range of ion-selective electrodes on the market and, of these, fluoride has proven to be one of the most selective. This method of measurement has been adopted for the determination of fluoride in a variety of matrices ranging from rocks to waters. A buffer is needed both to stabilize the pH and to free fluorine from complexation with such elements as hydrogen, silicon, iron, aluminium and beryllium.

After an extensive investigation, the following buffer solution was chosen: 1 M tri-ammonium citrate, 1 M sodium chloride and 0.06 M diaminocyclohexanetetra-acetic acid. A water sample is simply diluted 1:1 with the buffer and, after allowing for the fluoride and reference electrodes to reach equilibrium (~10 minutes), the concentration is read directly from a previously calibrated specific ion meter. Recent acquisition of a six electrode switch has eliminated this delay time.

Various fusion mixtures and techniques were tested on the USGS standards AGV-1, BCR-1, G-2 and GSP-1. A Na_2CO_3/KNO_3 flux was chosen for future work for two reasons; (1) it gave consistent and accurate results and (2) the fused product can also be used in the colorimetric determinations of chlorine, molybdenum and tungsten. A known weight of fused material is dissolved in a certain volume of deionized water, diluted 1:1 with buffer and the fluoride electrode system inserted into this final solution. A coefficient of variation of 5.4% at the 800 $\mu g\ g^{-1}$ F^- level and 9.8% at the 400 $\mu g\ g^{-1}$ F^- level was obtained, each based on 8 separate determinations. Table II gives a comparison of results obtained by this laboratory and the internationally accepted values on the 4 USGS rocks tested.

TABLE II

Rock	F^- content (ppm) This laboratory	F^- content (ppm) *
AGV-1	372	400
BCR-1	480	500
G-2	1,280	1,300
GSP-1	3,724	3,800

*Abbey

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Project 70087

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Work has continued in upgrading the analytical instrumentation of the Geological Survey Geochemical laboratories. The immediate task is computer control of two Perkin Elmer model 303 atomic absorption spectrophotometers which presently provide their output in the form of peaks on a strip chart recorder. The solid state interface unit and the new sampler with a multiposition capability previously described (ref. Geol. Surv. Can., Paper 73-1, Part B) has been interfaced to a Texas Instruments model 960A minicomputer and a program has been written to allow completely automatic analysis of up to 200 samples with the results being printed out in concentration units, together with sample identification in the form of a field grid reference. This same information is also punched out on paper tape in a form acceptable to the E.M.R. Computer Sciences Centre data processing system for incorporation into contoured geochemical maps. The tedious and error prone manual operations of reading strip chart records, calculating results, entering figures on successive data sheets and key punching them onto cards are thus completely bypassed. The computer package includes a data terminal complete with dual magnetic tape cassette drives, so that ultimately the data can be transmitted directly to the main data processing system via a data link. A photograph of the system is shown in Figure 1.

In the course of the software development for the system two programs of general applicability were written for the T.I. 960A. The first allows direct entry of machine language opcodes into successive memory locations from the keyboard, thus enabling rapid entry of small trial programs without the necessity of using the two pass assembler. It also allows the contents of any portion of memory to be listed or punched out in the same format, and any punched paper tape so produced to be read back into the same portion of memory. The second program is a Source Tape/Text Editor, which allows errors made in typing "SAL" assembly language text to be corrected without the necessity of retyping the entire program. It also allows for rapid generation of a new source tape from an original with lines of text added, changed or deleted. Both programs are now commercially available through an arrangement with Canadian Patents and Development Ltd.

GSC photo 202310

FOLLOW-UP INVESTIGATIONS ON THE BEAR-SLAVE GEOCHEMICAL OPERATION

Project 730009

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Introduction

In 1972, a geochemical reconnaissance of 36,000 square miles of the Bear and Slave Geological Provinces was carried out. Nearshore lake sediment samples were collected by helicopter; these samples were analyzed in Ottawa for 27 elements. A report and contoured maps for the more economically important elements were published earlier this year (Allan, et al., 1973; Allan and Cameron, 1973a-1973g).

The data obtained from the Bear-Slave operation are of restricted value in untreated form; they acquire wider significance only when interpreted into terms meaningful to economic geologists, or to those concerned with estimating mineral potential. The various anomalies across the survey area can be, in part, interpreted on the basis of our previous studies of primary and secondary geochemical dispersion within selected areas of these geological provinces (Allan, et al., 1972). However, a more authoritative interpretation demands follow-up investigations in the field. This was the purpose of this summer's project.

The region chosen for follow-up work (Fig. 1) is near the eastern boundaries of the Slave Province and the 1972 survey area. It is approximately 1,500 square miles in extent. This area was selected, firstly, because it contains a variety of geochemical anomalies, both in metasedimentary and granitic terrane. In addition, apart from a short summer season and uncertain weather, this part of the Barren Lands is splendid country in which to carry out geological work, because of good exposure of the rocks. A further factor was that this region has attracted little exploration activity, so that our studies can help to determine its mineral potential.

The amount of field work was governed by a budgetary limit of 100 hours of helicopter use, plus fixed-wing support. Field work was carried out throughout the month of July from a base camp at Regan Lake. A Hiller 12-E helicopter was used mainly for lake sediment sampling and a float-equipped Cessna-180 for rock and soil sampling traverses and gas caching. Follow-up studies of this type require immediate analytical results, in order to guide further sampling. Accordingly, a field laboratory was set up under canvas at Regan Lake where samples of lake sediments, soils and gossans were analyzed for Zn and Cu. A related activity in the field area during the summer was aerial colour photography of the southern part of the follow-up area (see report by V.R. Slaney, this publication). Also, a mineral exploration company carried out follow-up studies of geochemical anomalies in the eastern part of the 1972 survey area.

Mr. George Thomas (senior assistant) and Mr. Ken Lawrence (helicopter pilot) combined to form a highly efficient lake sampling team. Field analyses were carried out by Mr. Ron Crook and in Ottawa by Mrs. Alice MacLaurin and Miss Elizabeth Ruzgaitis. Mr. Robert Hornal, I.A.N.D. Resident Geologist, and his staff extended many courtesies during the field season. We are most grateful to all of these persons.

Analytical Methods

Colorimetric methods were used in the field to determine Zn and Cu in lake sediment, soil and some gossan samples. 2, 2[1] biquinoline was the reagent used for copper and dithizone for zinc. Lead was not determined because of the dangers involved in using the cyanide buffer required for this test in a tent laboratory. As will be described below, this lack of a lead test was a serious omission.

All samples were sieved using 80- and 250-mesh screens. The minus 250-mesh material was used for analysis. The drying and sieving of the samples proved time-consuming, and seriously strained the limited manpower resources of the party. We hope to determine by laboratory studies whether the consistency of analytical data gained by drying and sieving the samples is really essential for field determinations in this region.

Cu, Zn, Pb, Ni, Ag, Mn and Fe are presently being analyzed in our Ottawa laboratories by atomic absorption spectrometry, following a hot 4M HNO_3 leach. As is being determined colorimetrically using silver diethyldithiocarbamate following a hot 6M HCl leach. In both cases minus 250-mesh material is being analyzed. It is important to note that of the above elements Cu, Pb, Ni and Fe in the 1972 Bear-Slave samples were analyzed by a different method, namely, direct-reading emission spectrometry. For these elements the results of the two surveys are not directly comparable, since the HNO_3 leach only partly extracts the metal, while the emission spectrometer determines the total metal content. Differences between the two methods are greatest for Pb and Ni, and are only slight for Cu. The detection limit of Pb is approximately 3 ppm; samples with less than this value have been assigned a value of 2 ppm. For Ag the detection limit is 0.5 ppm; samples containing less than this amount are assigned a value of 0.2 ppm.

At the time of writing, analysis of rock samples was just commencing; this part of the study will not be discussed in this report.

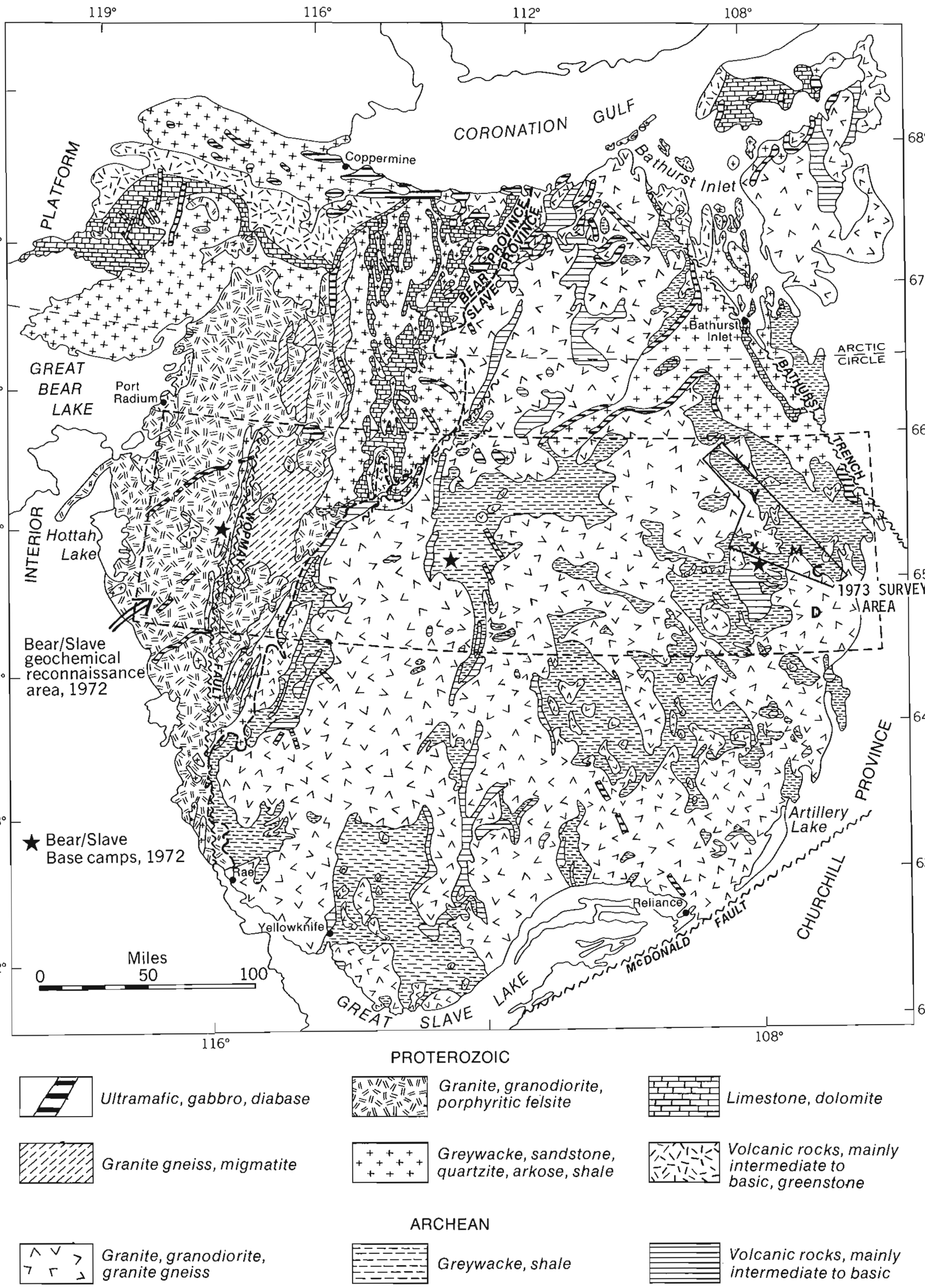

Figure 1. Geological map showing the location of the Bear-Slave Geochemical Operation, 1972 and the follow-up area, 1973. Letters X, Y, M, C and D refer to specific geochemical anomalies studied in 1973.

Approach to Follow-up Studies

The first phase of this year's work was to establish the reliability of the 1972 reconnaissance sampling data. This was done by resampling the 1, 500-square-mile area shown in Figure 1 using different lakes from those sampled in 1972. The contoured maps of the 1972 data show that many of the anomalies are of tens to a few hundred square miles in extent. Others are small, one sample anomalies. The 1973 lake sediment resampling confirmed that the large anomalies and some of the single sample anomalies are reproducible with a different sampling pattern. Some of the single point anomalies are confined to one lake or to part of a lake. These are, of course, not reproducible. This type of anomaly is generally found for those elements that do not migrate in solution in the lake systems, or in areas where environmental conditions tend to fix even the more mobile elements.

The second phase of the study was to determine the variation in the element content of samples taken at intervals along the shores of anomalous lakes. This work will not be discussed in this report.

The third and major part of the work was a study of the primary and secondary geochemical dispersion within a number of anomalous areas. This involved detailed sampling of lake sediments, plus sampling of rocks, soils and any gossans present. The anomalies were selected to represent a variety of different characteristics.

1. Anomailes for Cu*, Zn*, As*, Co*, Ni*, and Mn*, generally found in areas mapped as metasedimentary

Anomaly Y - A large, intense anomaly in the northern part of the Beechey Lake metasedimentary belt (Fig. 1). Anomaly peaks for Zn (230 ppm), Cu (161 ppm) and As (28 ppm) are approximately eight times greater than background values. The anomaly occurs near the margin of the metasedimentary belt and in the adjacent granitic terrane and is approximately 200 square miles in extent.

Anomaly X - This was chosen as a weaker and much less extensive anomaly of this type. It encompasses only a few tens of square miles. It also occurs at the margin of a metasedimentary belt and in adjacent granites.

Anomaly C - Anomaly C was selected as a single point, very intense anomaly. The sample from this anomaly contains 413 ppm Zn, 257 ppm Cu, 219 ppm Ni and 92 ppm Co, all one order of magnitude or more greater than the regional background for these elements. The anomaly occurs near the margin of the Beechey Lake metasedimentary belt.

Prior to visiting the field, the interpretation given these anomalies was that they were derived from sulphide mineralization associated with unmapped volcanic rocks that lie along the margin of the Beechey Lake metasedimentary belt.

2. Anomalies for U*, Zn*, Cu*, Mo*, As*, Ni*, Co*, La*, and Li*, in areas of granitic rocks

Anomaly D - This anomaly occurs in a larger area of granitic rocks south of the main 1973 survey area (Fig. 1). The anomaly is particularly distinct for U with values to 70 ppm or two orders of magnitude greater than background. Prior to visiting this area it was thought that possibly the anomaly was related to granitic rocks with a high background content of these elements, rather than to mineralization. To test this hypothesis only rock samples were collected from this area.

Anomaly M - This area contains a small anomaly of type 2 in granites and an anomaly of type 1 in the adjacent metasedimentary belt. It was sampled in order to test a possible genetic connection between the composition of granites and mineralization in nearby metasedimentary (or metavolcanic) rocks.

At this time of writing, the analytical data that are available allow only an interpretation of Anomalies X and Y. An interpretation of the other anomalies will be given in a later report, along with a more comprehensive account of Anomalies X and Y.

Interpretation of Anomaly Y

The area containing the west-central part and peak of this anomaly is shown in Figure 2, the centre of which is at 65°36'N, 107°55'W. The western part of the area shown comprises 7, 000 feet of near-vertical volcanic rocks of intermediate to acidic composition. They are in contact with granites to the southwest. Near the centre of this area a very thick sequence of metasediments rests upon the volcanic rocks. Slates form the base of this steeply dipping sequence; being easily eroded the slates form a narrow valley that strikes north-northeast, parallel to the contact with the volcanic rocks. The upper one thousand feet of volcanics are highly siliceous and form a ridge.

A narrow line of gossans derived from sulphide minerals is present along the contact between the volcanic and sedimentary rocks. This is termed the "A" horizon gossans. Another line of gossans – the "B" horizon gossans – is developed stratigraphically below the upper siliceous volcanics (Fig. 2). These "B" horizon gossans are restricted in lateral extent, although gossans may be observed in a similar stratigraphic position to the north and south. This gossan horizon is absent or is very thin near the northern and southern margins of the area in Figure 2. It thickens near the centre of the area and its maximum thickness is intersected by Soil Traverse 641. In this zone of maximum thickness the rocks below the gossan have been hydrothermally altered, with almost complete loss of Ca and Na.

The anomalous metal contents of lake sediments in this area we believe were derived from the oxidation of base metal mineralization within horizons "A" and "B". During the oxidation of these sulphides, Pb and Ag were largely fixed in the soils overlying the mineralization, while Zn and Cu were not retained but were dispersed in solution throughout the drainage system.

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*Elements having a concentration ratio of 3 or greater between anomaly peak and background.

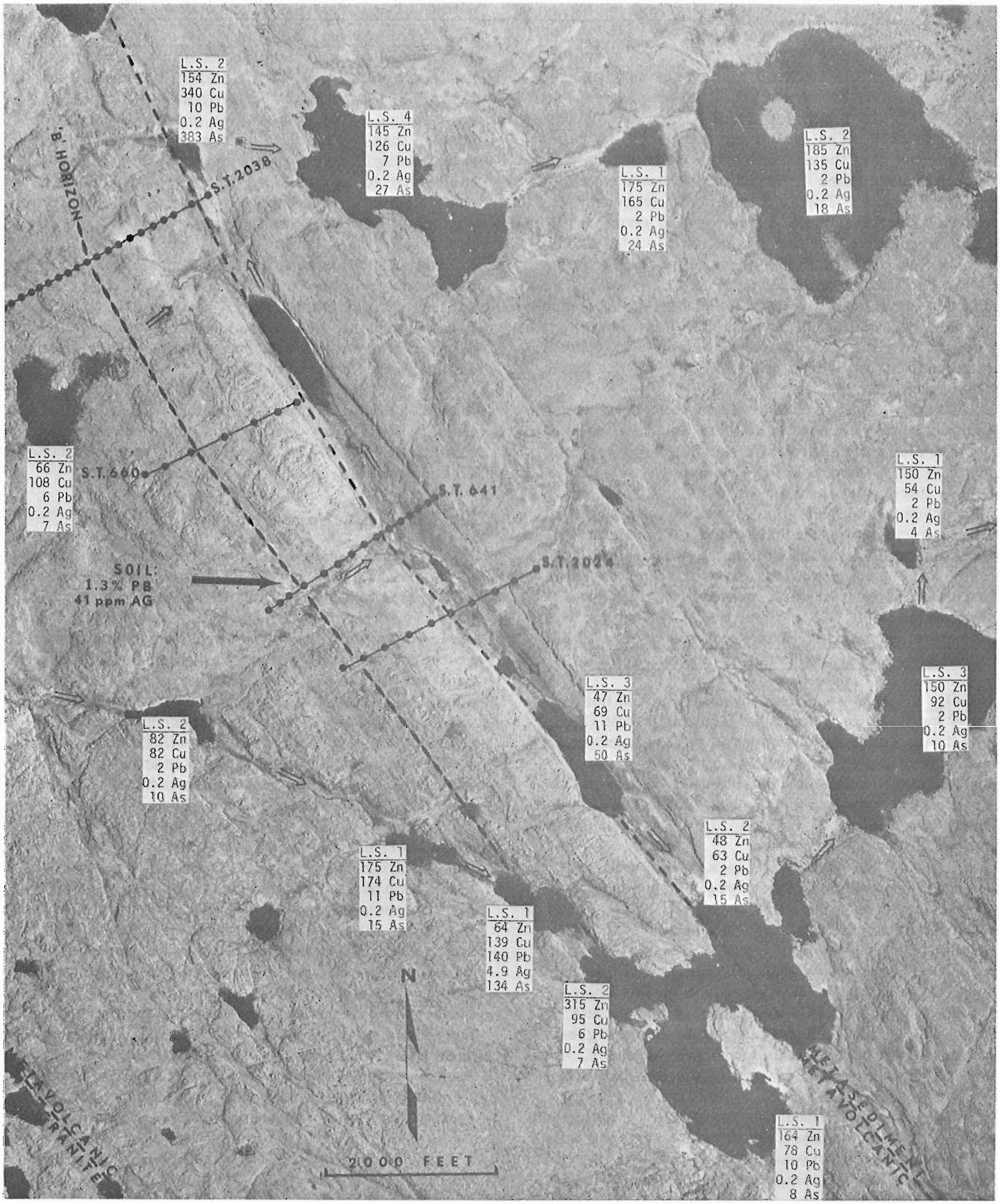

Figure 2. Geochemical data for the area of Anomaly Y. The numeral following lake sediment (L. S.) is the number of samples from that lake that were averaged to provide the analyses given below. Soil sampling traverses identified as S. T. Rock sampling traverses not shown. Drainage directions given by small arrows. Note that no lake sediments were found in the lake at the eastern end of traverse S. T. 660.

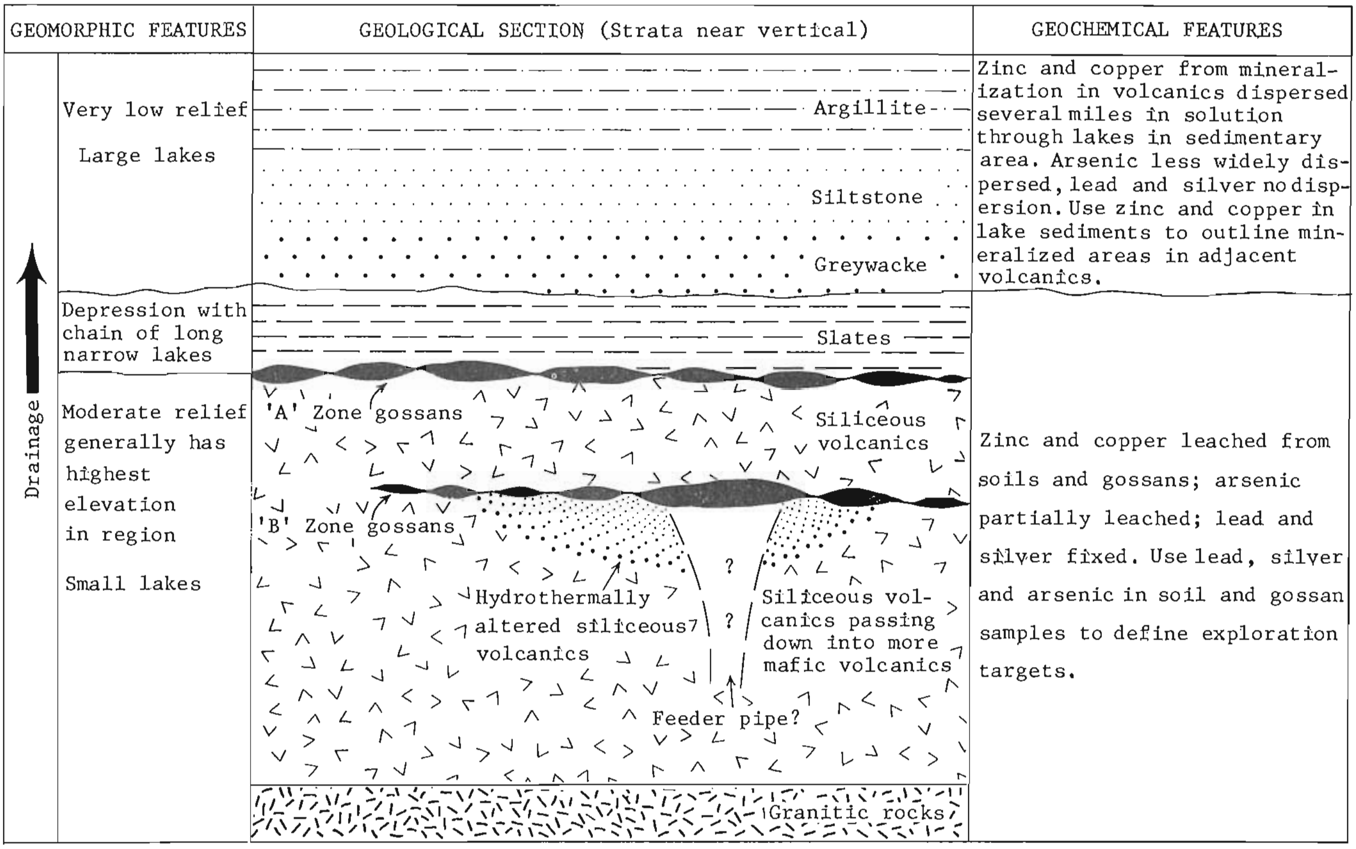

Figure 3. Diagram showing the suggested approach to geochemical exploration for massive sulphide deposits in the northern Canadian Shield. Based on studies at Anomalies X and Y (see text).

The retention of the former two metals in the soils is caused by the relative insolubility of their sulphates, compared to those of Zn and Cu, plus their lesser tendency to complex formation, and greater ease of hydrolysis. Arsenic has an intermediate character; much of this element is retained in the soils, but some is dispersed in the drainage system.

All lake sediments down-drainage from the mineralized volcanic terrane are notably anomalous in Zn and Cu, relative to the regional background of 32 ppm and 20 ppm respectively. Note that Pb and Ag begin to rise above background levels only in the immediate vicinity of the mineralized volcanic rocks. During the 1972 reconnaissance sampling, two lake sediment samples were taken from the area of Figure 2. One is from the lake in the northwestern corner, the other from the southernmost lake along the volcanic/sediment contact.

The four soil sampling traverses shown in Figure 2 were made in order to more closely locate the source of the base metals. Unfortunately, the field determinations for Zn and Cu were of no assistance, because of the leaching of these elements from the soils. The soils were sampled at a depth of 6-8 inches. Table 1 gives chemical data for Soil Traverse 641. Sample 641 is from the eastern end of this traverse, and 658 is the westernmost sample. The intermediate sample numbers missing from Table 1 are for rock samples collected along the traverse. Zn is low, in the range 14-79 ppm over the slates. It rises to twice this range over the volcanic rocks. Cu is also low over the slates, but rises to 858 ppm farther along the traverse. Pb and Ag show the most striking anomalies with peaks of 83 ppm Pb and 3.4 ppm Ag over the "A" horizon and 1.3% Pb and 41 ppm Ag over the "B" horizon. Arsenic has highly anomalous concentrations over both the slates and the volcanic rocks. In the case of this element, the lake sediment anomalies were probably derived from both of these sources.

The two northern traverse lines show much weaker, but distinct, peaks for Pb and Ag over horizons "A" and "B". Spot samples taken at irregular intervals along the length of horizon "B" are generally anomalous for these two elements, but the highest values occur only in the zone of maximum thickness near Traverse 641. It is significant that by far the highest values for Pb and Ag obtained from lake sediments are found in a lake that overlies the southern extension of horizon "B" (Fig. 2).

Lead is present in soil sample 654 (Table 1) as plumbojarosite and anglesite. These minerals occur as a fine powder or grain coating. No galena is present. The Pb and Ag are fairly evenly distributed between the different size fractions, but Pb reaches a peak of 2.2% in the minus 80, plus 250-mesh fraction.

Notable amounts of the sulphides of Zn, Cu or Pb were not found along either the "A" or "B" horizons,

Figure 4. Anomaly Y, photographed facing north from the centre of the area shown in Figure 2. Light coloured ridge of upper siliceous volcanics runs diagonally from right centre of photograph; metasedimentary rocks beyond. Light coloured outcrops in left centre are thickest portion of "B" zone gossans and the underlying altered volcanic rocks.

although it should be pointed out an intensive search for these minerals was not made. Pyrite and pyrrhotite are very common. We would suggest that if the former sulphides are present that they have been selectively oxidized, relative to iron sulphides. Minor disseminated sphalerite, that was difficult to identify in the field, was seen in the altered volcanic rocks under the "B" horizon gossans. Molybdenite was found on a rock sampling traverse near the base of the volcanic sequence shown in Figure 2.

In order to test the hypothesis that Zn and Cu are largely lost from the soils overlying mineralization, we sampled gossans from the Hackett River area to the north. One sample is from the Cleaver Lake zone and two are from the Camp Lake deposit. This deposit is reported to contain in excess of 10 million tons of 8% Pb-Zn, and 300 ppm Ag. The data for these samples are shown in Table 2. Needless to say, three samples are not representative of these very variable gossans, but they do confirm the loss of Zn and the retention of Pb. The data for Ag is ambiguous.

The geochemical data obtained from Anomaly Y area outline targets for more detailed exploration. Gossan horizon "B", near to its intersection with Soil Traverse 641, is a particularly interesting target. It displays the essential features of stratabound, volcanogenic, massive sulphide mineralization (Sangster, 1972a). The mineralization occurs in siliceous volcanic rocks, in which it is distributed along a plane of stratification. It thickens into what appears to be a lenticular-shaped body, which is underlain by altered volcanic rocks, characteristic of those found in feeder pipes. Neither the geochemical data nor the geological evidence allows us to estimate whether the mineralization is any more than an interesting prospect. Like all other exploration methods, only a small proportion of geochemical anomalies disclose economically viable deposits. However, irrespective of such considerations, the area provides an excellent example of geochemical dispersion from mineralization that provides the basis for geochemical methods of exploration and resource appraisal in the northern Shield (Fig. 3).

Interpretation of Anomaly X

This area, 25 miles south of the area of Anomaly Y, is very similar geologically to the latter. Near-vertical metavolcanic rocks, that strike east-west, are in contact with metasediments to the south. Slates at the contact form a long, narrow valley that contains a chain of lakes. The volcanic sequence is thicker here - in the

TABLE 1

Zn, Cu, Pb, Ag and As (as ppm) in soil samples from Soil Traverse 641 (see Fig. 2). Sample 641 is easternmost sample; 658 is westernmost sample.

SOIL SAMPLE	Zn	Cu	Pb	Ag	As
641	37	25	15	0.2	44
642	67	44	10	0.2	309
643	31	31	20	0.2	239
644	14	10	15	0.7	92
645	26	20	10	0.2	72
646	79	297	83	3.4	317
647	112	206	271	3.1	92
648	47	116	2	0.2	7
650	136	856	1,370	23.0	145
651	26	56	206	4.7	13
653	141	163	189	0.2	28
654	42	450	12,600	41.0	890
656	126	189	259	3.1	7
657	93	158	644	11.0	22
658	75	38	25	1.0	12

order of 25,000 feet - and is in contact with granites to the north. A line of gossans, equivalent to the "A" horizon gossans to the north, are present along the contact between the volcanic rocks and the sediments. These gossans may be followed for more than 10 miles. Another gossan horizon is present approximately 5,000 feet down the volcanic succession. Like the "B" horizon gossans to the north, these are much more restricted in lateral extent and are associated with hydrothermally altered volcanic rocks. At this location too, the two groups of gossans will be referred to as the "A" and "B" horizons.

The gossans present in the area of Anomalies Y and X are only a few of the many hundreds of gossans that may be seen in the eastern part of the Slave Province. Those that are associated with Anomaly Y are not conspicuous, which may account for us not observing any signs of exploration activity in the area. Gossans were not noted on the field map of the geological party that traversed the ground shown in Figure 2 during Operation Thelon (Wright, 1957). In contrast, those present in the area of Anomaly X are among the most conspicuous in the entire area, and are comparable to those in the Hackett River camp to the north. They have attracted a limited amount of exploration activity, for we observed a few shallow pits. Some parts of the area have, in the past, been staked.

Geochemical dispersion within this area follows the pattern shown in Figure 3, that is from the volcanic areas of high relief south into lakes in the metasedimentary terrane. We have found no evidence of base metal mineralization associated with the "B" horizon gossans in this area, which are developed at 65°18.5'N, 108°08'W. Lake sediment and gossan samples taken here are relatively low in Zn, Cu, Pb, Ag and As. In contrast, samples of sediments taken from lakes immediately adjacent to the "A" horizon gossans are often much richer in Zn and Cu than the samples from

TABLE 2

Zn, Cu, Pb, Ag and As (as ppm) in gossan samples from Hackett River area.

GOSSAN SAMPLE	Zn	Cu	Pb	Ag	As
Cleaver Lake, 1034	173	122	2,800	8.7	97
Camp Lake, 1035	232	209	956	0.2	22
Camp Lake, 1036	99	81	161	0.2	17

Anomaly Y (Fig. 2). Values as high as 948 ppm Zn and 1167 ppm Cu were obtained. The zone of maximum Zn and Cu values in lake sediments extends from 65°18'N, 108°09'W to 65o15'N, 107°55'W. Soil and gossan sampling traverses were carried out along this zone, paralled to the strike. The Zn and Cu content of these samples is much lower than the adjacent lake sediments, attesting again to the leaching of these elements from the soils. Some soil samples are anomalous for Pb, Ag and As, but there are no values as high as those measured on Soil Traverse 641 to the north. The most anomalous sample was taken at 65°16.5'N, 108°02'W and contains 20 ppm Zn, 38 ppm Cu, 134 ppm Pb, 21 ppm Ag and 8 ppm As. The closest lake sediment sample, approximately 750 feet distant, contains 948 ppm Zn, 201 ppm Cu, 2 ppm Pb, 0.2 ppm Ag and 4 ppm As.

Conclusions

Geochemical Methods of Exploration in the Northern Shield

Geochemical methods have had only limited success in mineral exploration in the southern Shield. The thick glacial cover, disorganized drainage and, in many places, the absence of deep weathering, has discouraged the introduction of such methods in the traditional exploration country. Many exploration geologists and geochemists have extrapolated these considerations to the colder northern Shield and have concluded that it is an even more difficult environment for the application of geochemistry.

Over the past four years, work on the surficial geochemistry of the northern Shield, mainly by our colleagues R.J. Allan, E.H.W. Hornbrook, and W.W. Shilts, has done much to discourage these beliefs. The anomalies that we have studied this summer serve to show that this country is eminently suitable for applied geochemistry; indeed, in places it may be close to ideal. The most critical element in this is that there has been intensive weathering of sulphides. This has allowed the wide dispersion of ore and indicator elements in the drainage systems. Moreover, chemical weathering has had little effect on the rocks and consequently there is a high degree of exposure in the region. This provides a particularly excellent opportunity for the integration of methods based on secondary dispersion with those based on primary geochemical dispersion.

Resource Evaluation in the Northern Shield

Evaluation of the resource potential of Canada's landmass is becoming an increasingly important part of the work of the Geological Survey. In the northern Shield this evaluation must depend on the reconnaissance geological mapping carried out since the fifties and also on aeromagnetic maps. Massive sulphide deposits and gold are most often found in the Shield in areas of siliceous volcanic rocks. Areas containing such rocks are considered to be of high mineral potential. It is, therefore, significant to note that in the reconnaissance surveys of the areas of Anomalies X and Y and the adjacent terrane, that siliceous volcanic rocks were not recognized. At Anomaly Y the main portion of the volcanic sequence shown in Figure 2 was identified as "gneisses probably derived from Yellowknife sedimentary rocks". The upper one thousand feet, comprising highly siliceous volcanics, was identified as granitic (Wright, 1957). In the south at Anomaly Y the volcanic rocks east of 108° were mapped as granites (Wright, 1957), while those west of 108° and in contact with the gossans were described as white quartzites (Fraser, 1964). It should be noted that the mapping was carried out by some of the most experienced geologists to have worked in the Canadian Shield. Further, similar rocks to the north, at Hackett River, have proven troublesome to identify even when less hurried study of their lithology was possible (Sangster, 1972b). In identifying the critical sections as volcanic rocks, the present writers had the benefit of chemical data and knowledge of the debate over similar rocks at Hackett River.

The point which we wish to make is that if terrane in the Shield is classified as quartzitic or granitic, estimates of mineral potential for the area are likely to be low. In contrast, if siliceous volcanics are known to occur the area will be assigned a high potential. Such considerations are particularly critical when map data are fed into a computer-based evaluation program. There may be many other similar examples in the northern Shield that are an inevitable consequence of the reconnaissance nature of existing maps. We suggest that reconnaissance geochemical surveys provides one means of focussing attention on particular areas for more detailed geological mapping.

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GASES AND THEIR RELEVANCE TO MINERAL EXPLORATION

Project 720067

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The gathering of background information on the composition of gases dissolved in natural waters, begun last winter (1972-73), was continued by collecting and analyzing water samples from a number of different geological settings. The dissolved gases were analyzed for Rn, H_2, CH_4, He, Ne, H_2S, CO_2, N_2, O_2, and Ar. Some water samples were also analyzed for U, Ra, and pH.

At the end of May, 46 water samples from two Rn anomalies in the vicinity of Moncton, N.B. comprising two stream, 10 spring, 11 well, and 23 drillhole water samples were collected and analyzed. The anomalies occur in Pennsylvanian and Mississippian red sandstones, conglomerates, and minor shales. Rn concentrations of from 0 to 18 nanocuries/litre of water were encountered. Drillhole profiles from these anomalies suggest that one stems from a weak shallow radioactive zone as indicated by decreasing Rn with depth and showing only background levels of U and He. The second anomaly gives increasing concentrations of Rn, U, and He with depth, indicating greater uranium potential than the first. Both locations have a rapid turnover of water as indicated by the relatively high O_2 content. The presence of O_2 may also explain the lack of Ra and H_2S in the water samples; Ra becomes extremely immobile and H_2S is oxidized in an oxidizing environment. Only four samples contained less than 2% O_2; these were also the only samples with measurable contents of H_2, ranging from 0.1% to 1%.

During the latter part of June, 57 water samples from 12 drillholes from a steeply dipping sulphide zone on the New Insco Mines Limited property 7 miles southwest of Duparquet, Quebec were collected and analyzed. The massive sulphide zone contains pyrite, pyrrhotite, and chalcopyrite with siliceous material and chlorite. Lack of O_2 (less than 1%), presence of H_2S (up to 2%), and increased CO_2 content (roughly from 30% to 60%) characterize the composition of the dissolved gases in the massive sulphide zone. A striking increase in H_2 from below the detection limit of 0.01% to 28% in one instance, occurs in the water in the top sample just below the water table, mainly in areas where the massive sulphide zone approaches the surface. Because the H_2-rich samples were well inside the steel casings within reach of atmospheric O_2, and deeper samples contained no H_2, it must have been generated where it was found. Two possible mechanisms could account for the H_2; electrolysis or bacterial action on H_2S and/or organic matter.

During the second half of August, 69 water samples from 14 drillholes from the Cavendish test range about seven miles south of Gooderham, Ontario were collected and analyzed. The area forms part of a calcite-quartz-calc silicate-sulphide (pyrrhotite-pyrite) alteration zone in Grenville mafic gneiss, crystalline limestone, and granitic gneiss. Here, as in the Duparquet area, the waters from the sulphide zones are characterized by low O_2 and high H_2S. Also the holes with H_2S contained noticeable amounts of CH_4 and slightly higher He levels as if the sulphide zones were paths for CH_4 and He from deeper strata. Although several holes contained traces of H_2, only one sample from the massive sulphide zone contained an appreciable amount of H_2. Again, this sample came from just below the water-table well within the steel casing.

Project 730003

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During the 1973 field season those rocks mapped as dominantly intrusive quartz, feldspar and quartz-feldspar porphyries were systematically sampled in the Wopmay Geological Subprovince from the vicinity of the abandoned Rayrock mine in the south to as far north as latitude 66°N.

The porphyry units are of Proterozoic age and show variable relations to the granitoid plutonics west of the Wopmay fault, but overlie unconformably the rocks of the Hepburn batholith to the east (see McGlynn and Hoffman in this report). During the field sampling a possible unconformity was noted 2 miles west of Hardisty Lake where felsic volcanics appear to lie unconformably on quartz monzonite. The porphyry units are complex in nature. The composition of volcanic extrusive and hypabyssal rocks vary from andesitic to rhyolitic. The mapped units also contain sediments and considerable thicknesses of pyroclastics. The currently available published geological maps of the area do not truly reflect the complexity of the volcanic units.

In addition to the regional sampling detailed sampling was undertaken in three areas where more recent mapping was available. These areas were around Hardisty (86C) and Maclaren (86K) Lakes and in the Camsell River silver district (86F). The data derived from these sampling programs will be used to aid in the interpretation of the regional survey. In total some 2, 200 rock samples were collected and are being analyzed for 15 major, minor and trace elements.

During the regional sampling, copper staining, believed to be previously unreported, was observed. Neither of these localities yielded any significant sulphides in the brief time spent at them; the localities are given in order that they be permanently recorded. Firstly, east of Mazenod Lake (85N) at UTM 504300 7069800 and secondly, south of Jaciar Lake (86K) at UTM 515800 7387200. Both localities occur in areas of red fine-grained volcanics.

A variety of sulphide mineral showings occur in the survey area in addition to the economically important silver deposits. Many of these occurrences were visited and two are considered to be of particular genetic interest. In the vicinity of Tommie Lake (86F, UTM 494200 7252500) a number of chalcopyrite-bearing veins were investigated in 1962. Close by these veins are apparently conformable units containing chert, magnetite ironstone and jaspilites lying with rocks postulated to be felsic pyroclastics, both the magnetite and jaspilite units contain disseminated pyrite. At a point west of Clut Lake (86F, UTM 459800 7272400) there is a breccia pipe where pyrite and chalcopyrite cement porphyry fragments intrudes relatively flat lying felsic volcanics. In the volcanic pile both magnetite-chert and black sedimentary horizons containing disseminated pyrite were observed. On the basis of these field observations it is suggested that the Wopmay geological sub-province felsic volcanic units might be favourable loci for volcanic exhalative-type sulphide accumulations.

23. CANADA – NEWFOUNDLAND MINERAL DEVELOPMENT PROGRAM, PROJECT 6; GEOCHEMICAL – GLACIAL GEOLOGICAL SURVEY (Geochemical Phase)

Project 720036

E. H. W. Hornbrook and P. H. Davenport*
Resource Geophysics and Geochemistry Division

The objective was to outline areas in Newfoundland with good potential in metallic mineral resources, in order to facilitate discovery by exploration companies and thus contribute to the economic and social development. The project was carried out for, and in cooperation with, the Newfoundland Department of Mines and Energy, Mineral Development Division.

Pilot studies were carried out in 1972 in two areas of Newfoundland. They are: New Bay Pond area of Notre Dame Bay where Cu-Zn sulphide mineralization occurs in the volcanic and sedimentary rock of the Wild Bight Group; and Daniel's Harbour area of the Northern Peninsula where zinc mineralization is associated with the St. George—Table Head disconformity. Results of these studies will be published in the near future and have been discussed in Hornbrook (1973) and Hornbrook and Davenport (1973).

Regional geochemical exploration pilot studies have demonstrated the effectiveness of lake sediment surveys in the Daniel's Harbour area. Here, zinc anomalies in the lake sediments have effectively defined known areas of mineralization as well as indicated others, some of which were associated with the St. George—Table Head disconformity in Ordovician carbonate rocks.

Thus, in 1973 a reconnaissance geochemical survey of the total belt of lower Paleozoic carbonate rocks in Western Newfoundland for zinc mineralization was carried out. This belt of carbonate rocks contains a number of zinc and zinc-lead showings in addition to the Daniel's Harbour zinc deposits.

Lake sediment samples were collected over a 3, 000 square mile region underlain by the carbonate rocks at a density of at least one sample per square mile. Lake-centre bottom organic sediment samples were collected, dried, seived to minus 80 mesh ($<177\mu$) and analyzed for Zn, Pb, Mn and Fe.

A preliminary examination of the analytical data has revealed the following: There are several areas with anomalous zinc values comparable to those associated with the zinc deposits at Daniel's Harbour. These areas constitute suitable areas for further work by more detailed lake and/or stream sediment surveys. The data has permitted an evaluation of the zinc potential of the total belt of lower Paleozoic rocks from Port au Port Peninsula to Pistolet Bay.

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* P. H. Davenport - Province of Newfoundland and Labrador, Department of Mines and Energy, Mineral Development Division.

24. AIRBORNE INPUT SURVEYS

Project 660043

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Further progress has been made towards the publication of results of the airborne INPUT surveys in the Winkler, Manitoba, Drumheller, Alberta and Hawkesbury and Ottawa, Ontario areas (Collett, 1969). Because of the complex nature of the INPUT response to various horizontally-layered conductivity models, it is impossible in the general case to utilize the concept of apparent conductivity in making maps. However, computer plotted maps of a particular parameter related to the ground conductivity structure seem possible in certain instances. For example, a program has been developed to map TCP (thickness-conductivity product) of a single, highly conducting layer such as in the Hawkesbury area. The program is a partial machine adaptation of the interpretation chart method discussed by Dyck et al. (1973a).

The time-domain scale model developed by Becker et al. (1972) has been used extensively to study the system response to particular conductors. The theoretical response of a conducting wedge model derived earlier has been verified by means of the scale model. Additional experiments were performed to aid in the interpretation of the Project Pioneer INPUT survey in the province of Manitoba (Dyck et al., 1973b). Some of the variables studied were:

1. Variation with dip of a conducting dyke,
2. Variation with width and TCP of a flat-lying ribbon of conductive overburden,
3. Variation with width of a moderately conducting dyke,
4. Variations with instrumental time constant of of the receiving system,
5. Various dyke conductors hidden beneath patches of conductive overburden.

The latter shows that under certain fortuitous circumstances a dyke may be detectable beneath conductive overburden even though the dyke anomaly is dwarfed by the overburden response.

The results obtained show that INPUT surveys can be helpful in the delineation of structural features and in the mapping of overburden. The results also provide helpful clues in the interpretation of surveys for mineral exploration.

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Project 680037

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A shallow hammer seismic survey was conducted in the Tilbury area of southwestern Ontario to determine if a hammer seismograph could be used to delineate the bedrock topography of the area.

A major bedrock low offshore in Lake Erie east of Wheatley, Ontario has been outlined by Hobson et al. (1969) (see Fig. 1). They suggest that a major bedrock channel exists which may possibly extend from Lake Erie to Lake St. Clair.

"Single ended" refraction seismic data were obtained at 91 locations between August 9 to August 20, 1973. Seismic control was run across the inferred preglacial drainage path. Field calculations were done on site and distances between profiles changed in an attempt to define the channel. Record quality varied from excellent to very poor, with poor quality data obtained near the Tilbury Creek outlet to Lake St. Clair. A bedrock low has been interpreted to extend onshore from Lake Erie and can be traced, from preliminary analyses of the seismic data, towards Lake St. Clair. Re-interpretation of seismic results and compilation of borehole information from oil and gas and water wells is currently being carried out.

At the request of N.R. Gadd of the Terrain Sciences Division an attempt was made to define the bedrock beneath the clay at the landslide area near Chelsea, Quebec. Difficulty was encountered in obtaining a signal return from the mud surface during late June and early July and it was decided to complete the survey in late fall giving the earth time to drain off some moisture.

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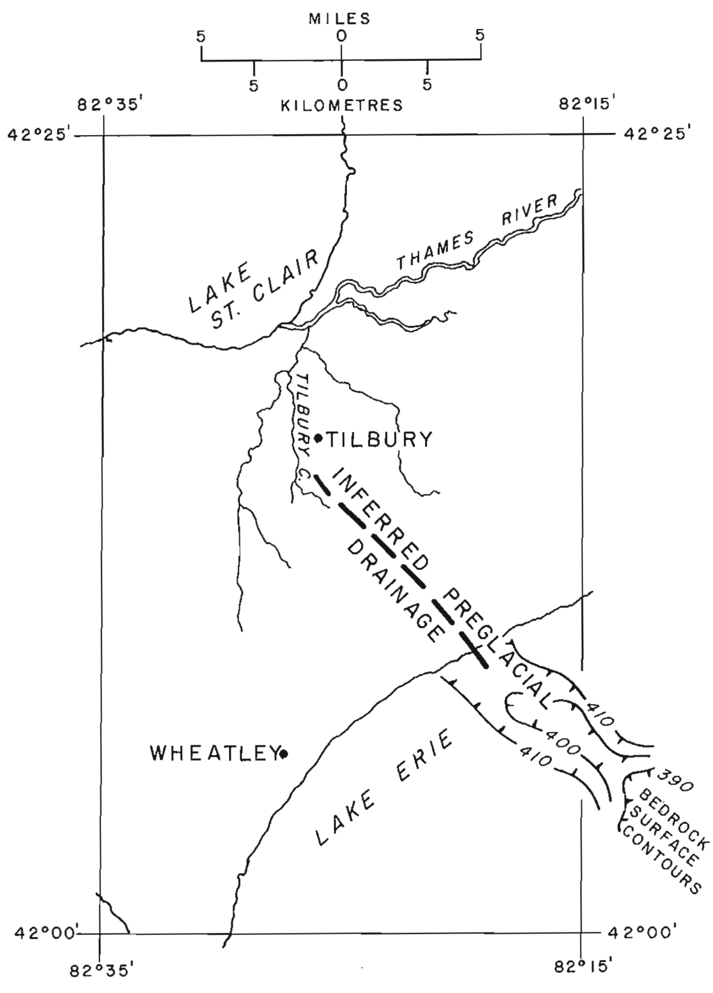

Project 720005

G. D. Hobson
Resource Geophysics and Geochemistry Division

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

Seismic refraction data pertaining to the sedimentary section were obtained over approximately 120 miles (190 km), gravity readings were taken at 4, 800-foot (1, 463 m.) spacing from shotpoints 36 to 44, and crustal seismic shots at stations 252, 304, 308, 316, 324 and 332 (Fig. 1) were recorded at Grosvenor Island, King Christian Island and Eureka. Analysis is proceeding using reversed profile techniques to define seismic velocities and delay times related to structural geology.

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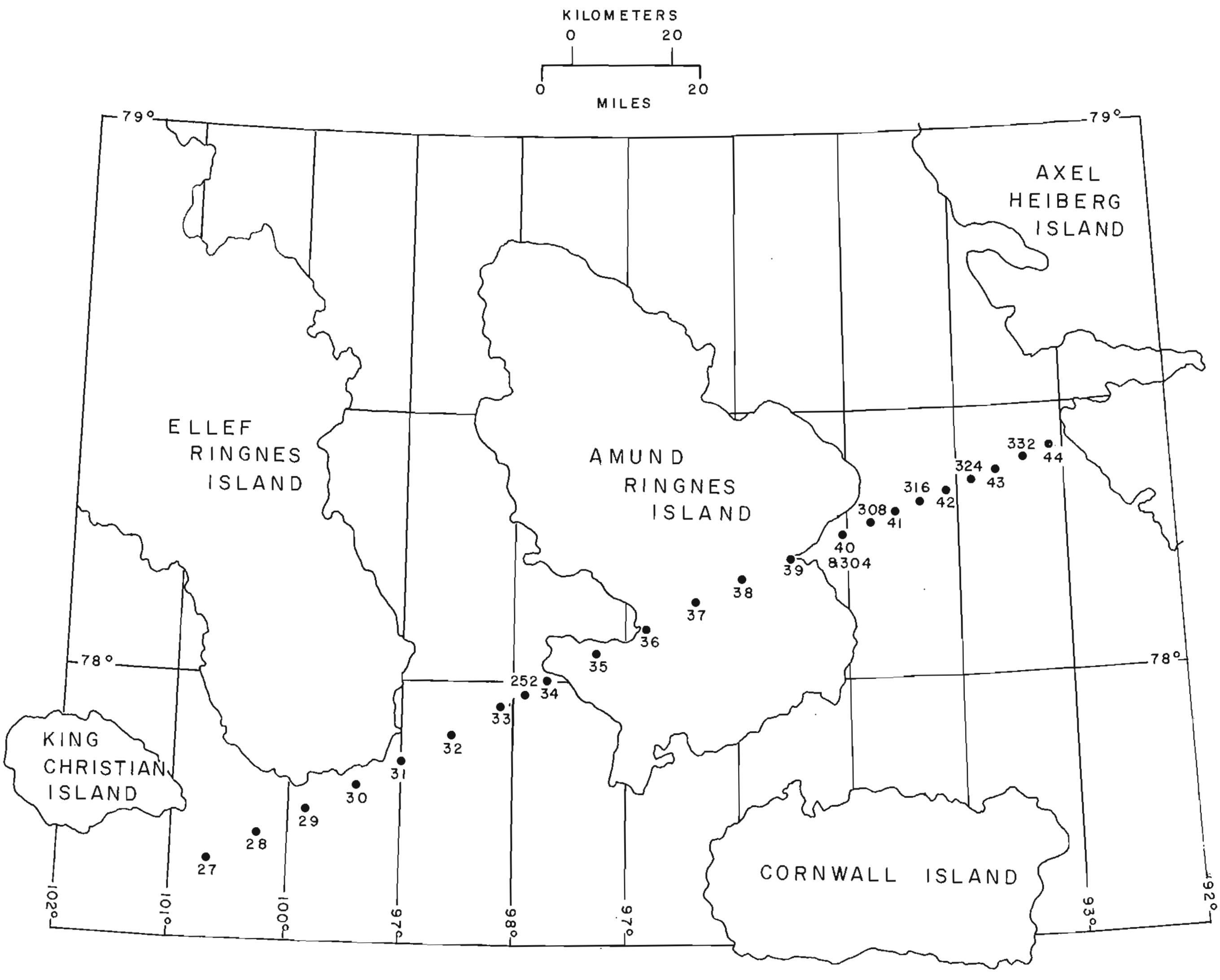

SVERDRUP BASIN 1973 PROJECT

• SHOT POINT LOCATIONS

Project 650007

Peter J. Hood and Margaret E. Bower
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The co-operative aeromagnetic project with the National Aeronautical Establishment was continued during 1973 and the low-level aeromagnetic reconnaissance of Davis Strait commenced in 1972 was completed (see Fig. 1). The North Star aircraft of the National Aeronautical Establishment is equipped with a cesium magnetometer was used. The objective of the field operation was two-fold, the first objective was to obtain low-level aeromagnetic profiles across the Davis Strait in order to throw light on the underlying geology, particularly the extent of the basalt flows which are known to extend over a much greater area offshore than those observed at the known onshore exposures at Cape Dyer on Baffin Island and in the vicinity of Disco Island, West Greenland. The second objective was an evaluation of a computerized electronic navigation system which uses fixes from the Global GNS-200 system and Doppler drift to compute the most probable position of the survey aircraft at any given instant. For the past several years the Omega navigation system had been used as the primary navigation aid however the GNS-200 system uses 8 stations with 150-1000 kilowatts VLF transmitters whereas the Omega presently uses 4 stations with 1-10 kilowatts of power. During flight tests carried out in the winter of 1972-73 the GNS-200 system performed well and the signal strength was much higher; it was therefore incorporated into the system replacing the Omega receiver. The computer uses the GNS signals in exactly the same way as it had previously used those from the Omega receiver computing a position every 10 seconds which is displayed to both navigator and survey operator. Concurrently, all other survey parameters are acquired and digitally recorded. The computer system worked exceptionally well during the Davis Strait survey and all the survey data was recovered and plotted without problems. The navigation system still requires some refinements in such areas as the determination of actual rather than theoretical propagation velocities for electromagnetic radiation, restarts of system while airborne, and compensation for phase shift when a station is re-acquired following a short or long outage.

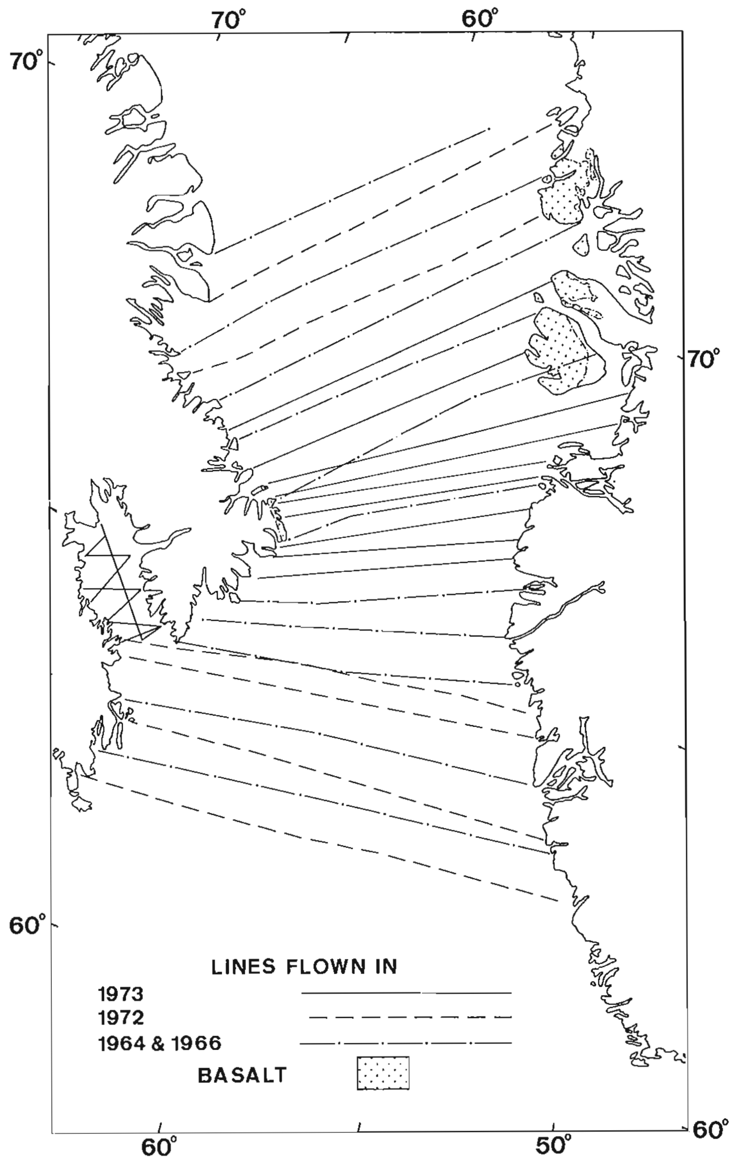

Figure 1. Aeromagnetic profiles obtained in the Davis Strait area by the NAE North Star aircraft. The onshore areas covered by Tertiary basalt has been stipled.

The operation lasted from April 26 to May 10, 1973 and the locations of the profiles obtained in the Davis Strait is given in Figure 1 together with those obtained in previous surveys by the North Star aircraft. It is apparent from the profiles that it will be possible to delineate the extent of the offshore basalt on both sides of Davis Strait (see Fig. 1) much more precisely as a result of the survey. This fact is illustrated in Figure 2 which is Profile 73-10. The boundary of the basalt has been inferred to be at the point where the character of the profile abruptly changes from a sequence of long wavelength anomalies to a train of sharp distinct anomalies which alternate positively and negatively with an amplitude of several hundred gammas (typically 200-500 gammas) and have wavelengths of between about 2 and 10 kilometres. A similar change in character occurs at the western end of the profile in the vicinity of Padloping Island where basalt is also known to outcrop.

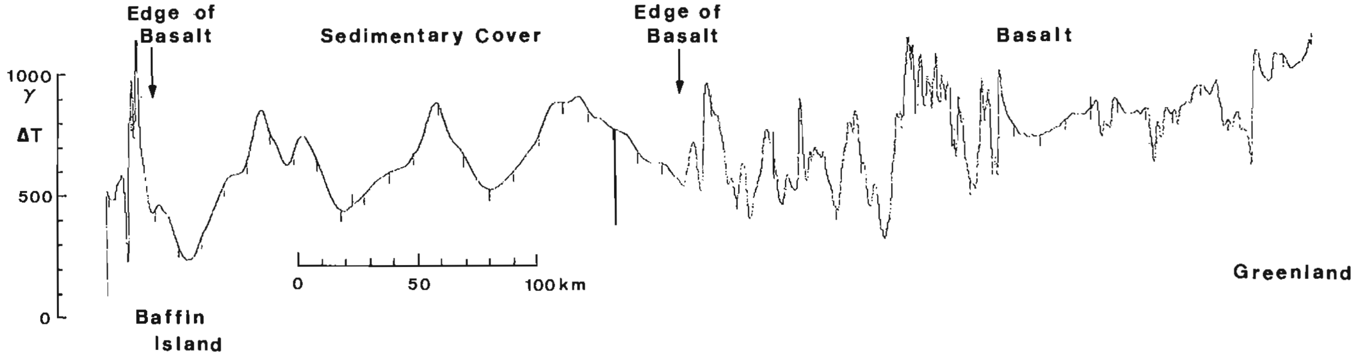

Figure 2. Profile 73-10 across Davis Strait from Padloping Island on the Canadian side of Disko Bay on the Greenland side. This total intensity aeromagnetic profile flown at 1, 000 feet elevation illustrates the distinctive anomaly pattern produced by the offshore Tertiary basalt formations.

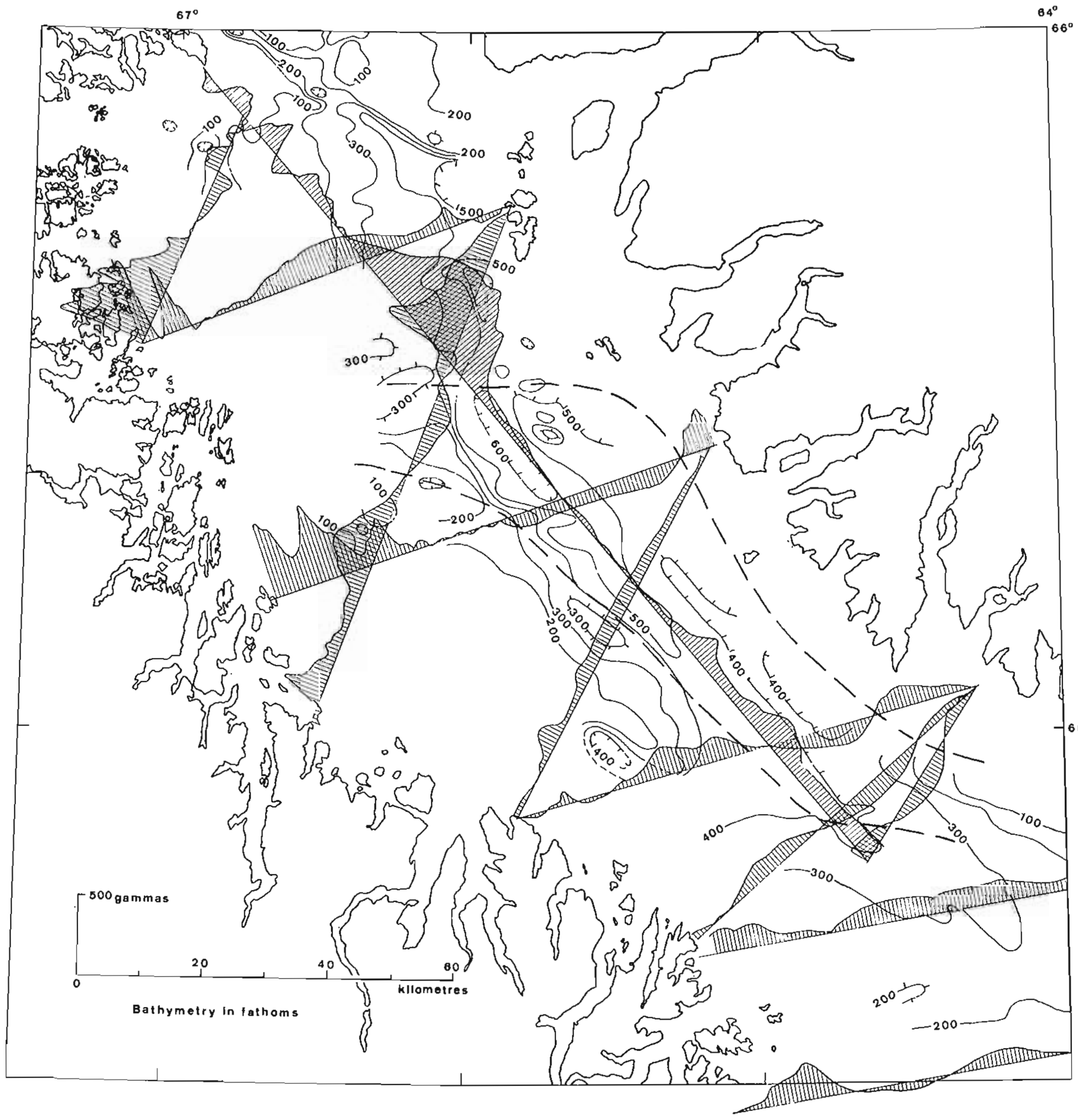

Figure 3. Aeromagnetic profiles obtained in Cumberland Sound, Baffin Island together with the known bathymetry (in fathoms). The inferred position of a graben is shown by the thick dashed lines.

Figure 4

Large iceberg in Jacobshavn Fiord which has calved from the Jacobshavn Glacier. The photograph (GSC 202228-D) was taken on May 4, 1973.

The opportunity was also taken during the 1973 survey of carrying out an aeromagnetic reconnaissance of Cumberland Sound. The resultant profiles with the regional gradient removed are presented in Figure 3 together with the bathymetry. The bathymetric contours have been obtained from Canadian Hydrographic Map 7051 published in 1973 by contouring the depths given on that map. It can be seen that several bathymetric depressions occur which are elongated along the length of Cumberland Sound. Unfortunately the troughs have not been completely delineated by the bathymetric survey, but depths of 3, 600 feet have been recorded.

In the central part of Cumberland Sound the profiles are quite smooth indicating that the depth to the crystalline rocks of the Precambrian basement is great and that an extensive sedimentary cover exists. Moreover the succession of U-shaped anomalies in the central part of the Sound are definite evidence for the existence of a graben. A tentative outline for the graben, which is about 20 km wide, has been indicated on Figure 3 by the thick dashed lines. Further analysis of the data will be carried out to obtain the thickness of the sediments in the graben which must exceed 5 km (16, 000 feet).

After completing Profile 73-9 at the Greenland coast, the opportunity was taken of viewing the Jacobshavn Glacier. It has been reported that this glacier moves more than 120 feet per day presumably because Jacobshavn Fiord is one of the relatively few outlets to the sea for the Greenland ice cap in the area, the surface of the ice cap rises relatively steeply inland from the glacier and moreover there are bedrock channels underneath the inland ice which lead to the Jacobshavn glacier. These have been indicated on the tectonic/geological map of Greenland published by the Geological Survey of Greenland in 1970. The glacier is consequently a prolific producer of large icebergs many of which would be carried southward by the Labrador current and be hazards for drilling operations on the Labrador shelf. Figure 4 shows one such iceberg in Jacobshavn Fiord which appears to be about 2, 000 feet long and which would possess a very large momentum when in motion.

We wish to acknowledge the excellent co-operation of the Canadian Armed Forces crew consisting of pilots, Captain J.L. Kite and Captain W.T. Chevrier and navigators, Captain T.R. Brownley and Captain D.M. Cameron in carrying out the survey. Low-level flying in areas such as the Davis Strait can be quite hazardous especially under poor weather conditions and the 1973 survey was no exception. Three murres, which are seabirds that nest in the cliffs at Cape Dyer, struck the aircraft at a height of about 600 feet after the aircraft turned at the west end of Profile 73-15 on May 2, 1973. One bird went into the leading edge of the port wing and hit the triggering mechanism for the Crash Position Indicator which was therefore ejected and began transmitting. Its signals were (reassuringly) picked up within 15 minutes by other aircraft flying in the area. The second murre went right through the propeller into the inboard port engine and was stopped by the radiator, and the third struck the lefthand side of the windscreen in front of the aircraft captain covering it with blood etc. The pilot took the aircraft to 8, 000 feet and returned directly to Sondrestrom. The wing was patched and the survey continued.

Acknowledgments are also made to C.D. Hardwick, B.W. Leach and N. McPhee of the National Aeronautical Establishment for their essential contributions to the project.

THE APPLICATION OF GEOPHYSICAL METHODS TO PERMAFROST INVESTIGATIONS IN THE U.S.S.R.

Project 730006

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The Second International Conference on Permafrost was held in Yukutsk, Siberia, U.S.S.R. in July, 1973. The authors attended the conference and presented papers on research in permafrost geophysics in Canada. Informal discussions with geophysicists at the conference and at subsequent meetings at various institutes in Moscow and Leningrad resulted in an overview of Soviet research in geophysical methods of geocryology.

In the Soviet Union several problems are being studied at present:

1. Mapping of discontinuous permafrost in plan

DC resistivity and high frequency EM methods have been used to map the change in apparent resistivity associated with frozen/unfrozen boundaries. Seismic reflection methods have been used to map the top of permafrost, and refraction methods have been used to map talik zones accurately.

2. Measurement of thickness of permafrost

DC resistivity methods are applied principally to measure the thickness of permafrost; however, frequency methods are being tested also. Measurements of thicknesses in excess of 100 metres have been made.

Experiments are underway using high frequency acoustic reflection methods to define the lower boundary of permafrost. The reflection seismic method has been used in limited areas where the thickness of permafrost is great. Seismic refraction methods have been used if permafrost in the upper unconsolidated materials overlies unfrozen bedrock of higher velocity.

3. Mapping of soil types in permafrost

Both electrical and seismic methods are used. Modified arrays of electrode separation are used to map areas of low resistivity contrast. Ice wedges are detected from seismic velocity contrasts determined by refraction methods. Seismic multiple reflections are used to measure the thickness of ice lenses.

Resistivity and seismic methods are used jointly in site investigations on a routine basis. However, other techniques have been used; a micromagnetic survey has outlined massive ice occurrences and radioactive and acoustic logging techniques have also been used.

4. Measurements of thickness of unconsolidated material overlying bedrock

The DC resistivity and seismic reflection methods have been used in a manner similar to non-permafrost areas to estimate thicknesses of overburden to within ±5% accuracy.

Soviet scientists suggest the following areas of improvements in geophysical techniques:

a. The lower permafrost boundary should be better defined. It is suggested that diffracted seismic waves from velocity gradients associated with the lower boundary may be definitive.

b. One should strive for higher resolving power of all geophysical techniques now in use.

c. Airborne techniques should be introduced to map the occurrence of permafrost.

d. Marine acoustic reflection methods should be applied on the continental shelf area of the Arctic Ocean to map the occurrence of sea bottom permafrost.

Project 630049

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Abstract

There have been a number of successful attempts to use radar techniques for surface and subsurface sounding. Recent electrical rock property studies indicate that the conventional concept of radar "having insufficient penetration" is not quite correct, and that there are a number of conditions in which it might be successfully used, especially in permafrost and frozen environments. Recent electrical rock property studies have shown how mineral composition, existence of conductive minerals and moisture affect the electrical characteristics of rocks. This indicates the areas in which radar may be applicable, particularly in Canada, where exploration in frozen environments are important. Sufficient evidence is thought to exist for supporting the application of radar to geology as a test, but not yet for a large scale operation. As radar has a potential of being a very powerful tool in exploration, it is suggested that serious consideration be given to its application to geology.

Introduction

Radar techniques have not been considered applicable to geological materials due to their shallow penetration. However, subsurface radar techniques have been used successfully in salt domes (Holser et al., 1972) and its application is being considered in salt. (Unterberger, pers. comm., 1973), coal and other mines (Cook, 1972; 1973). It is well known to us that experiments are being carried out on the use of radar in glaciers and for measurement of ice thickness. There are many scientists who are studying methods to penetrate the ground by radar techniques. Radar tests and surveys carried out by the Apollo 17 mission (Ward and Peeples, 1971; Ward, pers. comm., 1973; Strangway et al., 1973) are interesting, particularly in view of their application to exploration in the arctic regions. The Canada Centre of Remote Sensing (CCRS) is considering the use of radar techniques for detecting moisture in soils.

Recent findings by our Electrical Rock Property (ERP) laboratory (Katsube and Collett, 1972; 1973) indicate that the "shallow penetration" concept for radar is not quite correct, and suggest that there are a number of conditions where radar techniques may be used in mineral detection, geological mapping, energy source detection and moisture detection. The basis of these ideas were derived from measurements on igneous rocks which indicate the existence of displacement current effects and from theoretical studies which indicate the existence of conductive mineral and moisture effects at the higher frequencies. ERP studies indicate greater penetration than estimated in the past for certain cases, and the existence of resonance frequencies in materials (Unterberger, pers. comm., 1973) imply possibilities of still greater penetration for high frequency electromagnetic waves in geological materials.

It should be noted that application of frequencies near the visible frequencies seem to be under consideration for underwater communications in the U.S.A. and Japan (Imai, pers. comm., 1973). Some facts from recent papers that support the applicability of radar to geologic material are compiled and discussed in this paper.

Electrical Characteristics and EM Wave Penetration in Rocks

The recent work by Katsube and Collett (1972) has generalized the electrical characteristics of moist and dry rocks over a wide frequency range (10^{-2} - 2×10^8 Hz), perhaps for the first time. A typical set of electrical measurements (Diorite sample) for dry and moist rocks is shown in Fig. 1. The complex resistivity (ρ^*) of rocks when dry decreases with frequency at a rate close to 45^o on a log-log scale. When moist, ρ^* is more or less constant with frequency until the applied frequency reaches the critical frequency (f_{cr}). At frequencies above f_{cr}, ρ^* decreases with frequency at a rate close to 45^o similar to dry rocks. Below the critical frequency the rock is a conductor, and above it behaves as a dielectric material. The parallel

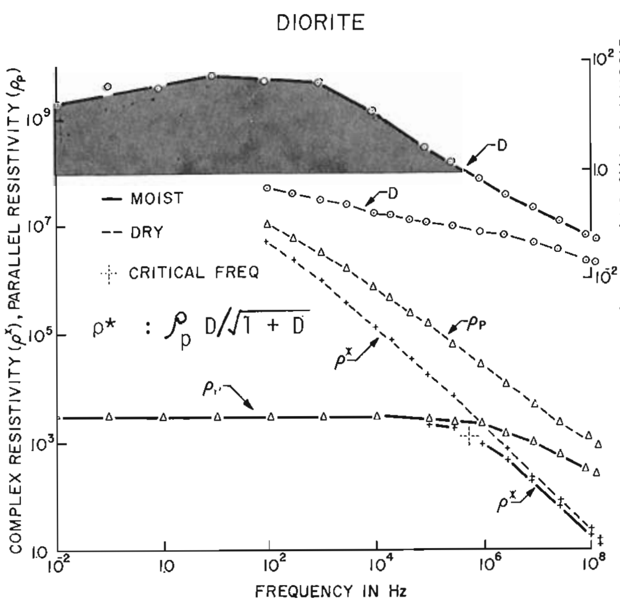

Figure 1. Electrical parameters of a diorite sample (by Katsube and Collett, 1972).

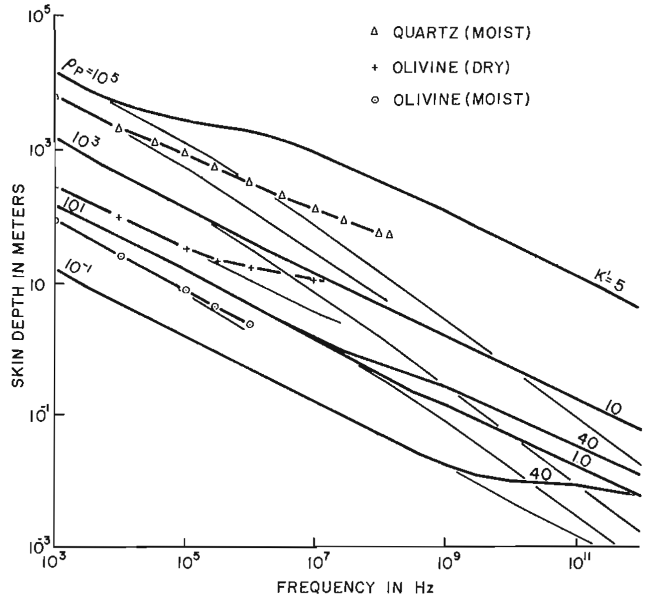

Figure 2. Skin depth vs. frequency for rocks with different values of ρ_p and K^1 (by Katsube and Collett, 1972).

resistivity, ρ_p, separates from ρ^* above f_{cr}, and also decreases with frequency, but at a smaller rate than that of ρ^*. This indicates that the displacement current effect is dominant at frequencies above f_{cr}, and this will effect the depth penetration of EM waves in the rocks.

Curves of the skin depth for rocks with various combinations of ρ_p and K^1 are shown by thick solid lines in Figure 2. These curves were calculated by use of an empirical equation which was determined from the actual measurements of the rocks and minerals.

Often geophysicists determine the skin depth from the conventional skin depth equation and do not consider the effect of the displacement current. In this case the following equation is used for the depth penetration (γ) calculation:

$$\gamma = \sqrt{\frac{2}{\omega \mu \sigma^1}}$$

$$\omega = 2\pi f$$

$$\mu = 4\pi \times 10^{-7} \text{ H/m}$$

σ^1 = real conductivity of the rocks ($\sigma^1 = 1/\rho_p$)

These curves are shown by the thin solid lines in Figure 2. On the other hand, communication engineers usually consider the effect of the displacement current but do not consider the frequency dependence of σ^1. In this case the attenuation, α, is calculated from,

$$\alpha = \omega\sqrt{\frac{\mu^1 \varepsilon^1}{2}} \left(\sqrt{1 + \left(\frac{\sigma^1}{\omega\varepsilon^1}\right)^2} - 1\right)$$

where ε^1 is the permittivity of the rocks. In these two equations σ^1 is considered constant with frequency. Actually σ^1 should be considered as being frequency dependent. The curves in Figure 2 which take into consideration both the displacement current and frequency dependence of ρ_p (thick solid lines) show larger values than those determined by conventional skin depth equations used by geophysicists, and generally smaller values than those determined by the equations used by the communication engineers.

The conclusion is that a larger depth penetration of radar waves than is normally estimated can be expected, especially in frozen ground.

Effect of Mineral Content

In the work by Katsube and Collett (1972) it is suggested that the dielectric constant (K^1) and parallel resistivity (ρ_p) at frequencies above f_{cr} are related to the mineral composition of the rocks. Basic minerals generally seem to show larger values of K^1 and smaller values of ρ_p than do acidic minerals. Particularly an olivine sample has shown a very large value of K^1 and a very small value for ρ_p. These facts suggest that certain horizons in the rock formation which is of economical importance may be traced by radar.

Detection of Conductive Minerals

Based on the trends of electrical parameters of lunar and terrestrial rocks, Katsube and Collett (1973) carried out a theoretical study on the effect of small conductive mineral content on the electrical characteristics of rocks. The model used in this study is highly conductive mineral grains isolated in an insulating mineral body. Results indicate that though the conductive mineral content may be small, they show a distinct effect on both ρ_p and the dissipation factor (D), particularly at the higher frequencies (above 10^6 Hz). These results indicate that there is a possibility for radar to be useful in detecting conductive minerals in rocks and particularly in frozen ground.

Moisture Detection and Application to Permafrost

The CCRS is studying the possibility of using radar techniques for detecting the moisture content in soils. Hoekstra and Delaney (1973) and Barringer Research Ltd. (1973) indicates that there is a dielectric relaxation phenomena in moist soils that appears mainly in the 10^8 - 10^{10} Hz range, and which can be used for moisture detection. This is a very interesting idea, but requires confirmation particularly in relation to the critical frequency of moist soils.

Another idea is introduced by Katsube and Collett (1973), that is based on the studies by Archie (1952), Keller (1966; 1967), Strangway et al. (1972) and Katsube and Collett (1972) in which a theoretical model consisting of grain-boundaries, contact and storage pores has been set up, and the electrical parameters have been calculated over a wide frequency range. The results from this study indicate that moisture in rocks can be detected and its content can be estimated by measurement of the dielectric constant at frequencies above f_{cr}, and information on the conductivity and pore structure can be obtained from comparison of dissipation factor measurements above and below f_{cr}. This idea has still to be confirmed by laboratory work.

The results of these studies can be extended or directly applied to permafrost and frozen ground conditions.

Radar Systems

Reviews are being made on the various radar systems, used in the past by scientists and engineers, that have worked underground or on the surface. Also investigations are being made on new developments in this area, especially on the systems that are being developed at the Communications Research Centre, Department of Communications, Ottawa.

The purpose of these investigations is to determine an optimum radar system for geological applications. So far no conclusions have been reached. Key factors for selecting radar systems are the frequency band and type of pulse generated by the system. Results from the electrical rock property studies suggest that capabilities for generating single frequency pulses whereby the frequency can be varied, are essential.

Conclusion

There are a number of facts that support the application of radar techniques to geology. Though many unknown factors still exist in the electrical characteristics of rocks and in the application of radar to geology, it is obvious that a field test program should be carried out. Further investigation of electrical rock properties are also essential for aiding the tests of radar to geology. One important subject in this study is the search for resonance frequencies of geological materials.

The future for radar applied to geology is not yet known. However, if radar techniques prove to be successful in geological mapping or mineral detection, due to displacement current effects or the resonance phenomena, they could turn out to be a very powerful tool. Radar techniques have the potential of being a very efficient exploration technique by either airborne or ground methods. For these reasons, serious considerations should be given to the application of radar to geology.

Acknowledgments

During this study and investigation, Mr. L.S. Collett has been most helpful and considerate in every way. The discussions with Dr. R.R. Unterberger (Texas A & M University) have been very inspiring and encouraging. Discussions with Dr. S.H. Ward (University of Utah) and Dr. D.W. Strangway (University of Toronto) and their staff (especially G.R. Olhoeft, University of Toronto) have been very helpful. I wish to also thank Dr. W.J. Chudobiak, Communications Research Centre, for his very fruitful discussions and co-operation.

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Project 630049

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Introduction

Differentiation of economic and non-economic ore deposits by electrical exploration methods is a very important subject. Scott (1972) suggested that phase-shift measurements should be added to the IP method. Zonge (1972) and Zonge et al. (1972) indicated, from laboratory and field work, that copper-rich orebodies can be separated from orebodies that lack copper, by using a new and more advanced IP method. Zonge also claimed that the copper content can be estimated by the same method. Many other scientists and engineers in North America, though showing an interest in Zonge's work, have been very skeptical about his claims. Therefore it was considered necessary for the Electrical Rock Property Laboratory to make an invesgtigation of this subject.

Background

There have been a number of papers, that appeared in the past, which show indications of the possibility of mineral differentiation by electrical methods (Katsube and Collett, 1973). Laboratory measurements by Marshall and Madden (1959), Collett (1959) and Anderson and Keller (1964) are some of the early works which show these indications, though that was not the main purpose of the work. Katsube (1967) carried out laboratory work on electrical transient measurements on a number of sulphide minerals. As a result of this work, he suggested that differentiation of sulphide minerals is possible by the analysis of the transient curves from these measurements. Some of his measurements also showed a relation between the electrical characteristics of the samples and copper content.

Measurements

At present a study on the electrical characteristics of various sulphide minerals that occur in Canada, is being carried out in the Electrical Rock Property Laboratory of the Geological Survey. The frequency range of the measurements is from 10^{-2} to 10^{5} Hz. During the last 6 months various specimens of pyrite, chalcopyrite, bornite, chalcocite, galena and other minerals supplied by Mr. H.R. Steacy and Dr. R.V. Kirkham of the Survey have been measured. Basic studies on the measuring systems and techniques have also been carried out for improvement of the measurement accuracy.

Results

Recent measurements (Katsube and Collett, 1973) have indicated that there definitely is a difference in the electrical characteristics of the various minerals. Measurements on disseminated samples also show good results. The investigations also show that there are still many problems in making positive identifications of the minerals. The main problems, at present, are (1) the electrical characteristics of pyrite varies to such an extent that it makes it difficult to distinguish differences between pyrite and copper-bearing minerals, and (2) the effect of the silicates in these samples make it difficult to identify the sulphide minerals, depending on the type and content of the silicate minerals.

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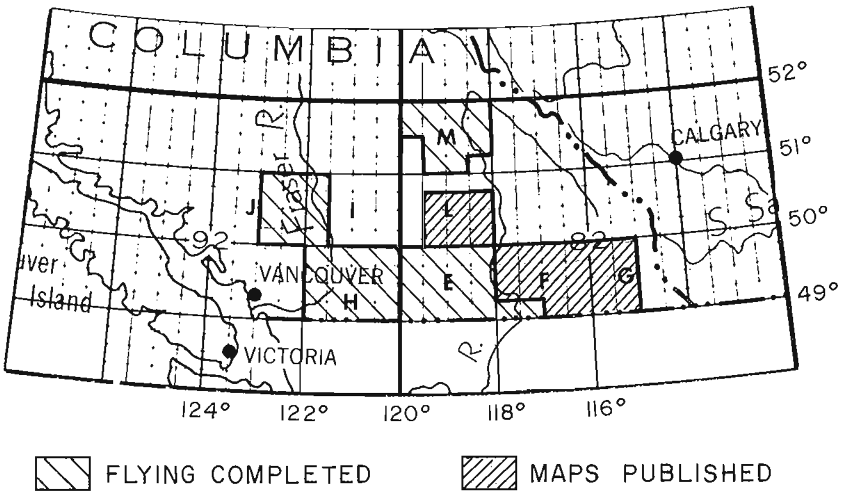
A. Larochelle
Resource Geophysics and Geochemistry Division

BRITISH COLUMBIA (Geoterrex Ltd.)

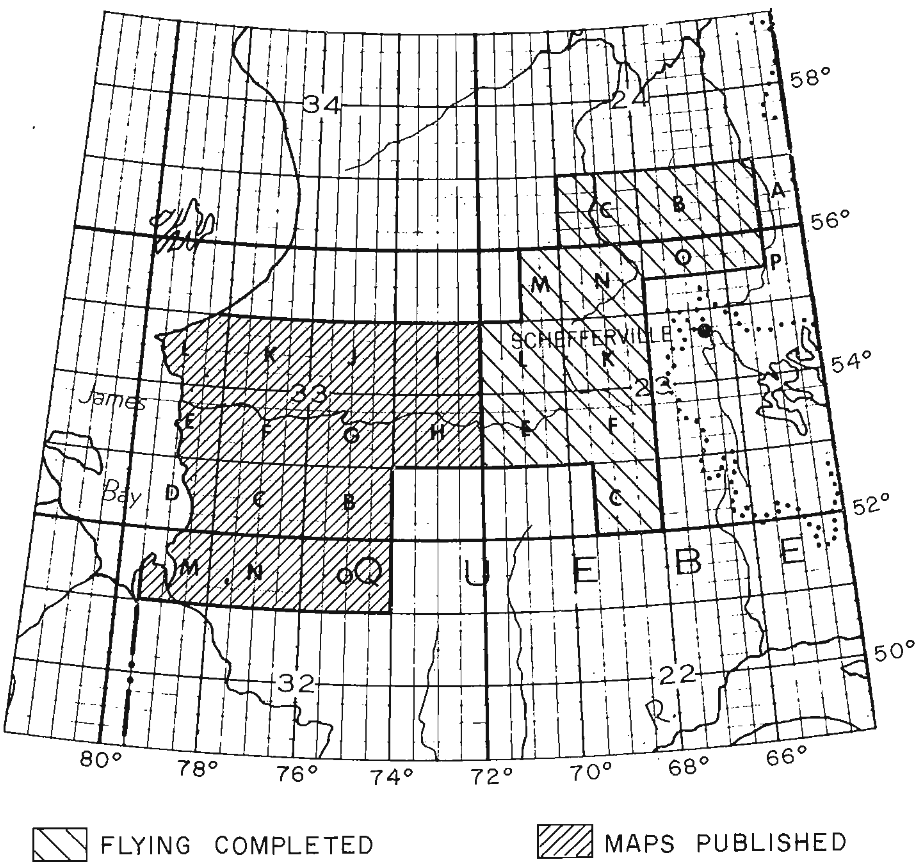


BRITISH COLUMBIA

Project 690066

The flying component of this survey, which amounted to a total of 73, 000 line miles, was completed in October 1972. To date, 30 one-mile map-sheets have been published. It is anticipated that 35 additional sheets will be printed before the end of October 1973 and that the remaining 25 sheets will be completed during the last month of this calendar year.

QUEBEC (Aero Photo)

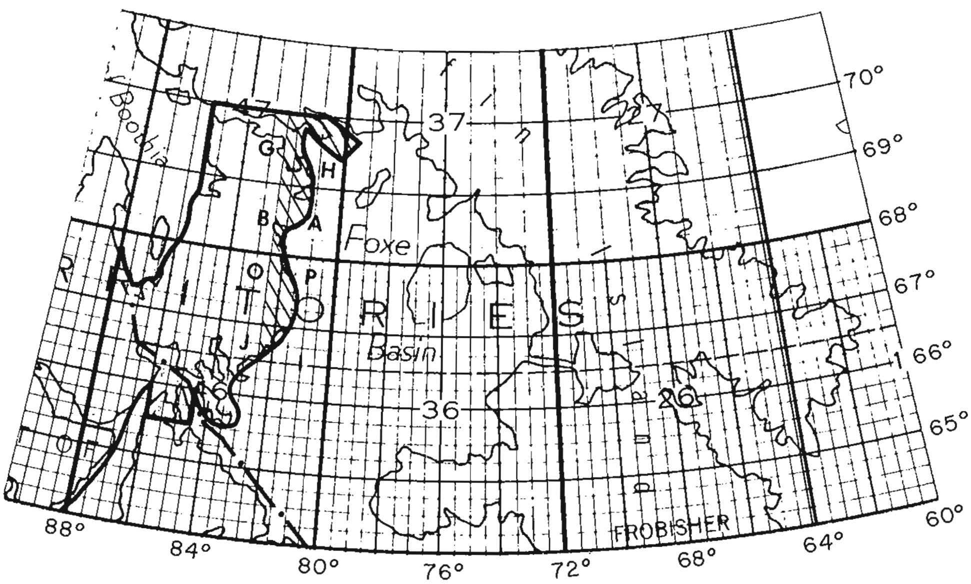


QUEBEC (Aerophoto)

Project 690073

The last 11, 733 line miles of this survey were flown in May 1973. Twelve one-mile sheets were published last April. Compilation of the remaining data related to this survey is scheduled for completion during the summer of 1974.

MELVILLE PENINSULA (Geoterrex, Lockwood, Survair)



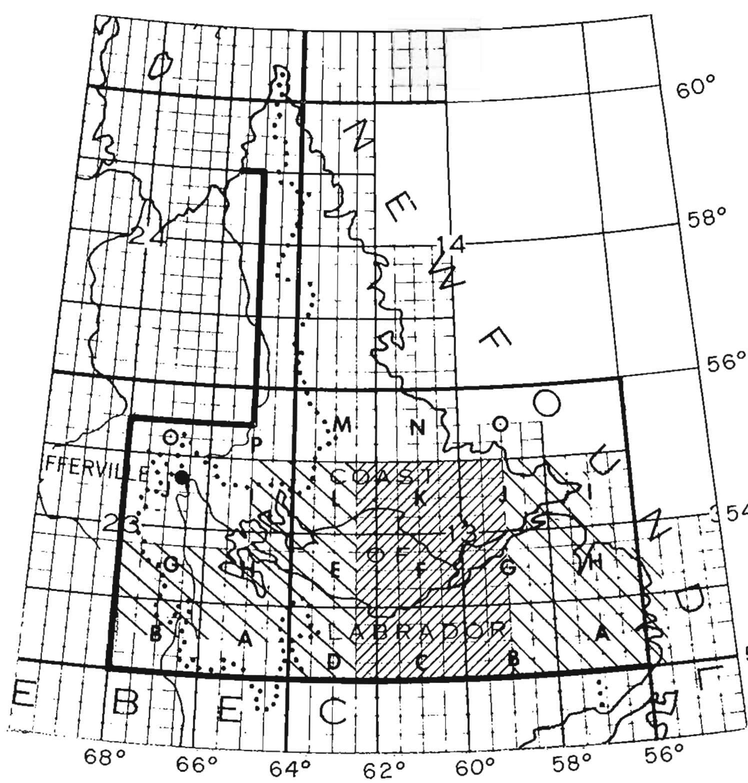
FLYING COMPLETED

LABRADOR-MELVILLE-COPPERMINE

Project 690072

A total of 18, 182 line miles was flown in the Melville Peninsula area while 21, 262 line miles were flown in the southwest part of the Labrador area during the 1973 field season. Eleven one-mile sheets of the Labrador area were released during the same period. To date, total mileage flown in Labrador is 184, 161 line miles (out of an estimated total of 314, 000 line miles) and 20, 609 line miles (out of an estimated total of 87, 500 line miles) have been flown in the Melville Peninsula area.

LABRADOR (Geoterrex, Lockwood, Survair)



FLYING COMPLETED

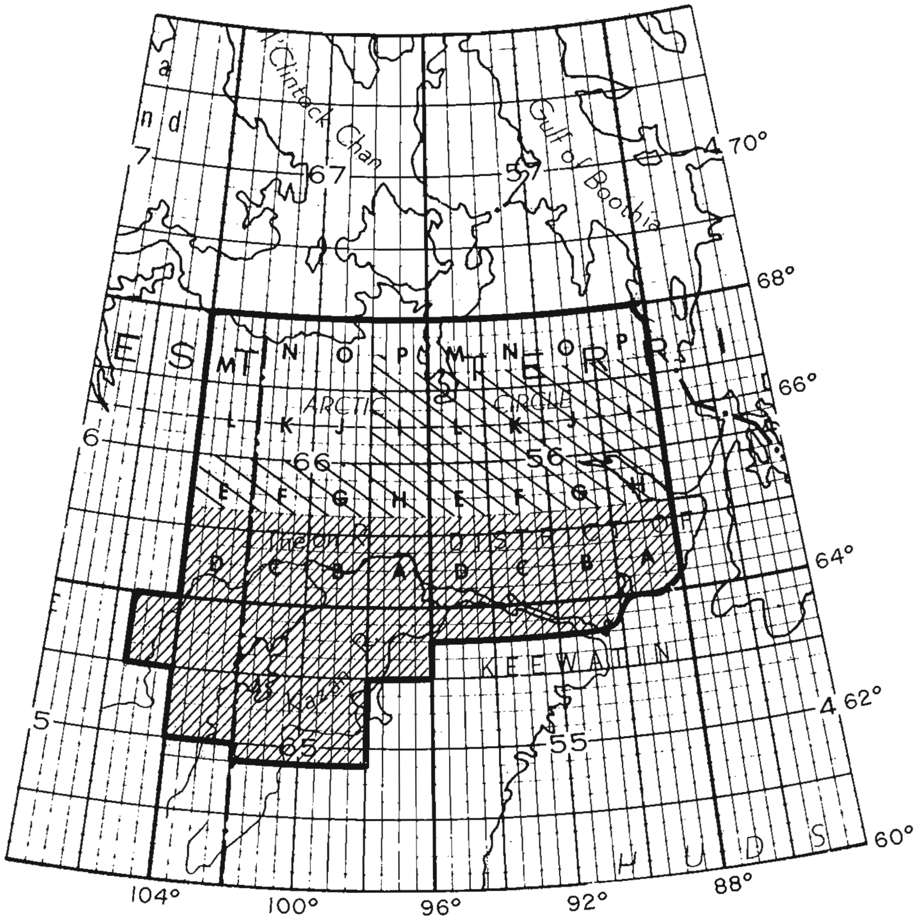
MAPS PUBLISHED

QUEBEC (PSI-GEOTERREX)

Project 730072

The first 2, 400 line miles of this survey were flown during the fall of 1972. This year's production amounted to 40, 342 on September 15, at which date flying operations were still in progress. No maps have been published yet in relation with this project. Total mileage estimated for the complete project is 332, 912 line miles.

KEEWATIN (Kenting)



FLYING COMPLETED MAPS PUBLISHED

KEEWATIN-MACKENZIE DISTRICTS

Project 690068

Flying production during the 1973 field season cumulated 54, 000 line miles. Total mileage flown to date totals 281, 859 line miles, out of an estimated 359, 536 line miles for the complete survey. Forty-eight one-mile map-sheets related to this survey were published so far in 1973.

32. SEISMIC REFRACTION SURVEY CANOL ROAD NORMAN WELLS AREA, N.W.T.

Project 730006

H.A. MacAulay
Resource Geophysics and Geochemistry Division

During the 1973 field season a conventional seismic refraction survey was conducted over a grid centred on a section of the Canol Road in the vicinity of Heart Lake in the Norman Wells area.

The purpose of this survey was to investigate the thickness of the active layer in the undisturbed area bordering the road and the degradation of permafrost beneath the road and right-of-way.

In conjunction with the conventional survey the Total-Time Method (MacAulay, 1973) was applied at four crossings of the road. This was done without any additional profiling over that required to conduct the routine refraction work.

The seismic model appears to be a low velocity wedge of unfrozen material beneath the road surrounded by high velocity permafrost (Kurfurst et al., 1973). This configuration is not easily amenable to solution using conventional refraction interpretation techniques. The total-time method however, offers a viable interpretation. Depths of thaw beneath the road-bed as calculated by the total-time method were as much as 90 feet.

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PROCEDURE FOR THE FIELD CHECKING OF DIGITALLY RECORDED HIGH RESOLUTION AEROMAGNETIC DATA

Project 680081

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Resource Geophysics and Geochemistry Division

In the aeromagnetic survey operations carried out by the GSC Beechcraft B80 aircraft the data is digitally recorded, and it is necessary to check the data between flights to verify that a malfunction has not occurred and that the data are in fact suitable for the subsequent computer compilation into magnetic maps. Such a verification procedure ensures that a given flight or perhaps several flights are not wasted with a consequent loss in time and money.

An improved method of field checking high resolution aeromagnetic data was successfully developed during the 1973 field survey operations. On the flight lines eleven parameters are recorded in Binary Coded Decimal form on seven track magnetic tape. Interrecord gaps are inserted automatically after each block of 1164 characters. Special letter identifiers are used to separate parameters. A convention has been established when recording the data with two end-of-file marks

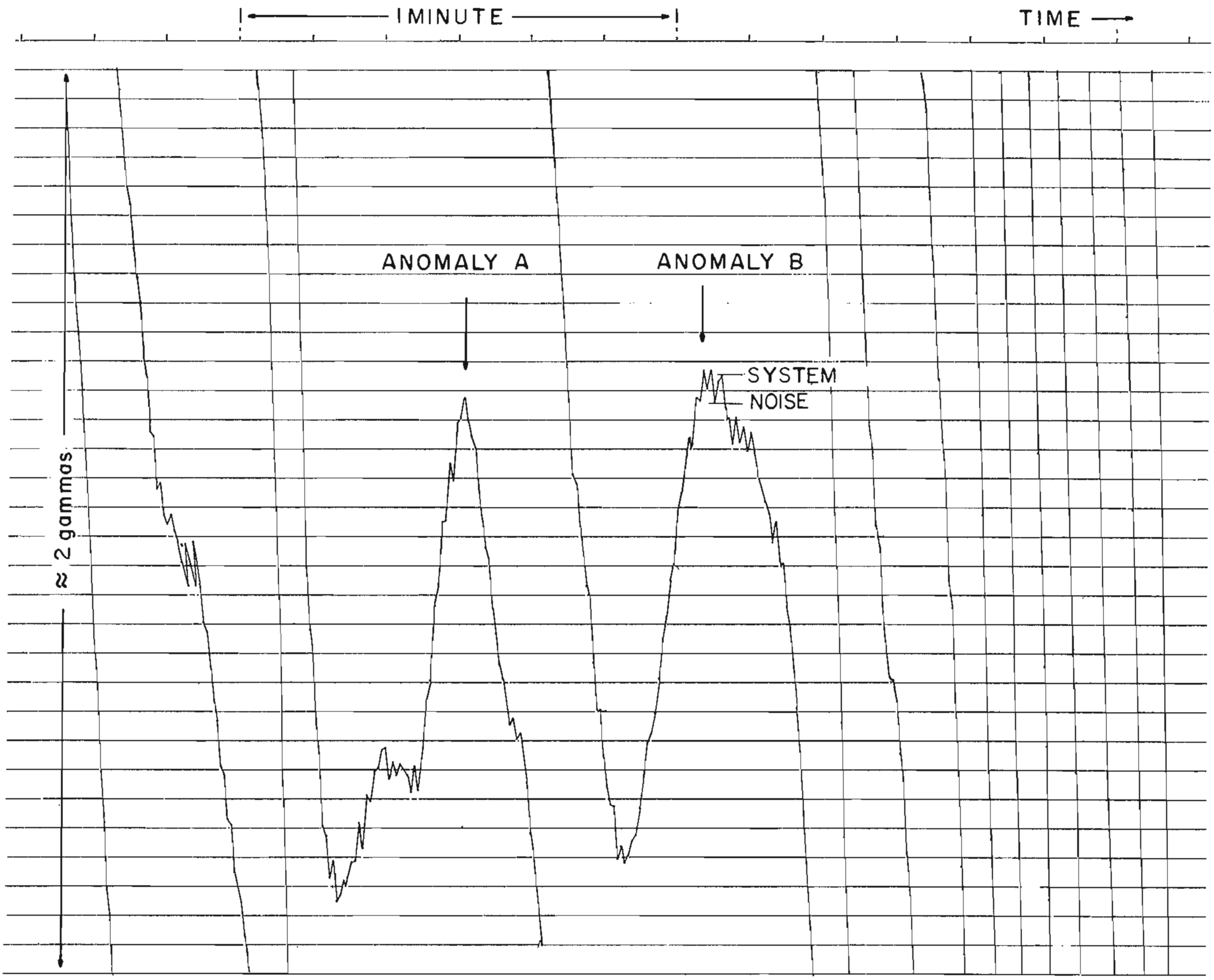

Figure 1. Profiles plotted on Versatek printer/plotter in the field to detect malfunctions of the GSC high resolution aeromagnetic survey system. (a) 2-gamma full scale.

being inserted manually after each flight and three if the magnetic tape is to be removed from the recorder.

The standard ground support system transported to the field consists of an Interdata Model 70 computer (with 32, 000 decimal bytes of core memory) interfaced with a Cipher 7 track 556 BPI tape recorder and a Versatek Model 200A matrix printer/plotter. A standard Model 33 teletype is used for system control.

Two ground checks are carried out on each magnetic tape immediately following its removal from the aircraft. In the first check, using a magnetic tape dump program developed by Margaret E. Bower, every tenth block of data is printed out in a special format. Each character is counted and the total character count in the block is printed out along with the block number. If any block in between deviates from the standard 1164 characters, it is printed out. This first check ensures that the digital recording system has performed satisfactorily during the flight. In previous field seasons, this was the only check carried out on the digital data in the field. It soon became evident that this check was inadequate as one had to spend considerable time visually scanning the printout in an attempt to check the validity of the numbers being recorded. During an extended period of good flying weather and low diurnal activity, the rapid accumulation of data made this check impossible.

Additional programming and interface changes were developed this spring to allow a second, more comprehensive, quality check to be carried out. On a second pass through each magnetic tape only the flight line number, time and high resolution magnetic field values are extracted. The magnetic field values are converted to plot values and a continuous profile is printed using the Versatek matrix in plot mode. The flight line number and line starting time are printed at the beginning of each profile. Time increment marks of ten seconds, one minute, and ten minutes are automatically inserted along one margin of the profile. If the time changes by more than one second from the previous sample, a new time is printed out. If any of these parameters is missing, a message is printed out to indicate this malfunction. The profile program continues through two end-of-file marks but halts if a third

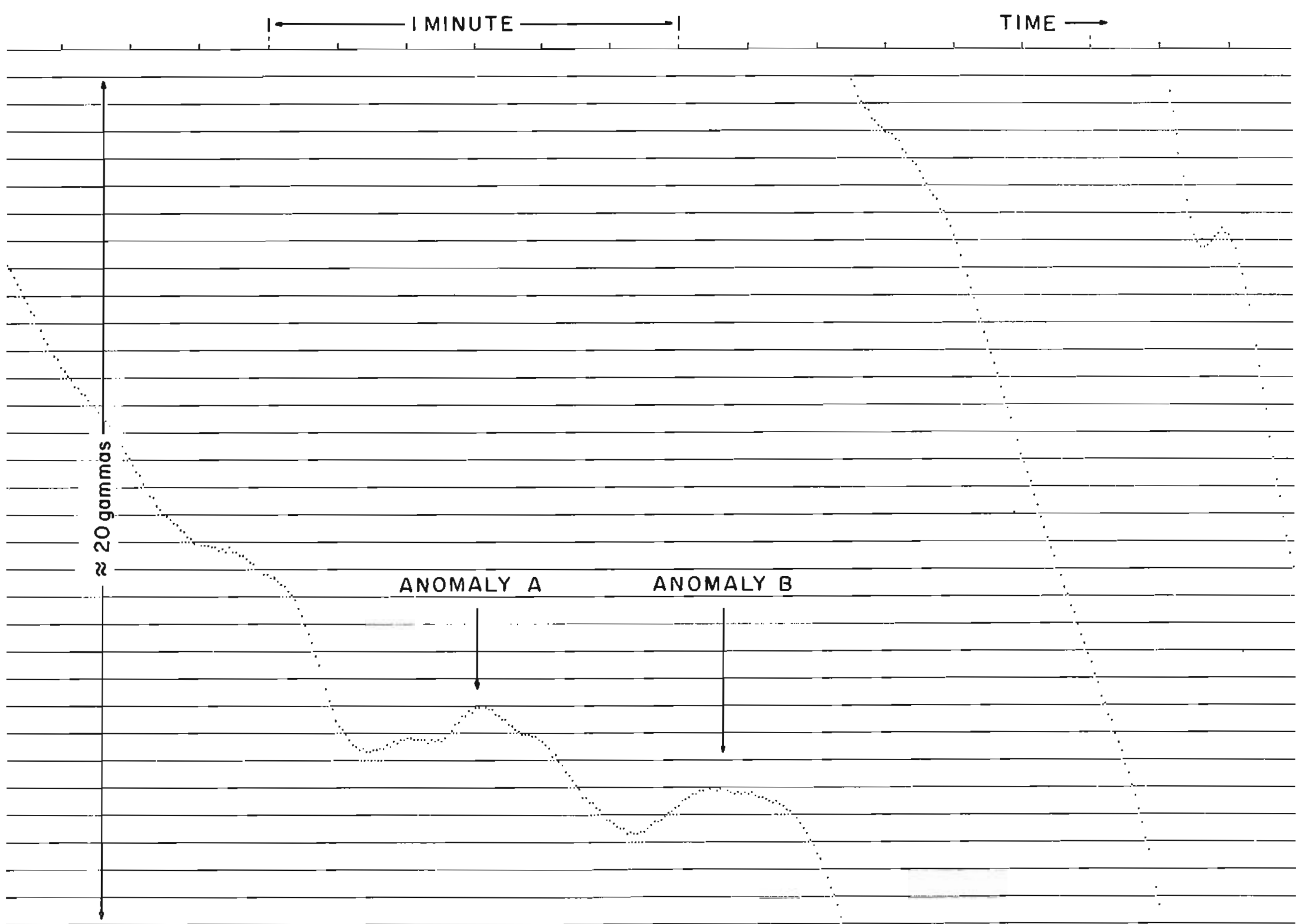

Figure 1. Profiles plotted on Versatek printer/plotter in the field to detect malfunctions of the GSC high resolution aeromagnetic survey system. (b) 20-gamma full scale.

is sensed. A message is printed out each time a file mark is sensed. The scale of the profile is selected using the teletype and can be changed at any time during the profile. Scale ranges of 2, 20, 200 or 2000 gammas across the 7-inch chart width are selectable. Longitudinal scale can also be changed allowing the profile to be stretched or compressed in length.

Where magnetic gradient allows, profiles of 20 gamma full scale are plotted from each magnetic tape with selected sections of low magnetic gradient rerun at 2 gamma full scale. If the magnetic gradient is exceptionally steep, the scale sensitivity is reduced by a factor of ten.

The profile allows an immediate visual check of the system noise, digital recording validity, and system clock operation. Moreover, the character, magnitude, and time period of the system noise is readily discernible on the profile. When using the 2 gamma scale, the resolution of the profile is approximately 0.06 gamma per division and noise magnitudes as low as 0.01 gamma are discernible.

The high resolution magnetometer readings recorded during the survey are obtained from a difference frequency which is electronically multiplied by 256 and counted for a 0.2 second time period. To convert each reading to an exact gamma value would involve a large dedication of core memory to arithmetic operations. To avoid this and keep the core memory requirements at a resonable level the magnetic values are used in the form they are recorded in and the scales are approximated. For example, the twenty gamma scale after conversion would be 20.92318587 gammas and a calibration scale could of course be readily devised for the chart to make the conversion.

The program was written in Assembler language for the Interdata Model 70 computer. The total computer core usage for the plot and print program is 12,278 decimal bytes. A basic operating system and hexidecimal debugging program occupy a large portion of the remaining core memory but would be considered superfluous on a production-oriented system. The complete core memory is stored off-line on magnetic tape and the system can be restored in less than five minutes. Individual programs are also stored on punch paper tape.

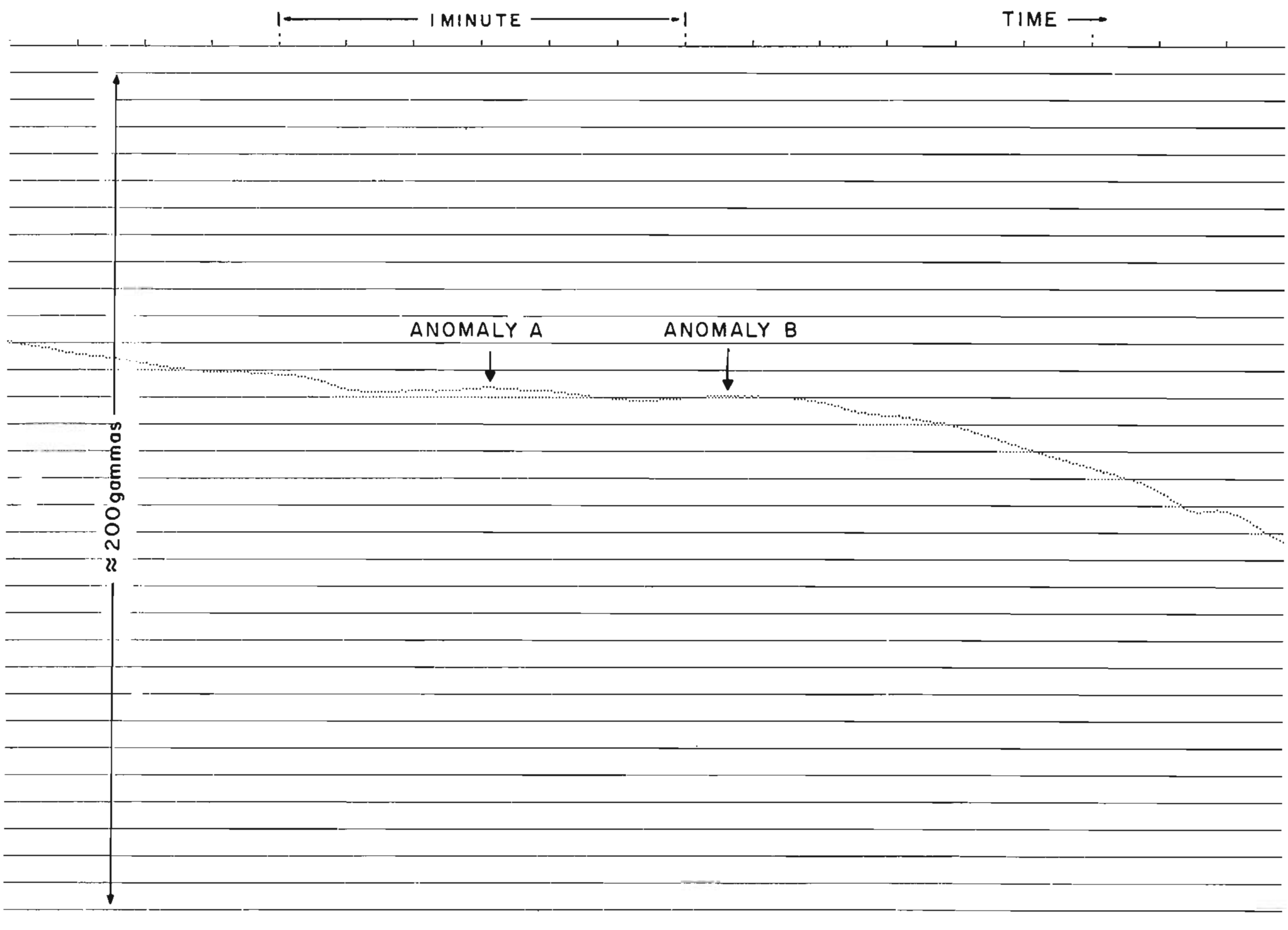

Figure 1. Profiles plotted on Versatek printer/plotter in the field to detect malfunctions of the GSC high resolution aeromagnetic survey system. (b) 20-gamma full scale.

In the accompanying examples, anomalies A and B are shown in three different plotted scales, namely 2 gamma, 20 gamma and 200 gamma full scale (Fig. 1a, 1b, and 1c). The system noise on the 2-gamma plot is very easily seen and the magnitude of the noise can be readily established. The sample of the printout format (Fig. 2) demonstrates the ease with which one can spot wrong block lengths and character misplacement. In block number 407 in Figure 2 the parameter identified by the symbol] is missing for 10 samples and an unwanted character is added to the parameter identified by the symbol ;. The rapid printing and plotting speed (600 lines per minute of print or 120 plotted points per second) of the Versatek printer/plotter allows a complete ground check on 8 hours of flying to be completed in approximately one hour. The computer program will be placed on open file by the Geological Survey of Canada if there appears to be a sufficient interest from industry in the way of requests for the program to warrant this action.

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Figure 2. Printout of the survey parameter values digitally recorded by the GSC high resolution aeromagnetic survey system.

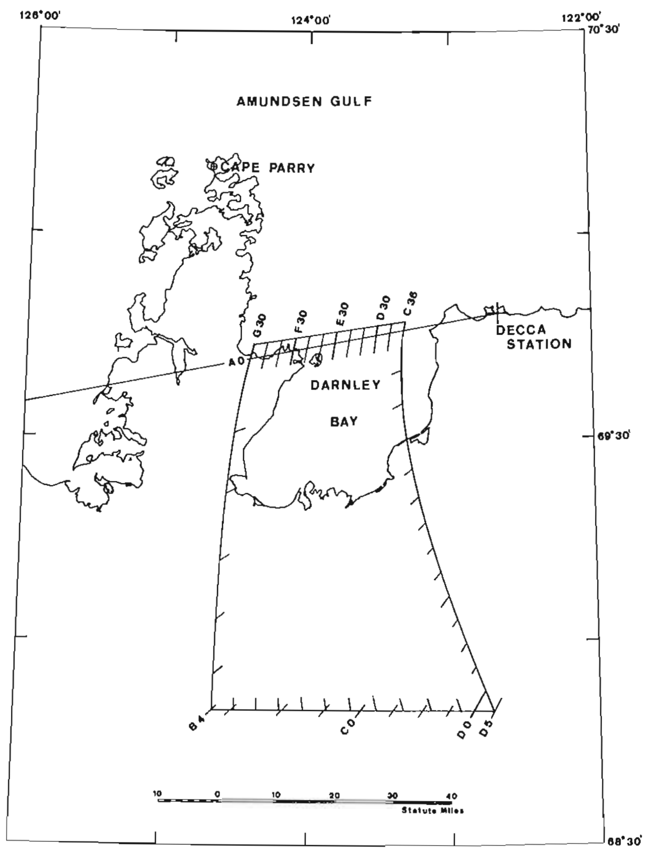
Project 680081

P. Sawatzky, D. G. Olson, A. Dicaire and Peter J. Hood
Resource Geophysics and Geochemistry Division

During 1973, the Geological Survey Queenair B80 aircraft, which is equipped with a digital-recording rubidium-vapour magnetometer, was used to carry out experimental surveys in the following areas:

1. Amundsen Gulf, N. W. T.
2. Kamloops, B. C.
3. Bathurst Mining Camp, New Brunswick

In addition a series of base line loops were flown in the Maritimes to be used in the compilation of the magnetic anomaly map for that area in which the contribution due to the main earth's field is removed using the International Geomagnetic Reference Field. The base lines will enable the various aeromagnetic surveys in the Maritimes which were flown over a twenty-year period to be tied to a common datum. This is particularly important for those aeromagnetic surveys flown during the fifties using fluxgate magnetometer, all of which were compiled using an arbitrary datum.



1973 DECCA SURVEY

Figure 1. Survey area flown with the Geological Survey high resolution magnetometer in the Amundsen Gulf area, N. W. T. during April-May, 1973.

Amundsen Gulf Survey

The first experimental high resolution aeromagnetic survey carried out during 1973 was originally planned to cover a substantial area of the Amundsen Gulf, south of Banks Island, and was a contribution to the Polar Continental Shelf Project. The base of operations selected was at Cape Parry (see Fig. 1) where an airstrip and heated hangar are located. The ancillary support equipment left Ottawa by departmental vehicle for Yellowknife on March 27 and was then airlifted by Wardair Bristol Freighter together with an International Scout vehicle and six of the field crew to Cape Parry on April 16th. Because of the extended length of daylight hours at that time of the year in Cape Parry, it was anticipated that it would be feasible to have three five-hour survey flights in one day. The field party therefore consisted of 3 pilots, 3 equipment operators and 2 aircraft maintenance engineers with P. Sawatzky as Party Chief.

The Decca chain operated in the Amundsen Gulf area by the Polar Continental Shelf Project was used for navigation which required that a Decca navigation receiver be installed in the Queenair aircraft for the purpose. The decca navigator receiver had been specially modified to provide a digital output so that the red and green decometer readings could be recorded along with the magnetometer, time, doppler along- and cross-track values. This will enable a completely automated compilation procedure to be carried out since all survey parameters were digitally recorded. Some trouble was initially encountered in getting the Decca receiver to operate properly but this was quickly traced to grounding problems.

A ground magnetometer was set up immediately upon arrival at Cape Parry on April 16 to record the diurnal variations of the earth's magnetic field. It was immediately apparent that the diurnal variations were excessive – far beyond even the more lenient specifications for standard-sensitivity aeromagnetic surveys. Repeated sinusoidal 150-gamma amplitude excursions in 4 minutes were recorded. Subsequently the diurnal variations quietened down to some extent but on all days they were considerably greater than those which would be recorded in southern Canada, and it transpired that diurnal activity was the greatest constraint to obtaining a good survey productivity. It is apparent that the area can only be effectively surveyed using a vertical magnetic gradiometer in order to nullify the interference of the diurnal variations of the earth's magnetic field. During the latter part of the operation (May 4-8) a four-day blizzard preceded by a day of freezing rain made survey flights impossible.

The area surveyed is shown in Figure 1; approximately 2, 500 line miles were flown at an altitude of

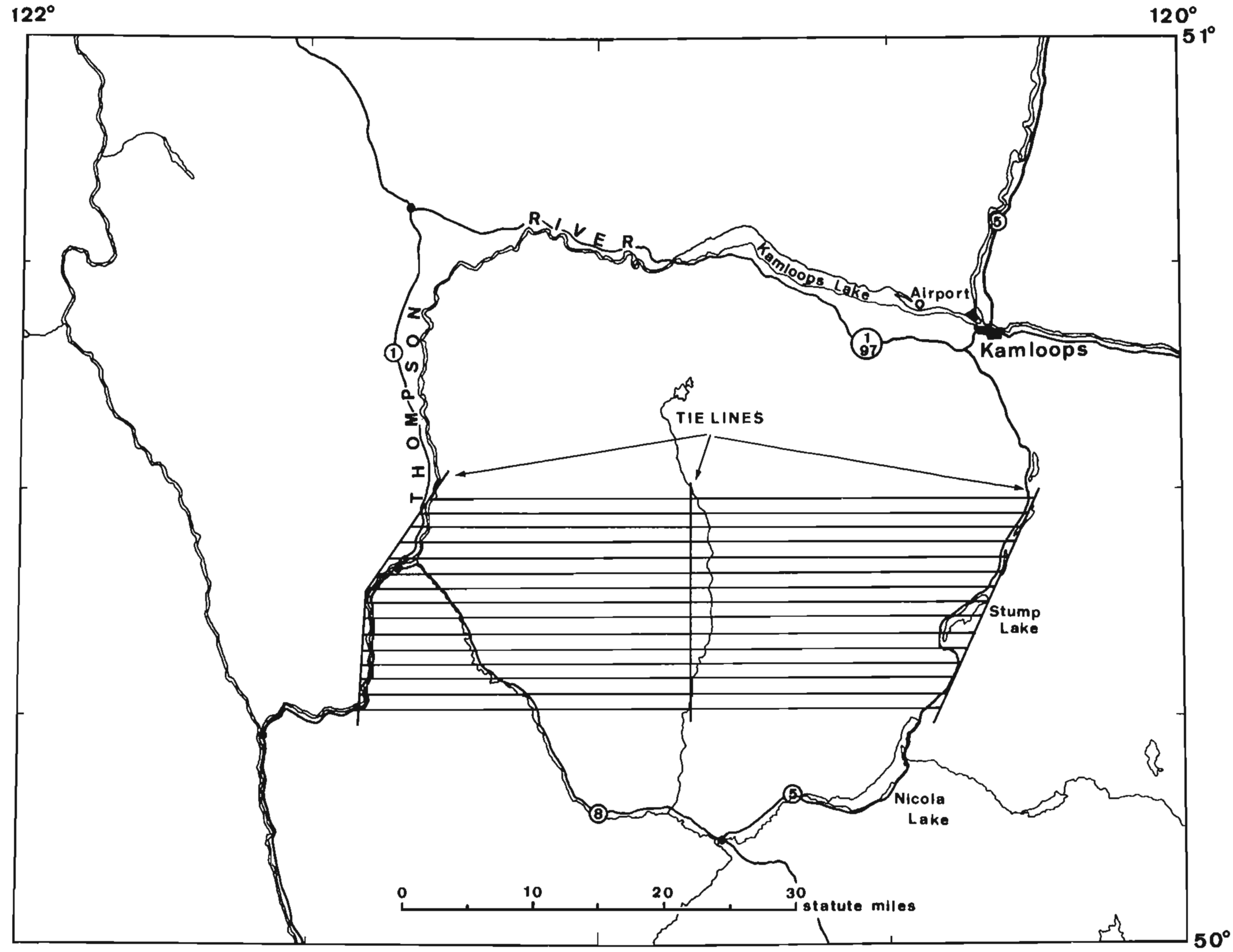


Figure 2. Experimental survey flown in the Kamloops area to ascertain the efficacy of high resolution aeromagnetic surveys mountainous terrains.

2, 000 feet above sea level. Every second (even-numbered) green Decca lane was flown and these were oriented approximately in a north-south direction.

When it became apparent that the original survey planned could not be completed because of the excessive diurnal activity, it was decided to concentrate on delineating the Darnley Bay anomaly. The feature was originally discovered as a result of a gravity survey carried out by the Gravity Division of the Earth Physics Branch (Hornal et al., 1970; Stacey, 1971). The survey delineated a circular gravity anomaly at the southern end of Darnley Bay having a radius of 50 km with Bouguer values rising 130 milligals above the background field. It was concluded by Stacey (1971) that the anomaly is due to a mafic body in the form of a truncated cone whose top is probably between 1 to 5 km below the surface. Riddihough and Haines (1972) studied five high level (11, 500 to 17, 000 feet) airborne magnetic component profiles obtained by the Geomagnetic Division of the Earth Physics Branch. They observed that a considerable portion of the body which gives rise to the gravity anomaly is magnetic and produces a large magnetic anomaly which exceeds 700 gammas for the vertical field component. They concluded that the depth to the top of the body was between 3 and 4 km subsurface. In the 1973 aeromagnetic survey, the anomaly peaked at about 1, 500 gammas above the background values. The dip of the earth's field is 84° in this location, so that the amplitude of the vertical and total field anomalies will be almost the same. Thus the anomaly only falls off by a factor of about 2 in going from 2, 000 feet to 11, 500 feet ASL. This is indicative of the fact that the top of the body is deeply buried being at least several kilometres below the surface.

Kamloops Survey

The second experimental survey was carried out to ascertain the efficacy of high resolution aeromagnetic

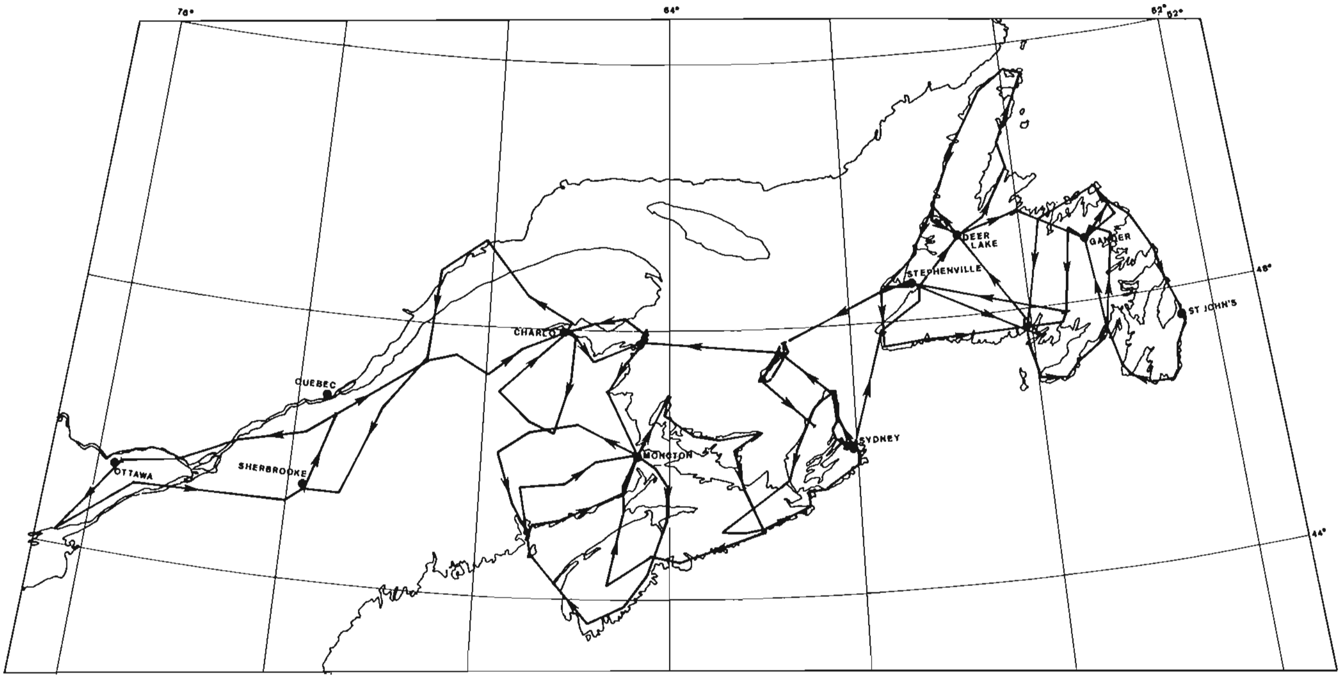


Figure 3. Aeromagnetic base line network flown in the Maritimes during June-July, 1973 to be used in the compilation of residual magnetic anomaly maps.

surveys flown at a constant barometric elevation over areas of rugged topographic relief. There are considerable operational problems in flying fixed wing aeromagnetic surveys at a mean terrain clearance of 1, 000 feet over such areas, and in recent years use has been made of helicopters to carry out the surveys. Because of the limited range, low speed and a relatively high cost of operation of helicopters compared to fixed-wing aircraft, the line mileage cost is much higher. Thus it was decided to carry out a test to see whether the data from high resolution aeromagnetic surveys flown at a constant elevation above sea level compares with that obtained from standard sensitivity surveys flown at a constant terrain clearance. The relative survey costs should also be borne in mind together with the fact that filtering techniques can also be subsequently applied objectively to the higher level data which is obtained in a horizontal plane i. e. at a constant height above sea level.

Approximately 790 line miles were flown during the Kamloops test between May 17-21. The flying height was 6, 500 feet above sea level because mountain peaks in the survey area reach 6, 000 feet. The position of the 15 east-west lines flown are shown in Figure 2, and three double tie lines were also flown for control purposes. The base of operations was Kamloops, and the party chief for the operation was D. Olson.

Bathurst Mining Camp

The main survey was flown during 1972 and was a co-operative project with the Department of Natural Resources of New Brunswick. The area covered by 1972 survey and the survey specifications are given in the field report by Sawatzky et al. (1973). During the subsequent compilation of the aeromagnetic maps, it was found that the specification for the flight line spacing was exceeded in a number of instances. The specification in question is that the line spacing should not exceed 2, 000 feet over any 5-mile-distance and that in no place should the spacing exceed 2, 667 feet. It was therefore necessary to fly additional lines between a number of the lines flown in 1972. For this additional survey flying, which amounted to about 1, 000 miles, the aircraft was positioned at the Charlo airport during the period June 28 to July 22. This survey was combined with the base line survey described later and A. Dicaire and D.G. Olson were Party Chiefs for the operation.

Base Line Network, Maritime Area

A series of base line loops (see Fig. 3) were flown in the Maritimes during the period June 28 to Aug. 17 starting from Ottawa.

The Geomagnetic Division of the Earth Physics Branch operate geomagnetic observatories at Blackburn near Ottawa and at St. John's, Newfoundland. Thus the value of the earth's magnetic field at these locations is accurately known and can be used as 'magnetic bench marks' that the aeromagnetic values at 1, 000 feet elevation can be checked against. The opportunity was therefore taken of flying at 1, 000 feet along the four cardinal headings over the building containing the recording magnetometer at the Blackburn geomagnetic observatory before and after the survey operations. A similar procedure was carried out while the Queenair aircraft was at St. John's.

The base line network was laid out so that most of the larger surveys were crossed at least twice and the crossing points were located at easily identified points, for instance at Moncton, the intersection of the runways of the abandoned Scoudouc airport was used. Two ground monitors were used for the survey. The first was usually located at the base of operations which were successively Charlo, Moncton, and Sydney. The second monitor was a mobile unit which was positioned at a convenient location usually about halfway around a given base line loop. For Newfoundland, both ground monitors were mobile and were located at Stephenville and Gander respectively. In no case was aeromagnetic data acquired more than 200 miles from either one of the two mobile ground monitors or the Blackburn and St. John's geomagnetic observatories.

Approximately 7, 960 line miles of aeromagnetic data were obtained along the base lines, and the party chiefs for the operation were A. Dicaire for the period from June 28 to July 16 and D. G. Olson for the period from July 16 to August 15.

For all the surveys described in this report, Mr. A. Lambros was the senior pilot for Kenting Earth Sciences Ltd. who operate and maintain the Beechcraft Queenair B80 aircraft. Keith Owens functioned as navigator/observor during the Bathurst reflights and the Maritime base line network. An Interdata model 70 computer located at the base of operations to field check the digital aeromagnetic survey tapes except for the Kamloops survey where logistics prevented this. This field checking procedure is described in the following report by D. G. Olson.

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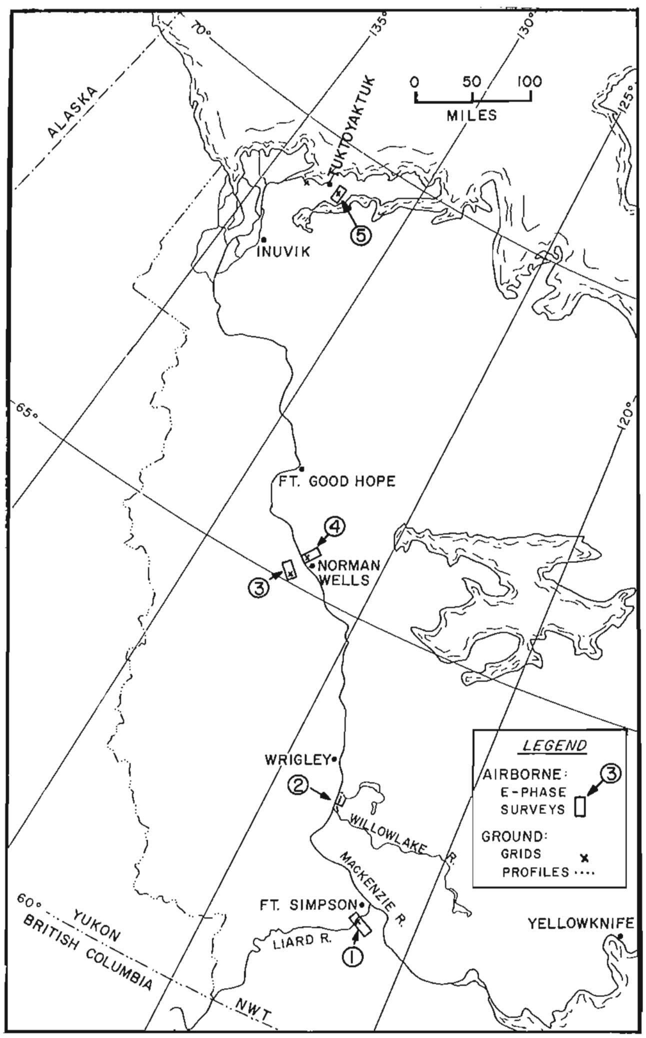
Projects 670041, 680036

W. J. Scott
Resource Geophysics and Geochemistry Division

In the spring of 1973, test grids were established at four sites in the Mackenzie Valley: one south of Fort Simpson, two near Norman Wells and one near Tuktoyaktuk. DC and VLF resistivity measurements were made on these grids in the spring. In late April an airborne E-Phase survey was flown over these sites and over an area south of Wrigley between Willowlake River and River Between Two Mountains (Fig. 1).

During the period June-August, the winter grids were revisited and expanded, and a second set of electrical measurements made, for comparison with the winter data. Shallow refraction seismic measurements were made during the summer season by a crew from the Seismic Section, Resource Geophysics and Geochemistry Division.

In the Willowlake River area, DC and VLF resistivities were measured at close spacing along approximately 15 miles of the centre line of the future Mackenzie Highway. Hammer seismic work was carried out by the Seismic Section at the same time. This section of the highway, on which construction has already commenced, will serve as a test area. It is planned to repeat the geophysical measurements on the same profile after several years to assess the impact of construction on permafrost conditions.



THEORETICAL STUDIES TO AID EM INTERPRETATION

Project 730004

A.K. Sinha
Resource Geophysics and Geochemistry Division

Work is continuing on the quantitative assessment of various dipole-dipole coil systems for electromagnetic mapping of stratified media. In most geological areas, the frequency of the transmitter current must be kept low (usually below 30 KHz) in order to achieve good penetration. To model such situations, therefore, quasi-static solutions provide sufficient accuracy for interpretation purposes for both ground and airborne surveys. A comprehensive study (quasi-static case) on the comparison of different coil arrangement systems used in airborne surveys over a multi-layer medium has been published recently in the literature (Sinha, 1973; Sinha and Collett, 1973).

In areas with very high ground resistivity (ice-sheets, permafrost zones, deserts), however, use of higher frequencies may be desirable in order to obtain sufficient resolution of the subsurface layers. In such cases, the effects of displacement currents are no longer negligible, and so, the simpler quasi-static solutions must be replaced by the complete solutions. The most important difference between the two cases is that TM (transverse magnetic) mode effects are no longer negligible at higher frequencies. Completely generalized computer programs have therefore been devised to obtain the electromagnetic field components and mutual coupling ratios of magnetic dipoles placed on (ground case) or above (airborne case) a multi-layer lossy dielectric medium (e.g. permafrost zones). For the airborne case, the numerical integration of the infinite integrals required to obtain the mutual coupling of loops is relatively easier as the integrals converge quickly, thus yielding higher accuracy in the final result.

For the case of ground systems, however, some of the infinite integrals even after suitable transformations to accelerate their convergence, converge rather slowly. Therefore accuracies beyond four places of decimals are difficult to achieve for some frequency or induction parameter ranges. Standard curves based on these theoretical results are being plotted now which will have ready use in the interpretation of dipole-dipole multi-frequency e.m. sounding results over any type of terrain.

References

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ERTS IMAGERY REVIEWED

Project 730008

V. R. Slaney
Resource Geophysics and Geochemistry Division

The Geological Survey's collection of ERTS imagery has grown to include 1147 sets containing about 2,600 prints. Half of the imagery depicts scenes with a snow cover. Most of the snow-free scenes originated this year. New material is added to the collection at the rate of about 50 prints each week. Prints are received within 4 to 6 weeks of their being recorded at Prince Albert.

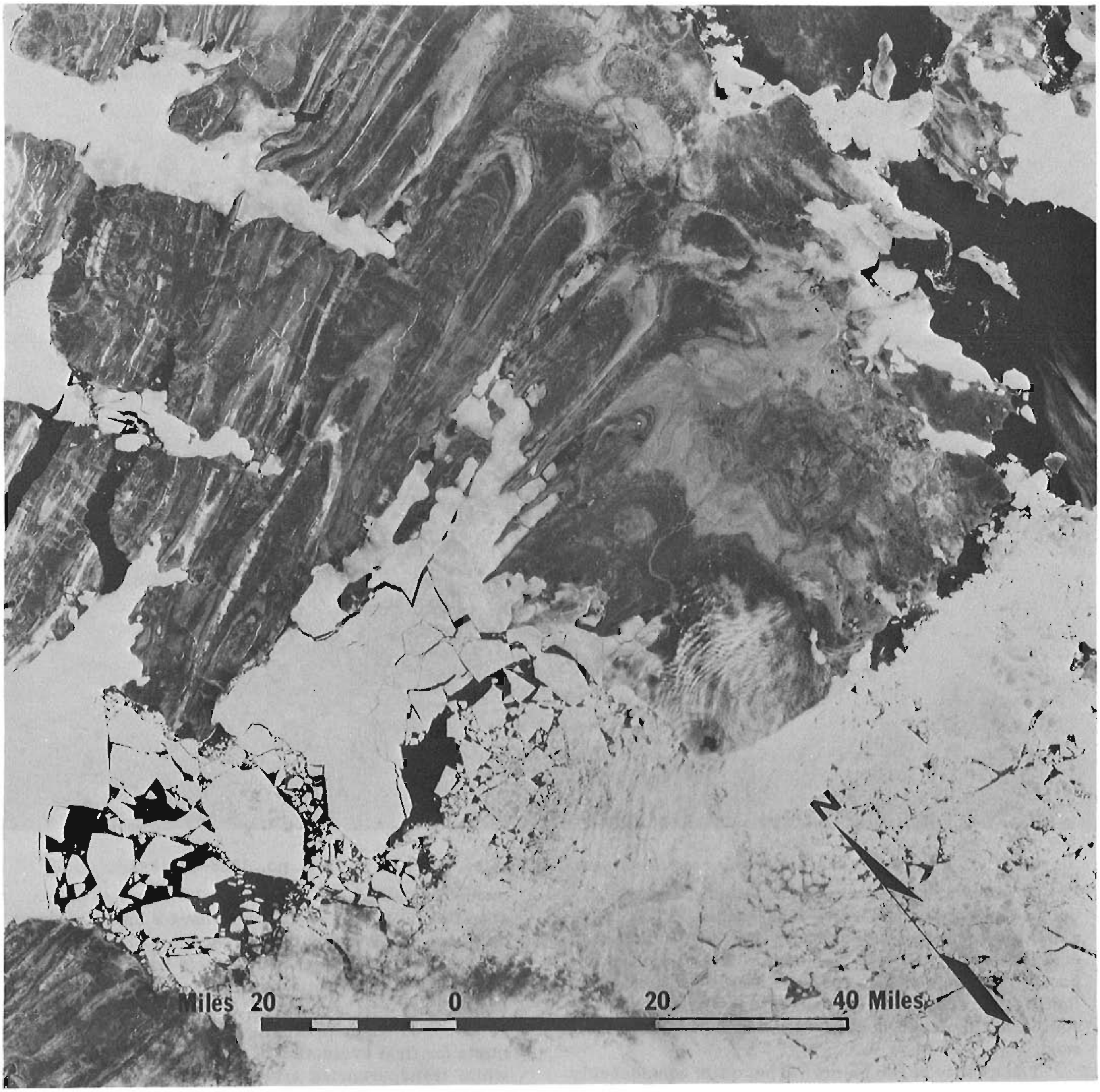

Figure 1. Bathurst Island, Northwest Territories, 29th July, 1973, no. 1371-10514-5.

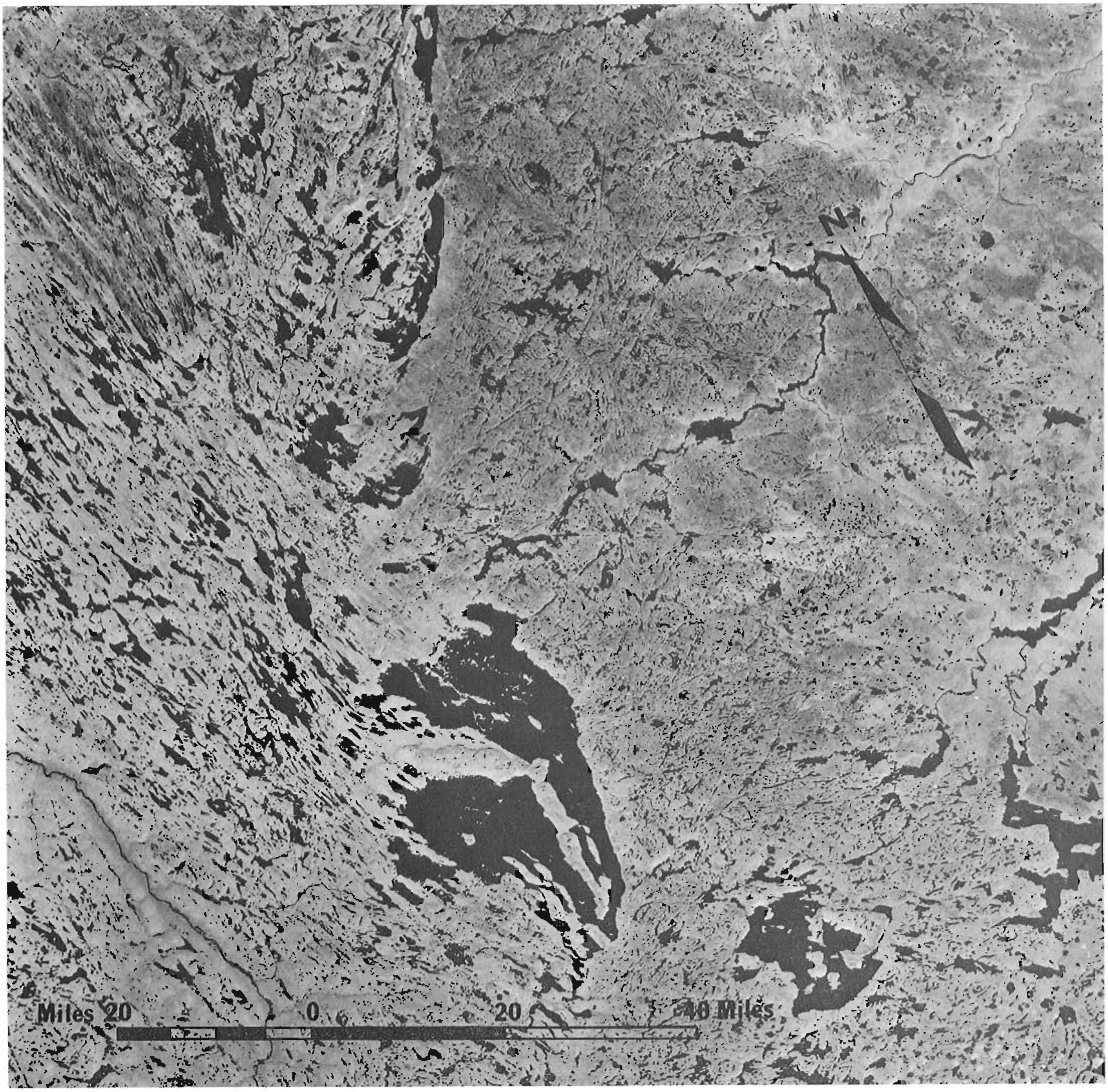

Figure 2. Takijuq Lake area, Northwest Territories, 26th July, 1973, no. 1368-18373-7.

More than 80 per cent of Canada is represented by both snow scenes and snow-free scenes. The main gaps in winter coverage are northern Quebec and northern and central British Columbia. The only areas poorly represented by snow-free imagery are eastern Baffin, Labrador and Newfoundland in the east, and southern Yukon and northern British Columbia in the west.

The quality of the prints varies quite considerably. All of the prints have less than 20 per cent total cloud cover. Irregular or uneven distribution of cloud reduces the usefulness of only a relatively few prints. A significant proportion of prints have a lower contrast and poorer resolution than expected, particularly in band 4 (0. 5 - 0. 6 micron). This is believed largely due to unfavourable atmospheric conditions at the time the imagery was recorded.

Dodged paper prints have proved to be quite adequate for first evaluation of subject areas. Black and white transparencies are recommended for detailed work. These have a higher resolution and a far greater range of grey tones than paper prints, and can also

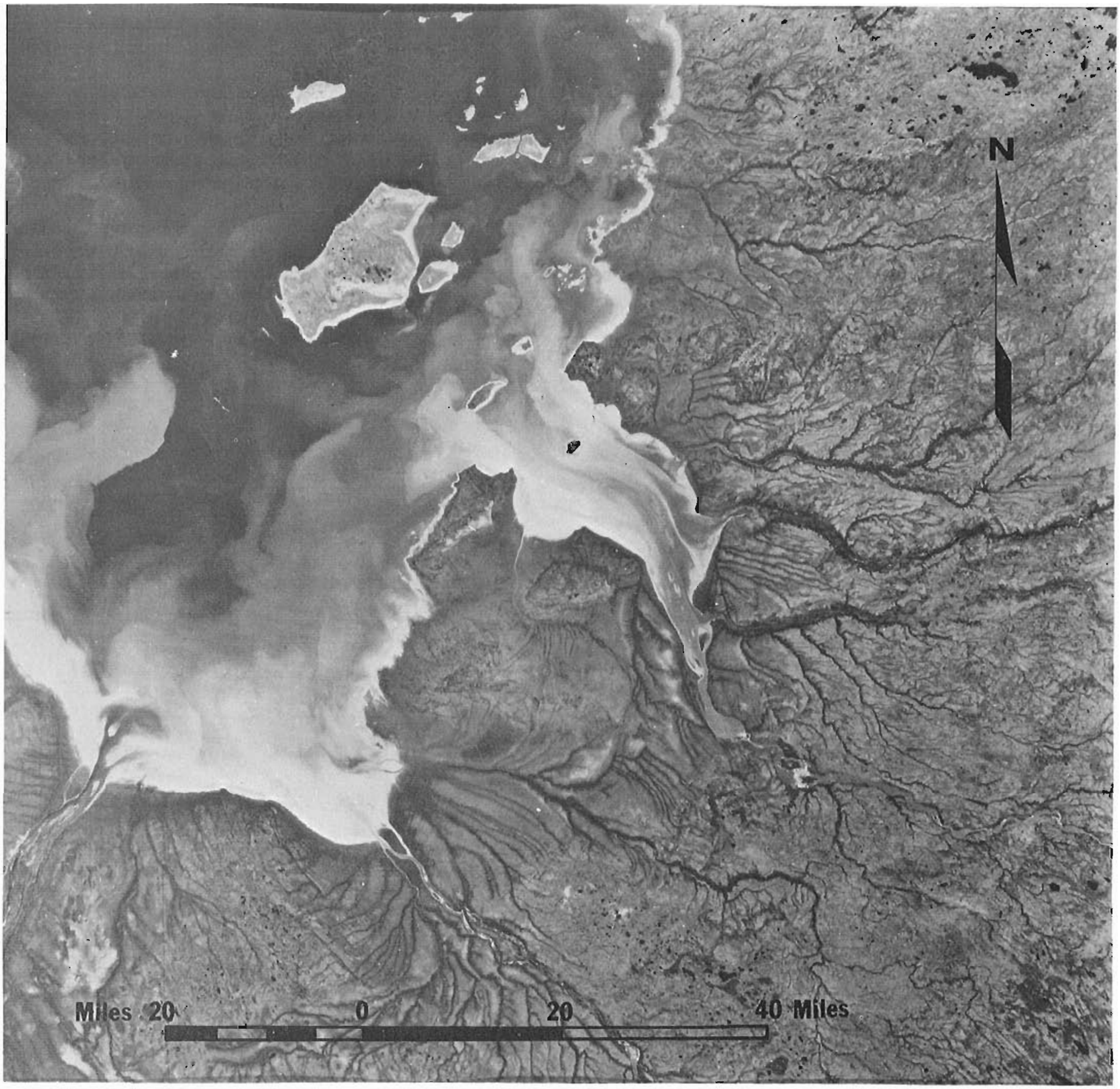

Figure 3. James Bay area, Quebec, 31st July, 1973, no. 1373-15440-5.

be used for density measurements because they are not dodge-printed. All of the better quality images can be enlarged at least 4 times (1: 250, 000) before image detail begins to break up. The value of colour composite prints (combinations of bands 4, 5 and 6 or 5, 6 and 7) is still uncertain. Colour prints are usually decorative in appearance, but always have a lower resolution than the individual bands, and cannot be analyzed radiometrically.

It is still difficult to predict the eventual impact of ERTS type imagery on the earth sciences. The initial appeal of the imagery to most geologists is the view of 10, 000 square miles of familiar territory on a single print.

Quite possibly the main contribution of ERTS type imagery will focus about two areas:

a. The study of large features, having amplitudes of 10's to 100's of miles. Most of these studies will be structural, however many will be lithological in nature. For example, it may be more fruitful for a geologist using imagery to study fold belts rather than individual folds, and to study the relationships of geological provinces rather than of individual lithological units.

b. To study large scale dynamic processes through the examination of imagery acquired at different times. A good example of this class of phenomenon would be coastal sedimentation.

The vagaries of weather greatly influence this kind of study. It is quite impossible to be sure that suitable quality imagery will be acquired at the times it is needed. However, there is a very reasonable probability that over a sufficient period of time - say 2 summers - 2 to 4 sets of acceptable imagery will be obtained of most parts of Canada.

Figures 1 to 3 are included to illustrate some of the kinds of applications mentioned above. Figure 1 includes about 75 per cent of Bathurst Island in the Canadian Arctic. The style of the folded Paleozoic rocks making up the island is very clearly displayed on this image.

Figure 2 is located in the Northwest Territories about 100 miles east of Great Bear Lake. The strongly lineated western half of the image represents rocks of the Bear Province, while the more massive area forming the eastern half of the image represents rocks of the Slave province.

Figure 3 pictures the south and southeast parts of James Bay. The complex drainage pattern, the sedimentary plumes and the effect of nearshore currents are all illustrated by this remarkable image. This is one of 4 sets of imagery acquired at separate times, each showing differences in the pattern of the turbid water.

38. PORTABLE WEATHER SATELLITE RECEIVING UNIT AT RESOLUTE BAY, N.W.T.

Project 700089

S. Washkurak
Resource Geophysics and Geochemistry Division

Weather satellites, together with communication satellites are among the products of space research of most practical benefit to mankind. The United States conducted its first experiments in satellite meteorology with Vanguard 2 and Explorer 6 and 7, launched in 1959. The first high level photography was accomplished by a noted French photographer, Gaspard Felix Tournachon, who began photographic balloon ascents over Paris in 1858. Albert Stevens took the first photograph showing the curvature of the earth from the

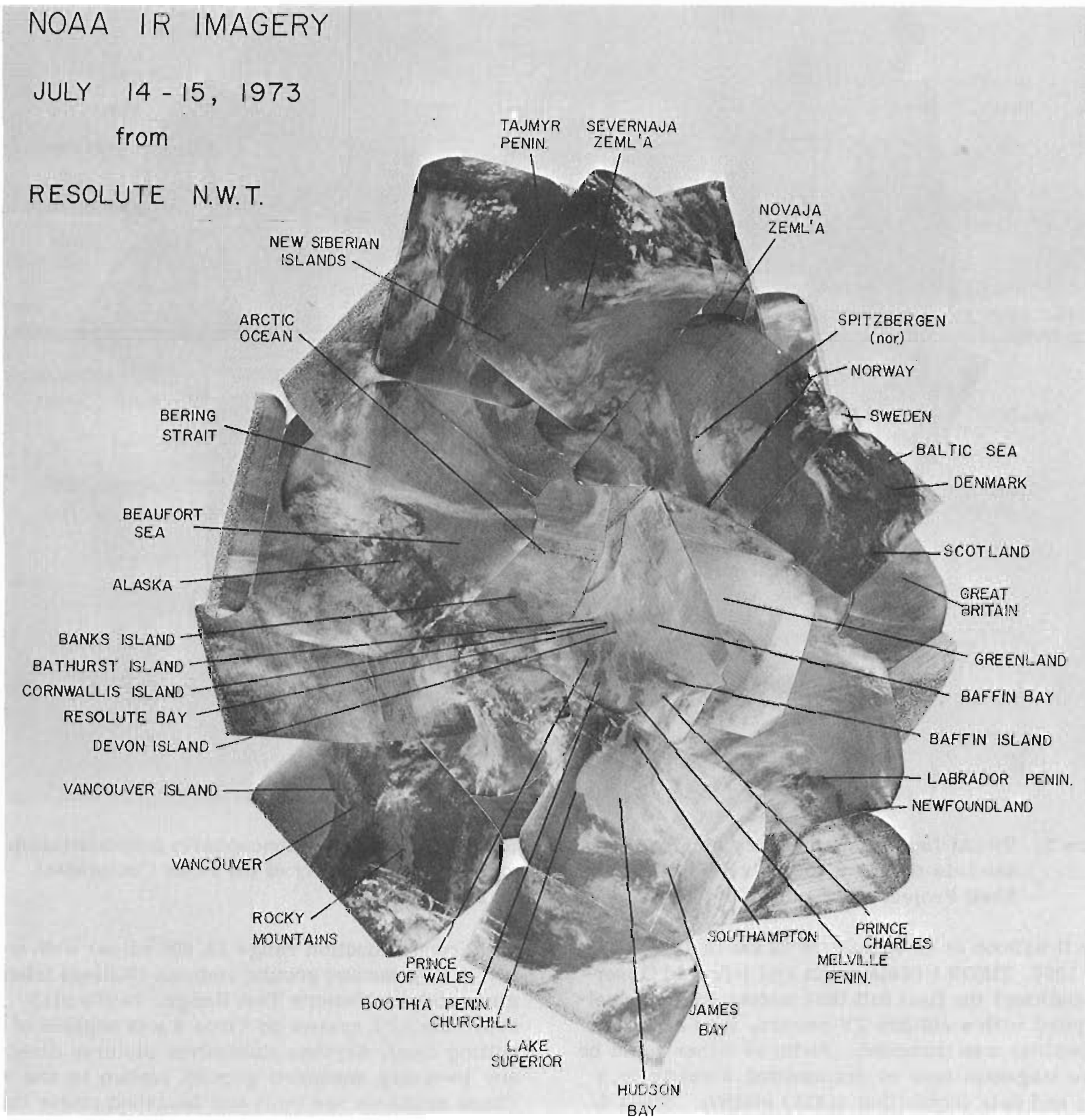

Figure 1. Infrared imagery obtained from the National Oceanic and Atmospheric Administration satellite (NOAA 2) on July 14-15, 1973 at the ground readout facility of the Polar Continental Shelf Project at Resolute Bay, N.W.T. Photo no. 202259.

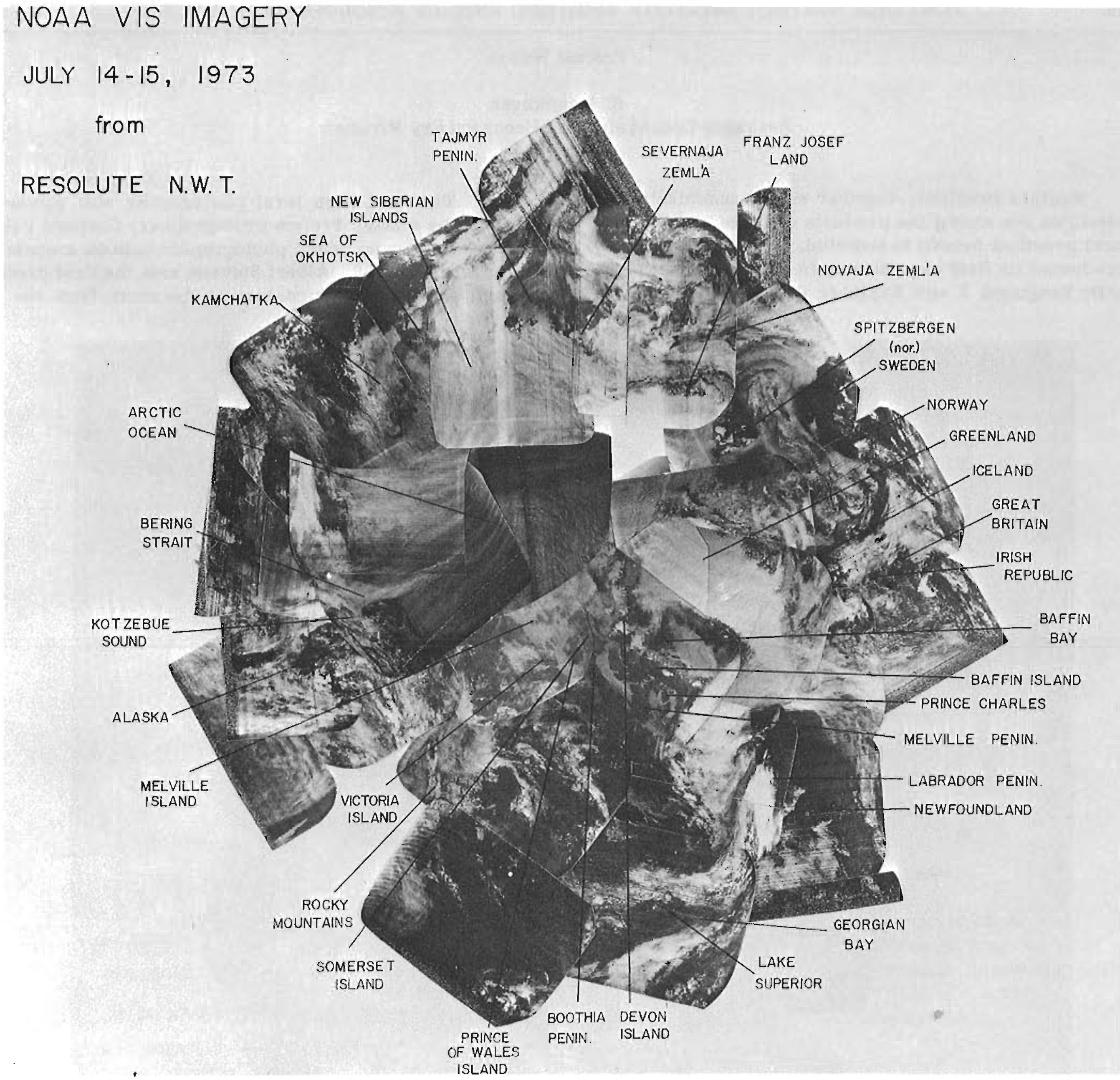

Figure 2. Visual (spectrum) imagery obtained from the National Oceanic and Atmospheric Administration satellite (NOAA 2) on July 14-15, 1973 at the ground readout facility of the Polar Continental Shelf Project at Resolute Bay, N.W.T. Photo no. 202259-A.

Explorer II balloon at an altitude of 22 km in 1935. On April 1, 1960, TIROS I (Television and Infrared Observation Satellites) the first full time meteorological satellite equipped with a vidicon TV camera, tape recorder, and transmitter was launched. Pictures either could be stored on magnetic tape or transmitted directly to a command and data acquisition (CDA) station. Tiros 8, launched December 1963 was the first satellite to be equipped with automatic picture transmission (APT) capabilities. On previous Tiros satellites TV transmission was possible only when the satellite was in line of sight communication range (3,500 miles) with either of two U.S. command ground stations (Wallops Island, Virginia and the Western Test Range, California). However, the APT system on Tiros 8 was capable of transmitting local, daytime cloudcover pictures directly to any properly equipped ground station in the world. These satellites are built and launched under the technical direction of the NASA Goddard Space Flight Center and are operated by the U.S. National Oceanic and Atmospheric Administration (NOAA).

The Tiros Operational Satellite, Environmental

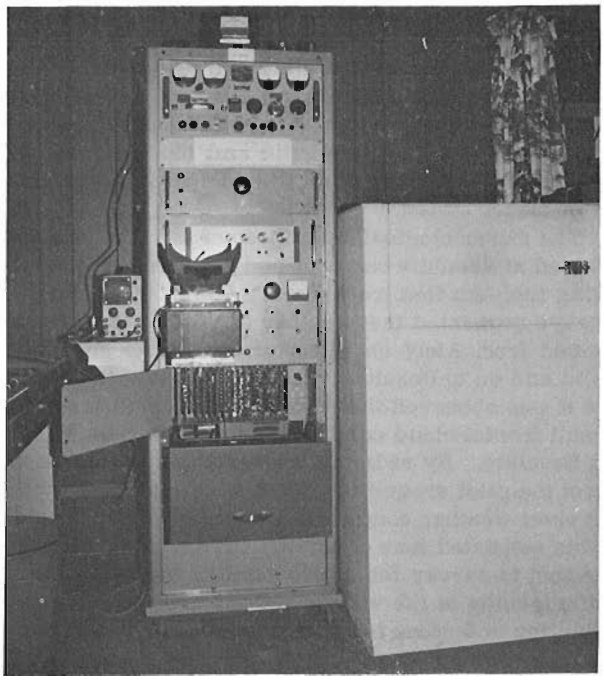

Figure 3. Automatic picture readout facility in the meteorological office at Resolute Bay, consisting of VHF receiver, tape recorder, synchronizing circuitry and polaroid camera.

Science Services Administration (TOS/ESSA) system grew out of the experience gained through the TIROS, R & D program. The system was initiated on February 3, 1966 with the launch of ESSA I and continued through to ESSA 9 which was placed in an operational off mode in November 1972. ESSA 8 is still functioning and transmitting data to over 600 APT stations throughout the world.

The Improved Tiros Operational Satellite (ITOS), (designated NOAA National Oceanic and Atmospheric Administration after being successfully launched) represents a new generation of operational satellites and replaces the TOS, ESSA system. The ITOS represents a considerable improvement over the TOS system. The inclusion of an SR (scanning radiometer) gives ITOS both daytime and nighttime monitoring capabilities. ITOS E through G carry a modified dual instrument payload that includes a scanning radiometer (SR), a very high resolution radiometer (VHRR) and a vertical temperature profile radiometer (VTRR). These improved spacecraft do not carry a TV camera but instead rely entirely on a scanning radiometer for earth cloud cover imagery.

A second version of the ITOS operational satellite is also under consideration for launch in the late 1970's which includes an advanced very high resolution radiometer (AVHRR) and a Tiros operational vertical sounder (TOVS) for obtaining atmospheric profiles of temperature, water vapour, and ozone.

The Synchronous Meteorological Satellite (SMS) is a NASA-developed NOAA-operated spacecraft that will be positioned in a geosynchronous equatorial orbit in early 1974. A visible and infrared spin scan radiometer (VISSR) will provide both visible and infrared observations of the entire earth disk to 60° north with ½ mile ground resolution in near real time; one picture being generated every 20 minutes.

The meteorological satellites have provided voluminous data useful to an improved understanding of atmospheric processes. However, some of these data have also been successfully supplied in other branches of the earth sciences. Oceanography, geology, geography, hydrology and cartography are among the disciplines that have benefitted from the satellite data.

Observations of the sea ice are of great interest. The amount of open water strongly influences the heat balance. Besides its interest as a climatic indicator, sea ice conditions are also of great practical importance owing to their restriction on shipping. Originally sea ice observations were made from the coast or by ship. Now aircraft observations are used to obtain better coverage and, in recent years, satellite and radar observations have become more important. Satellite observations have a great advantage compared with other ways of conducting an ice survey; daily photographs of nearly an unlimited area can be obtained with hardly any cost, compared to the same coverage by aircraft. In the Arctic, the high amount of cloudiness interferes with the usefulness of visual and infrared imagery. Microwave radiometers proposed in satellites will penetrate cloud cover similar to radar imaging systems.

The type of earth surface features which can be identified in satellite data is dependent on the geometric and spectral resolutions of the sensors; and the geometric size, contrast and spectral reflectance on emittance characteristics of the phenomena being observed. Ground resolutions range from approximately 100 metres for ERTS, 1 km for NOAA II (VHRR) and 8 km for NOAA II (APT), SR satellites. The spectral interval covered by NOAA II, APT is 0.5 to 0.7 micron (visible) and 10.5 to 12.5 microns (infrared). The NOAA II spacecraft is in circular orbit at 790 nautical miles (1463 km) sun-synchronous and nearly polar in inclination.

Over the past two years the Geological Survey has developed a small portable APT system to receive weather satellite data over the entire North American continent including the Arctic Islands. Geological Survey field parties can check ice break up and snow conditions from imagery received daily at Ottawa prior to departing for the field.

The past summer an experimental station named George was installed and operated at Resolute Bay, NWT for the Polar Continental Shelf Project. From the ESSA 8 and NOAA II satellite, each picture received covers an area measuring approximately 1,200 miles square. Because of the northern location of the station every satellite orbit (2 hours) can be received and over a 24-hour-period a composite image showing the entire Arctic region including the Great Lakes and Siberia can be produced (Figs. 1 and 2). On completion of the aircraft ice patrol the APT station was moved to the Atmospheric Environment Service (AES) Meteorological office for the convenience of meteorologists at Resolute (Fig. 3) through the winter months.

Pack ice boundaries have been established for the polar sea using satellite imagery. Conventional means have proved to be inadequate to determine accurately the distribution, variability and behaviour of sea ice. Surveillance by satellites can offer a major service to shipping by frequent monitoring of ice cover conditions in established sea lanes for the annual supply of provisions to remote scientific stations in the Arctic. Information about the location and size of polar leads and polynyos (non linear ice-free areas within the ice) is valuable for both economic and scientific purposes.

The repetitive global coverage of satellite imagery in the different visible and infrared spectral bands has provided a wealth of image tonal patterns. Some of these tonal patterns can be recognized at first inspection and mapped for what they represent. For instance snow fields, changing pack ice boundaries of the entire Arctic, Barnes Ice Cap (Figs. 1 and 2) can be identified and mapped. However, there are many tonal patterns which do not seem to correlate with any feature depicted in conventional maps.

Discrimination between different lithologies or surface composition using remote sensor data of low resolution is, at best, very difficult. Gross geological structures such as the Coastal Plain, Rocky Mountains and Trench can be easily recognized (Fig. 1) on the IR imagery due to the thermal signature. The surface temperature is dependent on solar radiation, conduction (specific head, thermal inertia, moisture) and convection (atmospheric cooling and heating). With the additional dimension of time (diurnal and seasonal) requiring synoptic daily coverage and making use of snow enhancement of dendritic and topographic features, some improvement on lithological interpretation can be made.

The meteorological usefulness of satellite imagery obtained at Resolute can best be illustrated by the following incident that transpired. A pilot from Alert Airways requested that weather prognosis for a flight planned from Alert on Ellesmere Island to Meighen Island and on to Resolute. From a recent satellite picture it was observed that Meighen was cloud-free but a small frontal cloud condition existed between Meighen and Resolute. By radio the meteorologist was able to direct the pilot around the cloud bank and inform him that clear weather conditions would persist at Resolute for his estimated time of arrival (ETA). The daily line mile cost to survey the entire country including the Arctic Islands in the visible and infrared with a ground resolution of 5 miles is approximately 0.002 cent per line mile ($20 per day).

We wish to acknowledge the financial and manpower assistance provided by Polar Shelf to establish the first satellite receiving station at Resolute Bay, N.W.T.

ENVIRONMENTAL MARINE GEOLOGY OF A COASTAL INLET

Project 730078

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Geological, chemical, biological and oceanographic processes in the marine environment interact to produce a net effect in the accumulated sediments and usually result in a permanent integrated record of the environment. For example, fauna and flora preserved as fossils in sediments can be studied in cores in order to reconstruct paleoenvironments and determine the changes which have taken place to the time of the contemporary environment and may be used to predict future environmental trends. Textural changes in the sediments reflect changes in the hydrodynamic environment of deposition which may be related to tectonic or climatic change or may have been brought about by the activities of man, such as the construction of highways and harbour facilities, or the exploitation of natural resources such as forests or sand and gravel deposits. The chemical content of sediments includes both the inorganic mineral composition and the organic remains of plants and animals. Chemical analyses of sediments may reveal chemical inputs from natural and man-induced sources. The effect of industrial development may be recorded in the sediments by an increased content of heavy metals, while catastrophic events such as large oil spills may be noted by anomalous hydrocarbon residues. An understanding of environmental marine geology requires the study of present-day processes in order to interpret the imprint of paleoenvironments and in order to predict the impact of man's activities on our future environment.

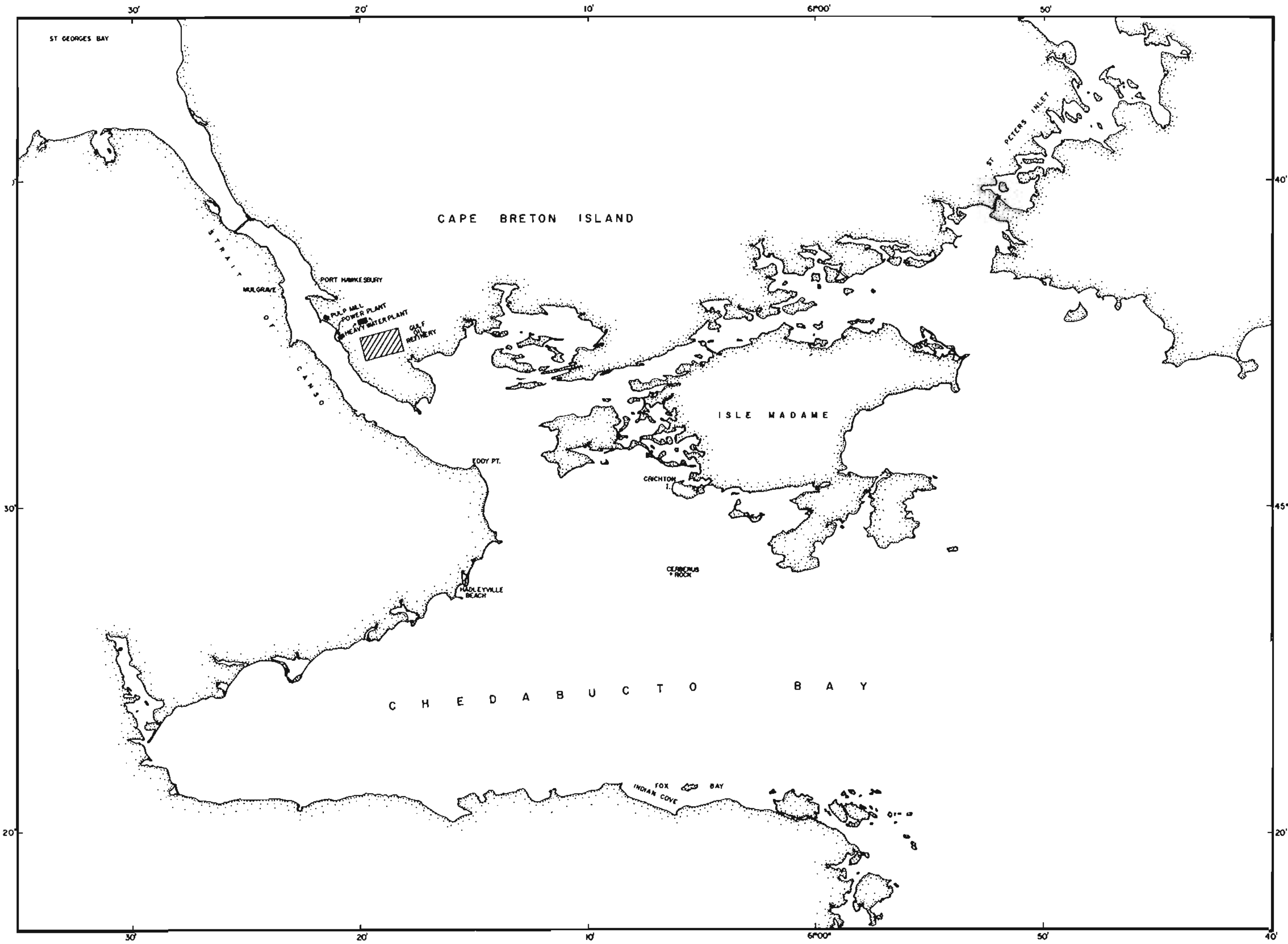

Figure 1. Canso Strait and Chedabucto Bay, Nova Scotia.

The Canso Strait and Chedabucto Bay areas of Nova Scotia (Fig. 1) provide an ideal study area in which to test the sensitivity of modern research methods in evaluating the present environment and detecting the record of change which has occurred in these areas over historical and geologically recent periods of time. By a scientifically integrated study using expertise in the fields of paleoecology, geochemistry and coastal geodynamics, four principal objectives were defined for evaluation.

1. To determine the impact of causeway construction on the environmental marine geology in Canso Strait, including sedimentological, ecological (foraminifera, molluscs, and ostracods) and geochemical imprinting effects on the accumulated sediments south of the causeway and comparsions with sediments north of the causeway.

2. To determine the effects of historical changes and trends on the marine geological environment resulting from recent intensive urban and industrial development south of the causeway using detailed studies of the paleoecology and geochemistry of recent sediments to delineate areas affected by urban and industrial waste disposal and to determine the rate of change in quality of the environment.

3. To determine the degree of recovery of the coastal and marine environment from the effects of a catastrophic oil spill (tanker ARROW, 1970) in Chedabucto Bay and approaches to Canso Strait with particular emphasis on beach and nearshore processes and their relationship to the dissipation or degradation of oil residues.

4. To measure the geotechnical properties of marine sediments as determined *in situ* and by laboratory tests in order to obtain data on the mechanical properties of sediments in Canso Strait and Chedabucto Bay which may be utilized in engineering studies related to construction of coastal and nearshore facilities.

Beginning on July 16, 1973, an integrated field laboratory and sampling program was established at Port Hawkesbury, Nova Scotia. This field program involved 31 scientific and technical staff representing 5 research agencies from government and a university. Activities included comprehensive bottom sampling using several coring techniques and grab sampling, water sampling for suspended solids and dissolved constituents, shallow seismic survey and coastal mapping. Several technological innovations were tested and evaluated during the field studies. These included a 4-inch diameter gravity corer with a pvc core barrel to obtain undisturbed sediment cores; a modification of a Huntec boomer and recorder system for high resolution shallow acoustic profiling; a prototype *in situ* shear vane device designed to obtain geotechnical data of bottom sediments to be correlated with information obtained from core samples; and a prototype remote TV telerecording system to monitor bioturbation and sediment dynamics at the bottom sediment inferface in nearshore environments.

The integrated paleoecology and geochemical field laboratory processed 550 sediment subsamples for foraminiferal, mollusc and ostracod content and completed 3964 elemental determinations. Water samples were analyzed for trace element concentrations, suspended particulate matter, organic carbon, bacteria and dissolved oxygen for a total of 1589 determinations.

Some preliminary observations and results have indicated the following tentative conclusions.

1. Canso Strait is now divided into two distinct oceanographic environments, one north of the causeway, the other south of the causeway with pronounced differences in the salinity and temperature stratification. These differences may be most accentuated in the late spring and mid-summer. The dynamic mixing of the water mass now appears to be controlled by wind direction and strength whereas the mixing prior to the construction of the causeway may have been tidally controlled. Bioturbation of the recent bottom sediments by burrowing organisms appears to have greatly disturbed micro-stratigraphic sequences to a depth of at least 10 cm, making interpretations of recent environmental imprints difficult to obtain.

2. The quality of bottom sediments and water reflect the input of industrial wastes in the area of the industrial park at Point Tupper. Evidence of this impact is found in the total absence of living foraminifera, high concentrations of organic fibre, high concentrations of some trace metals and high turbidity in the water.

3. Much of the coastal environment of Chedabucto Bay is still affected by the residue of bunker C oils from the ARROW disaster. Low energy beach environments appear to be little changed over the past 3 years, however, a few high energy environments have only small occurrences of chemically degraded residues. The beaches of Chedabucto Bay appear to be in delicate equilibrium with the littoral processes. Where this equilibrium has been disturbed by sediment removal, major changes in beach morphology have resulted.

4. Recent sediments throughout most of the Canso Strait area are soft, fine-grained muds commonly underlain by a sand or gravel horizon at a depth of 10 cm to 1 metre below the interface. These coarse textured sediments overlie older marine muds. This sequence of textural facies produces a geotechnical profile of low shear strength at the interface followed by high shear strength and a third deep horizon of low shear strength.

40. GEOPHYSICAL INVESTIGATION OF THE LAURENTIAN CHANNEL AND THE SOUTHERN GRAND BANKS OF NEWFOUNDLAND

Project 720106

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Atlantic Geoscience Centre, Dartmouth

The author participated in the field work of L.H. King (project 730072; this publ., rept. 43) to the south of Newfoundland in order to collect more gravity and magnetic data in an attempt to trace tectonic patterns from Newfoundland across the southern Grand Banks and Scotian Shelf. Much of the data were collected in the Sydney Basin area, to the east of the 1972 field season survey area. However, additional work was carried out in areas highlighted by the earlier survey, and those yield the most interesting results. In Hermitage Bay, there is a distinct magnetic signature which correlates well with the offshore extension of what Williams et al. (1970) called the Hermitage flexure, the eastern border of the central mobile belt of Newfoundland. The magnetic trends apparently continue offshore, closely paralleling the onshore trends suggested by Williams and his colleagues, for a distance of at least 150 km at which point the trends across the Cabot Strait become predominant. In a somewhat parallel fashion, the magnetic trend across the Avalon Peninsula continues in a southwesterly direction and gradually deflects to become slightly north of west. This trend then merges with the anomaly to the north of the Orpheus Gravity Anomaly thence passing through Nova Scotia and down the Bay of Fundy. It may be that this gross pattern is the expression of the eastern edge of the proto-Atlantic before its mid-Paleozoic closing. The pattern, together with the landward Appalachian flexure, is well illustrated by a compilation at a scale of 1:1,000,000 of gravity and magnetic data for the area 42^{o}N to 50^{o}N, 68^{o}W to 43^{o}W.

Reference

Williams, H., Kennedy, M.J. and Neale, E.R.W.
1970: Hermitage flexure, Cabot fault and disappearance of Newfoundland central mobile belt. Geol. Soc. Amer. Bull., v. 81, p. 1563.

41. GEOPHYSICAL INVESTIGATION OF THE GULF OF ST. LAWRENCE

Project 720105

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Atlantic Geoscience Centre, Dartmouth

Extensive gravity and magnetic coverage of the eastern portion of the Gulf of St. Lawrence has been obtained. These data have been compiled together with other available gravity and magnetic data at a scale of 1:1,000,000 on a base compatible with the bathymetry chart 811 of the Canadian Hydrographic Service and the surficial geology map of the Gulf prepared by D.H. Loring. In preparation is a manuscript describing the method of production of the geophysical maps and the interesting features which they show. The greatest interest has centred around the method of tracing the limit of Appalachian deformation through the Gulf from Gaspé to Newfoundland. This has been done by many workers on the basis of the steep gradients to be observed in the gravity field. The gradient is generally steep raising the regional Bouguer gravity field from about -50 mgal over the Quebec north shore to approximately 0 mgal over Newfoundland. However, this simple situation is not substantiated in the vicinity of Anticosti where the regional field is higher than would be anticipated. To the east of the island is a feature observable in both the gravity and magnetic fields which is best interpreted as a sedimentary basin but across which little useful seismic information is available. The feature is of considerable interest because it seems to be the northern termination of a pronounced magnetic gradient which might be associated with compression in the Gulf as part of the hypotheses regarding closing of a proto-Atlantic ocean.

42. NATURAL RESOURCE CHARTS CONTRACT

Project 720107

R. T. Haworth and R. F. Macnab
Atlantic Geoscience Centre, Dartmouth

Early in 1973 Computer Data Processors delivered final copies of all 72 resource charts as described in Geological Survey Paper 73-1A. The maps were consolidated and reduced to a scale of 1: 1, 000, 000 and have been used in preparation of the compilations underway as part of projects 720105 and 720106. The 1: 250, 000 maps are all at press and the dates of publication will be announced through the GSC monthly information circulars, and the Canadian Hydrographic Service information bulletins. Simultaneous with the release of the contour maps, digital data from which the maps were produced will also be made available on open file.

Future work on the production of Natural Resource charts will form part of project 730081. Haworth (in press) has described the techniques which have been used in preparation of the maps to date, and this has been used as the basis for contract specifications to process data presently being collected.

Reference

Haworth, R. T.
Gravity and Magnetic Natural Resource Maps (1972), Offshore Eastern Canada; Philosophy and technique in preparation by computer. To be published in the International Hydrographic Review, January 1974. (in press).

43. SURFICIAL AND BEDROCK GEOLOGY OF THE SCOTIAN SHELF AND GRAND BANKS

Projects 730072, 730073, 730074, 730075

Lewis H. King, Brian MacLean and Gordon B. Fader
Atlantic Geoscience Centre, Dartmouth

Field activities were conducted across the Cape Breton Shelf, Laurentian Channel and western Grand Banks during a 7-week cruise aboard the CSS Hudson. This cruise, together with a 10-day cruise on the CFAV Sackville in October, will complete our second and final season of activities on this area of the shelf.

The broad scientific objectives of the program are: (1) to obtain a better understanding of Appalachian geology between Nova Scotia and Newfoundland, (2) to extend our knowledge of Appalachian geology seaward beneath the submerged Atlantic Coastal Plain Provinces, (3) to obtain information on the broad structural framework of the area, (4) to map the surficial geology of the area, and (5) to map the sub-Pleistocene bedrock geology of the area.

During the Hudson cruise the following work was completed: 1,500 miles of seismic reflection profiling, 800 miles of sidescan sonar profiling, 3,000 miles of gravity and magnetic profiling, 4 bedrock cores, 3 piston cores, 340 bottom grab samples, and 25 bottom photo stations.

Cruise highlights included the procurement of 4 bedrock cores between 8-15' lengths using the BIO electric drill, and the discovery of numerous iceberg furrows along the Laurentian Channel. The latter presumably were formed when the continental ice sheet stood at the head of the Gulf of St. Lawrence.

44. INTERTIDAL FLUID-SEDIMENT RELATIONSHIPS IN COBEQUID BAY OF MINAS BASIN, NOVA SCOTIA

Project 730094

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During the summers of 1971 through 1973, a sedimentological study was carried out on the intertidal sand complex in Cobequid Bay, Nova Scotia. The area is characterized by the largest reported tides in the world, with a mean semi-diurnal, anomalistic tidal range of 11.7 m at Burntcoat Head (mean spring range of 12.3 at lunar apogee and 15.4 m at lunar perigee). The tides generate currents which generally do not exceed 2 m/sec in Minas Basin and decrease to 0.5 to 1.5 m/sec over the intertidal sand bars. Locally the velocity and direction of tidal currents is determined by the shore and bar topography.

The modern deposits of Cobequid Bay occur as a major subtidal sand body 6 to 25 m thick and some 10 by 30 kms in area. Most of the sand in the bay has been derived from the erosion and reworking of Pleistocene, Triassic and Carboniferous deposits in and around the basin. Parts of the modern sand deposits become exposed as intertidal sand bars at low tide. Most of the bars that have been studied in detail are close to shore. On the basis of field observation and of airphoto reconnaissance over a 35-year period, the bars near shore appear to be relatively stable. The offshore bars, however, shift their position much more rapidly than those protected by shore topography.

The study of the intertidal sand bars has involved three aspects: the morphology of the intertidal sand deposits, the erosional and depositional events that determine the morphology, and the environmental conditions under which these events occurred.

In many areas either ebb or flood currents dominate, producing strongly asymmetrical patterns of sediment transport. The sand bars are covered by a wide range of bedforms: (i) ripples, with wavelengths less than 15 cm and amplitudes less than 5 cm; (ii) megaripples, with wavelengths from 1 to 12 m and amplitudes from 10 to 70 cm; and (iii) sand waves, with wavelengths of 15 to 30 m and amplitudes of 40 to 150 cm. The bedforms recorded by echo sounder can be observed to reverse their orientation during each ebb and flood tide. The degree of reorientation and reworking is related to the time velocity asymmetry of the tidal currents, the flow duration (a function of topographic exposure and position) and flow strength. Migration rates for megaripples are variable as a result of the differing degrees of reorientation and reworking of the bedforms with successive tides, but generally net rates of movement are only a few decimetres per tidal cycle. Megaripples are the commonest bedforms that are directly observed at low water following an ebb tide, therefore they are either ebb-oriented megaripples or flood megaripples that have been strongly modified by the ebb flow. All medium to small scale bedforms are modified to some extent by wave action, or shallow sheet or channel flow during the last stages of the ebbing tide.

At low tide, the sand waves are covered by small ebb-oriented megaripples. Echo-soundings show that at high water, the sand waves have superimposed flood-oriented megaripples. The migration rates for sand waves is about 15 to 30 cm per tidal cycle.

The internal structure of the bedforms seen in trenches and recorded by peel samples gives further evidence of the reorientation and reworking of the bedforms by tidal currents. The thickness of preserved sets of cross-bedding is generally less than the height of the active megaripple as a result of stoss-side erosion during bedform migration and particularly because of erosion by the subordinate tidal current. The large sand waves rarely show thick, unbroken crossbedding sets. The slip face of the superimposed megaripples migrates only a short distance with each tide and the next tide partly erodes this material producing a surface of discontinuity (or reactivation surface, Klein, 1970) that might be mistaken for large scale low angle crossbedding in a poor exposure.

It is anticipated that this study will further the knowledge and understanding of fluid-sediment relationships in the tidal environment.

Reference

Klein, G. deVries
1970: Depositional and dispersal dynamics of intertidal sand bars; J. Sediment. Petrology, v. 40, p. 1095-1127.

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MARINE GEOPHYSICAL SURVEYS NORTHEAST OF NEWFOUNDLAND AND IN THE ST. LAWRENCE ESTUARY

Project 730081

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In collaboration with the Atlantic Region of the Canadian Hydrographic Service, Department of the Environment, the Atlantic Geoscience Centre has been performing detailed marine geophysical measurements in two areas.

The major effort in 1973 has been concentrated in mapping the gravity and magnetic fields of the continental shelf and margin northeast of Newfoundland (see Figure). For the second consecutive season, the Motor Vessel MINNA has been chartered by the Atlantic Oceanographic Laboratory and fitted out as a hydrographic-geophysical survey vehicle. Equipped with echo sounder, gravimeter, and magnetometer, the ship has been obtaining continuous coverage at line intervals of 2½ nautical miles in depths of less than 1000 metres, 5 nautical miles in depths to 3000 metres, and 10 nautical miles in depths exceeding 3000 metres. For part of the survey season, the ship has also had a seismic capability; 40- and 300- cubic-inch airguns and a four-section hydrophone streamer have been used to obtain reflection profiles concurrently with the acquisition of other types of data at intervals of 20 nautical miles. Through a combination of satellite navigation, two-range Decca 12F, and rho-rho loran C, ship's positions have been determined to an accuracy estimated at ± 200 m anywhere within the survey area.

Gravity and magnetic data have also been collected aboard the Canadian Scientific Ship BAFFIN, in conjunction with a hydrographic survey in the St. Lawrence Estuary (see Fig. 1). Limited coverage has been obtained at line intervals of ¼ and ½ nautical miles, depending on water depth. Ship's positions have been determined by means of Hi Fix hyperbolic.

On both vessels, the major responsibility for field activities rests with the hydrographic personnel, who are charged with the operation of gravimeters and magnetometers owned by the Atlantic Geoscience Centre, in addition to standard echo sounding equipment. The same personnel also perform the routine computer processing of geophysical data on board ship for preliminary verification and quality control, and ashore for final checking and archiving. The production by computer of contour maps of geophysical parameters is usually contracted out to a data processing firm working under E.M.R. supervision. Otherwise, E.M.R. participation in the project is generally restricted to one professional working in a consultative and advisory

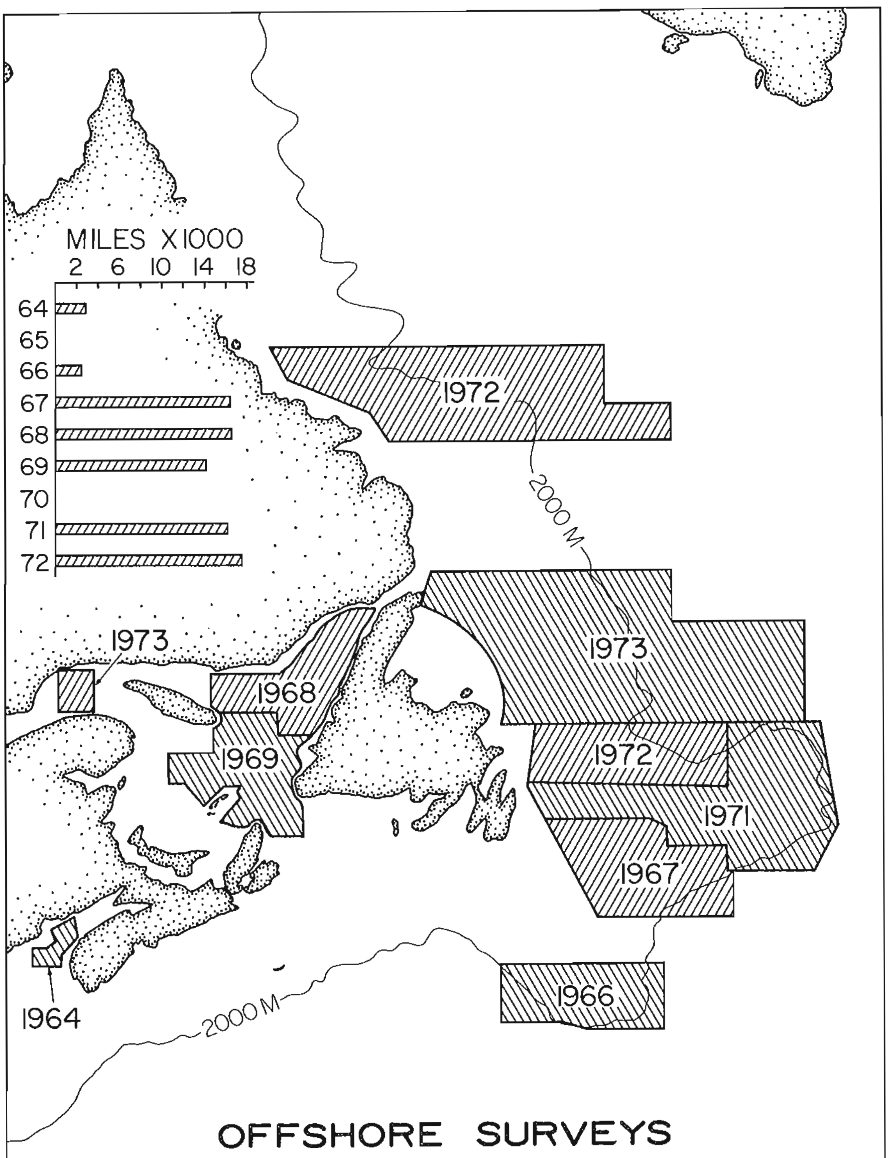

Figure 1

Survey coverage obtained to date on joint hydrographic-geophysical operations. Areas shown for 1973 are approximate; combined mileage is estimated to be in the vicinity of 15,000 nautical miles.

capacity, and to the technical support required for project mobilization and maintenance of geophysical equipment in the field.

The information collected during these survey operations will be added to the data bank which is available to Atlantic Geoscience Centre scientists working on problems related to the geology and geophysics of the eastern Canadian seaboard. In addition, the bathymetric and potential field data will be issued as maps in the Natural Resource Series, published by the Marine Sciences Directorate, Department of the Environment.

Project 730088

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Atlantic Geoscience Centre, Dartmouth

Nine permanent survey stations were established in 1972 to monitor changes in littoral zone profiles and to measure rates of cliff erosion in the shore zone of the southern Gulf of St. Lawrence. The determination of rates of change at the beach/dune profile stations will require surveys over several years as the differences over a twelve-month period are within the limits which would be expected from normal short-term variations. Although retreat of the unresistant sandstone cliffs and Pleistocene deposits is rapid in this region (changes up to 2.5 m were recorded over the twelve-month period) accurate prediction of erosion rates at different localities requires long-term monitoring in conjunction with measurements from aerial photographs over the past 30 years.

In addition to the regular surveying program two areas were revisited in 1973 to record specific changes.

1. Low altitude (200-400 m) oblique aerial photography is being used to indicate morphological changes at Neguac, N.B. (Fig. 1). A series of low barrier beaches (maximum elevation 2 m above Mean High Water) are undergoing marked changes in morphology in response to storm waves and to the longshore transport of sediment in the littoral zone. This is particularly evident in the distal portions of the barrier islands which have extended southwards rapidly since 1970 (Fig. 2). These barriers are also migrating landwards and several peat outcrops were observed in the beach face during the 1972 reconnaissance.

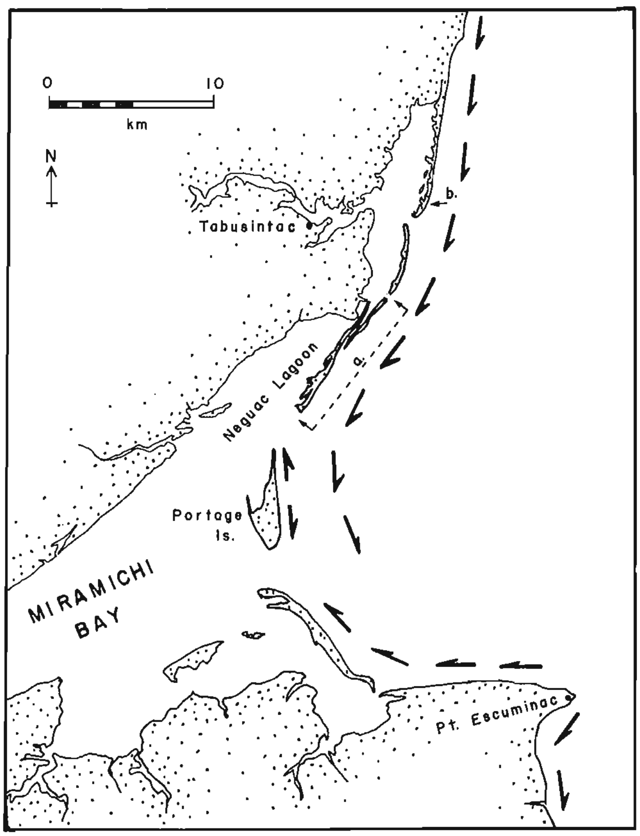

Figure 1. Miramichi Bay, New Brunswick. Arrows indicate direction of sediment transport:
a. - limits of Figure 2;
b. - location of Figure 3.

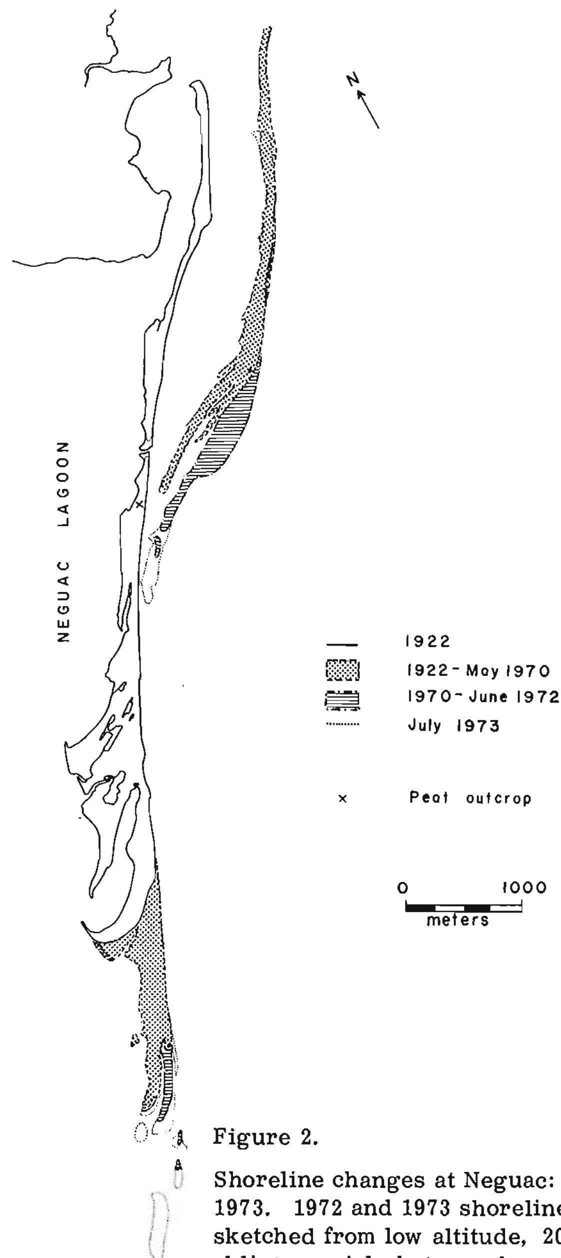

Figure 2.

Shoreline changes at Neguac: 1922-1973. 1972 and 1973 shorelines sketched from low altitude, 200 m, oblique aerial photography.

Figure 3. Infilled inlet, Tabusintac, N. B., sediment transport in the littoral zone is from top to bottom.

2. At Tabusintac, N. B. (Fig. 1) an inlet was dredged, under contract to the Department of Public Works, through a barrier beach during August 1972. Maps and profiles were surveyed on this barrier in July, before work commenced, and in August, prior to completion of the operation. The inlet, approximately 240 m long, 50 m wide, and 4 m deep, remained open for less than 24 hours following the final breach. By July 1973 most of the dredged channel had become infilled by sediment trapped from longshore drift and overwash (Fig. 3).

The barrier island system of northeast New Brunswick is one of the most dynamic coastal environments in the Gulf of St. Lawrence. Annual reconnaissance of shoreline changes and inlet migration is necessary to predict changes and to explain the morphological processes which characterize this area.

Project 720108

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Three separate field experiments were conducted during the report period.

(a) Repeated marine magnetic measurements were made along selected tracks during several cruises off the east coast of Canada. The purpose of this experiment was to check on the applicability of the newly proposed method of extracting temporal variation information of the earth's magnetic field from repeated measurements at sea. The technique was used for obtaining temporal variations on the Continental Shelf and in the Abyssal Plain off Nova Scotia, Canada. Using this technique, it was possible to resolve variations as small as 3 gammas for periods from 20 minutes to 24 hours. The results obtained by this method were then compared with the simultaneous recordings made at shore based stations. A method has been developed and used for applying diurnal correction to the marine magnetic data using the recordings made at a nearby shore based station and from the repeated measurements at sea.

(b) Measurements of temporal variations of the earth's magnetic field were made in the magnetic quiet zone off Nova Scotia from specially designed magnetometers housed in moored surface buoys. The data obtained from this experiment were used to assess the errors involved in using recordings monitored at Bedford Institute to apply diurnal correction to marine magnetic data. The technique was used to correct magnetic data collected over the magnetic quiet zone during 1972 and 1973. This reduced r. m. s. crossover difference to less than 5 gammas. Comparison of the simultaneous recordings at sea off Nova Scotia with those on land show considerable attenuation in variations of periods less than two hours. Modal computations show that this attenuation may be due to the difference in the subsurface conductivity distributions in the two regions as obtained from previous induction studies and also due to the high conductivity of the sea.

(c) Temporal variations were also monitored at shore based stations at Cartwright on Labrador Coast (August - October 1973) and at Bedford Institute (May - December 1973). The recordings from these stations will be used in applying correction to the marine magnetic data.

A paper summarizing our recent results from experiments (a) and (b) was presented at the Second General Assembly meeting of the International Association of Geomagnetism and Aeronomy held in Kyoto.

Project 710048

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A co-operative seven-week geophysical survey of Queen Charlotte Sound was completed as part of a continuing program to systematically map the Pacific continental margin of Canada. Geological Survey of Canada, Earth Physics Branch, and Canadian Hydrographic Service, combined to collect magnetic, gravity and bathymetric data and obtain 3,000 kilometres of continuous seismic profiles on the shelf, slope and base of slope area. Contoured data will appear in the Natural Resource Chart series at a scale of 1:250,000. The first Pacific coast charts of this series covering the Strait of Juan de Fuca, are in final stages of preparation for publishing.

The new data in Queen Charlotte Sound area indicate that revisions are necessary in published contoured charts (U.S.H.O. Publ. 1303, 1971; Mammerickx and Taylor, 1971) particularly on and near the base of the continental slope. Seismic profiles, supported by gravity and magnetic highs, show the presence of a seamount 9 kilometres west of the base of the slope at 51°28'N, 130°51'W. Later dredge hauls and a camera station on the site resulted in recovery of one large pillow and several fragments of fresh basalt with negligible manganese coating. Photographs of the seamount at 2,000 metres show clearly fresh lava flows, tensional cooling fractures, and negligible sediment cover. At least one large earthquake (1929, magnitude 6.1) was centred in the seamount area. This unnamed seamount is 13 kilometres east of that reported previously (Tiffin, 1973) which has also yielded fresh basalts (Chase, UBC Geology Dept.; pers. comm.). These seamounts may be part of a linear chain of seamounts extending to the northwest, the Kodiak-Bowie chain, which lie upon the same oceanic basement arch that subtends the continent at Queen Charlotte Sound. The chain may result from oceanic crust moving over a mantle hot-spot (Silver, et al., in press). If so, the hot-spot must be located very near the continent at Queen Charlotte Sound.

Seismic profiling data was obtained in the Winona Basin and extended over the site of the 1971 JOIDES drillhole on Paul Revere ridge. Acoustic units from that area have been correlated with lithologic units dated from the cores (Kulm, et al., 1972). These show that upwards of 0.8 kms of Pleistocene sediments fill the basin, overlaying at least 2.3 kilometres possibly much more, of Pliocene sediments. Older sediments could be present below the Pliocene, but considerations of sea floor spreading under the assumption that oceanic crust underlies Winona Basin, make this doubtful. Large scale folding and faulting in the basin includes the Pleistocene sediments, leaving no doubt that tectonism is active in that area. Because seismicity is high in the basin, folding and faulting are probably continuing.

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A STUDY OF COPPER MINERALIZATION IN MISSISSIPPIAN ROCKS OF NOVA SCOTIA

Project 700059

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Seven weeks were spent by the first author, and two weeks by the second, examining copper occurrences near the Windsor-Grantmire and Windsor-Horton contacts in Cape Breton Island and mainland Nova Scotia. In the area from Antigonish to Sydney (100 miles) and Baddeck to McIntyre Lake (40 miles) wherever dark, laminated, fine-grained Windsor limestone was found overlying conglomerate, sparse but persistent copper mineralization was noted. At most localities examined the widths are too narrow and copper tenors too low to be of economic interest but, as suggested by Kirkham (1971), the large areal extent and consistent stratigraphic relations of this mineralization indicate the possibility that significant stratiform copper deposits may exist somewhere in the area.

Regional Study

Copper occurrences (about 20) were examined at as many widely separated localities as possible. Samples were collected for mineralogical, petrographic, geochemical and isotopic studies.

In general, the copper occurrences are remarkably similar from one locality to another. The typical occurrence consists of a variable thickness of red conglomerate, overlain by a few inches to a few feet of green conglomerate, overlain by a few inches to a few feet of dark, laminated, fine-grained limestone. This dark, laminated limestone grades upward to paler fossiliferous limestone. Pyrite, chalcopyrite and, at a few localities, bornite and chalcocite have been observed disseminated in the upper part of the green conglomerate and lower part of the dark, laminated limestone. However, at many sites the sulphides are weathered and malachite stains in the green conglomerate are the only indication of copper mineralization.

The conglomerates are typically poorly sorted and contain subangular to subrounded clasts up to 2 feet in diameter in some areas. At most localities interbedded sandstones and siltstones are not abundant. Southwest of Sydney these conglomerates have been assigned to the Grantmire Formation of the Windsor Group (Bell and Goranson, 1938; Weeks, 1954) but in other areas they have been included in the Horton Group (e.g., Kelley, 1967; Benson, 1970). Weeks (1954, p. 73), Kelley (1958, p. 7), Murray (1960, p. 90-93) and many other workers have noted the problems involved in stratigraphic correlation and nomenclature of these units. Despite these problems in correlation and nomenclature the conglomerates are remarkably similar in many ways from one copper occurrence to another even if the occurrences happen to be 50 to 100 miles apart.

The dark, laminated, fine-grained limestone that contains some copper minerals and overlies the conglomerate is typical A_1 limestone (Kelley, 1958) or Macumber Formation (Schenk, 1967b). This thin unit has vast areal extent and is known to occur in many of the Carboniferous basins of eastern Canada. Schenk (1967a and b) has suggested that this is a strandline carbonate analogous to some that are being deposited in the Persian Gulf and other areas. Regardless of the environment of deposition this unit apparently marks a fairly rapid transgression of seas into Mississippian basins and obviously played a very important role in the deposition of copper.

There are, however, some exceptions to this pattern of copper occurrence. In the Black River area in southwestern Cape Breton Island chalcopyrite and bornite occur in Windsor carbonates higher in the sequence and are structurally controlled analogous to many "Mississippi Valley-type" Pb-Zn deposits. At McIntyre Lake in eastern Cape Breton Island abundant chalcopyrite occurs disseminated over a couple of feet in sandstone and conglomerate in a flat lying, very small erosional remnant of what is probably Grantmire unconformably overlying Fourchu basement. This locality might be similar to others but the writers could not find any evidence (float blocks) that the A_1 limestone occurred above this sandstone and conglomerate. In the Ohio area along the south side of the Antigonish basin chalcopyrite, galena and barite occur erratically disseminated in conglomerate interlayered with limestone beds. The conglomerates and limestones are not similar to the characteristic conglomerate - A_1 limestone sequence and may represent marginal basin beds higher in the Windsor Group.

In the Gays River area in central Nova Scotia so far as the writers know no significant amount of copper has been found in or beneath the Windsor carbonates. In this area the A_1 limestone is missing and drusy reefoid carbonates with sphalerite and galena sit directly on Goldenvale basement.

Lake Enon

In addition to the regional study, a detailed investigation of copper mineralization at the Lake Enon celestite mine of Kaiser Celestite Corporation was carried out by the first author. The mine occurs in a small Mississippian sedimentary basin that is approximately ½ mile in a northeast-southwest direction, one mile in a northwest-southeast direction and was open to the northwest. Several basement paleotopographic highs occur within the basin. The stratigraphy is similar to that described for other occurrences, except that green conglomerate, rubble or dark, laminated, fine-grained limestone without red conglomerate directly overlies basement at some locations and there are important amounts of celestite in the section.

The copper mineralization occurs at two levels in a terrigenous, carbonate, evaporite sequence. The basal part of the sequence consists of 0 to 100 feet of red conglomerate and 1 to 20 feet of green conglomerate overlain by 0 to 2 feet of dark, laminated, fine-grained limestone with sparse oncolites. This dark limestone grades upwards to a paler, more massive, fine-grained, drusy limestone which varies from 0 to 40 feet thick. Fossils occur near the top of this unit. A sandy, red conglomerate that averages 4 feet thick and ranges from 0 to 8 feet overlies the limestone. This bed is in turn overlain successively by 0 to 6 feet of limy stromatolitic dolomite; 6 to 30 feet of mottled red and green siltstones and sandstones, celestite, gypsum, anhydrite and minor algal limestones; 0 to 20 feet of green conglomerate; 0 to 18 feet of dark, laminated, fine-grained limestone with abundant oncolites; and 10 to 30 feet of very porous, light brown, fossiliferous limestone. Gypsum, anhydrite and red conglomerate occur above this light brown limestone.

Chalcopyrite occurs disseminated in the top of the two green conglomerates and in the overlying dark, laminated, fine-grained limestones. The lower copper-bearing zone averaging 2 feet in thickness is sparsely mineralized throughout the basin; whereas, the upper copper-bearing zone averaging 1 to 2 feet in thickness is not mineralized in all areas. Nowhere does the grade or thickness in either zone approach economic proportions.

Disseminated sphalerite has been tentatively identified only in the limestone units and galena has been observed as fracture fillings in both the green conglomerates and dark limestones. The economic celestite beds occur generally about 30 feet stratigraphically above the basal Windsor limestone contact and associated copper mineralization of the lower zone.

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Project 720095

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During the field season of 1973 trips were made to southeastern Ontario, Nova Scotia, and Newfoundland to visit known deposits and occurrences of barite, fluorite and celestite. The objective was to contact companies actively developing such deposits and from them to learn the whereabouts of new occurrences and to collect additional information regarding those already known.

In southeastern Ontario the three minerals occur in four classes of veins: 1. calcite-barite-galena; 2. barite-calcite; 3. calcite-fluorite-barite; and 4. calcite-fluorite-silicate veins. The veins are lenticular fissure fillings in dilatant zones on fault planes. Those in the first three classes generally strike northwest and are either vertical or dip to the northeast parallel to the only known regional structure, the Ottawa-Bonnechere graben, but across the regional trend of the Grenville host rocks. Class 4 veins strike northeast and dip steeply west more nearly parallel to the regional trends of the Grenville rocks. The wall-rocks of the veins are mainly Grenville marble or calc-silicate rocks and less commonly the overlying Paleozoic limestones. Class 1 veins carry minor galena, sphalerite, marcasite, pyrite, chalcopyrite, and celestite. They are illustrated by the Bedford township and Frontenac Mine vein systems from which there has been a small production of galena concentrates. Class 2 veins are similar in most respects but are characterized by minor fluorite and galena. Class 3 veins are best represented by the fluorite producing veins of the Madoc area where the wall-rocks are mainly Grenville rocks and to a lesser degree the overlying Paleozoic limestones and arkoses, and Deloro and Moira granites. Such veins contain 50 to 70 per cent fluorite in a calcite gangue with accessory celestite, pyrite, quartz, marcasite, and sphalerite. Fluorite was the only mineral produced and the veins related to the Moira fault have been more productive than those in the Lee-Miller group in the southwest corner of Madoc township. Class 4 veins occur in Cardiff township east of Wilberforce where they characteristically outcrop and strike northeast in a band of syenites and calcsilicate rocks. They contain variable amounts of apatite, pyroxene, hornblende, mica, feldspar and traces of molybdenite, scapolite, and sphene. The Cardiff Uranium Mine veins, the Richardson and Dwyer deposits represent this class of veins.

The field trip to Nova Scotia included visits to the Middle Stewiacke deposit, the Brookfield barite mine, the Walton barite mine, the fluorite-barite veins at Lake Ainslie and the celestite deposit at Lake Enon. These deposits and occurrences are related to the Windsor-Horton contact in the Walton mine, to the base of the Horton at Lake Ainslie and to the base of the Windsor at Lake Enon. The Walton orebody, which is an "S"-shaped pipe of barite plunging to the southeast occurs in brecciated basal Windsor Group Macumber and Pembroke formations related to intersecting faults. The mine also produced base metals and silver from a small orebody beneath the barite. The barite ore consists of siderite, barite with minor pyrite, marcasite, galena and silver sulphides. In the Lake Ainslie area the values occur in dilatant fault fissures in upper Fisset Brook Formation welded tuffs that underlie the Horton Group sediments that outcrop north and above the George River Formation (Precambrian) and the Devonian granites to the southeast. The ore minerals are fluorite and barite with a gangue of calcite, and accessory limonite, pyrite, and chalcopyrite. Barite, the major constituent at the top of the veins, is replaced by more abundant fluorite at depth. The celestite ore at Lake Enon occurs in the lower Windsor Group as mantos on the flanks of igneous basement topographic highs. More specifically they occur at the base of the Uist Formation, in the Loch Lomond Formation, and Enon Formation overlying the Grantmire conglomerate. The maximum values in the replacement lenses do not occur where they terminate against the basement highs.

The field trip to Newfoundland included visits to the Port au Port barite-celestite deposits, the barite veins of the Avalon Peninsula, and the fluorite mining camp at St. Lawrence on the Vurin Peninsula. The barite-celestite deposits occur as replacement bodies within small fault-bounded basins of the Carboniferous Codroy Formation at the top of the Table Head Formation. The distribution of these bodies is limited to the Port au Port Peninsula near the Aguathuna limstone quarry. The ore reserves are small but their accessibility might make a small operation economic.

The largest number of barite veins occur as steeply dipping fissure fillings in the rocks along the west side of the Avalon Peninsula. The wall-rocks include the relatively undeformed late Precambrian volcanic and sedimentary rocks that are overlain by a Cambro-Ordovician shale-sandstone-limestone succession. The reserves are small but a small operation might be economic and the occurrence of lead and silver values might improve the economics of such an operation. A large reserve of barite occurs as the gangue (25 per cent) in the polymetallic ore of the Buchans mine. The ore-bodies occur in thick openly folded Ordovician basic pyroclastics and pillow lavas and Silurian? volcanic rocks. The barite might be recovered from current production by a modification to the mill flowsheet or be reclaimed from the tailings. The offshore oil drilling program of the last several years might provide a nearby market for barite concentrates.

Canada's only fluorite producing area occurs in the alaskitic granite near the town of St. Lawrence on the Burin Peninsula. The mineral is produced from lenticular bodies in north- and east-trending fault zones mainly in the southern end of the batholith. Newfoundland Fluorspar (ALCAN) is the only producer and its reserves are large enough to continue for many years.

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51. SIGNIFICANCE OF SOME AUSTRALIAN AND AFRICAN OCCURRENCES FOR CANADIAN ARCHEAN NICKEL DEPOSITS

Project 630037

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A trip to Western Australia and South Africa was sponsored by the Geological Survey of Canada, the principal purpose of which was to gain a better appreciation of Archean nickel sulphide deposits affiliated with ultramafic rocks. Canadian examples of this type are the Alexo, Texmont, Langmuir, Dumont, McWatters, and Marbridge deposits of the southern Abitibi belt. Some of the Abitibi ultramafic rocks have recently been shown to be volcanic flows with diagnostic layering and textural features (Pyke, et al., 1973) and it has become apparent that most of the small to medium-sized Abitibi ultramafic bodies are probably volcanic flows or shallow, subvolcanic intrusions (Eckstrand, 1972, 1973). Consequently the nickel ores, being contained within these ultramafic bodies, must also be volcanic or subvolcanic in origin (Eckstrand, 1973; Naldrett, 1973) although it has not been possible to clarify the exact relationship of ores to flows. The Dumont deposit is an exception because the serpentinite host appears to be a sill areally unrelated to ultramafic volcanic rocks.

Examination of the Western Australian nickel deposits was considered desirable because (1) they are numerous (about 20 deposits were visited), (2) many are under active exploration, so good access and guidance is available, and (3) much geological information has resulted from eight years of active investigation by industry, government and universities. In South Africa, the Barberton Mountainland was visited because of the excellent documentation of Archean ultramafic rocks.

Other objectives of the trip were to examine other nickel and platinum deposits, including those in the Bushvelt Complex, and the garnieritic ores of New Caledonia.

The following are some of the main impressions obtained with regard to Archean nickel sulphide deposits affiliated with ultramafic rocks, and their relevance to the understanding of Canadian nickel deposits.

1. Two types of deposits. Evidence from the Western Australian deposits strongly suggests two distinct models of nickel sulphide deposits. For convenience these will be termed "vent type" and "sill type", expressing the writer's subjective bias concerning their genesis. Both types are considered to have originated from segregation of an immiscible sulphide melt from the olivine-bearing ultramafic host magma.

The "vent type" of deposits cannot be definitively demonstrated to be near a volcanic vent, but their relation to ultramafic flows suggests that they were emplaced at or very near the surface. Characteristically these deposits occur at the stratigraphic base of the lowermost of a superposed series of ultramafic units in which the upper units are spinifex-bearing flows (Pyke, et al., 1973). Grade and tonnage are usually in the 1 to 4 per cent, 1 to 5 million ton ranges. Grain size of original olivine averages 1 to 2 mm. Thin cherty and shaly beds are commonly intercalated between the extrusive units. The ore-bearing unit is the most magnesian of the pile. In some cases it is simply the lowest in the series, and may itself be extrusive, as at Kambalda (Woodall and Travis, 1969; Ross and Hopkins, 1973). In other cases, the ore-bearing unit is separated from the overlying pile of flows by a significant thickness of sediments, and shows the textural or structural characteristics of a sill. Nevertheless it is close spatially to the ultramafic flows and can logically be interpreted as a feeder sill, near the vent. The writer considers that the Nepean (Hudson, 1973) and Miriam (Hallberg, et al., 1973) deposits are probable examples.

The vent type of deposits usually consist of massive sulphides at or near the base, overlain by matrix or net-textured ore (25 to 75 per cent sulphides). These are commonly overlain by sulphides of marginal or sub-economic grade. Departures from this mode of distribution can often be attributed to post-ore deformation and metamorphism. Canadian examples are considered to include the Alexo, Langmuir, McWatters, Texmont and Marbridge deposits.

The "sill type" of deposits consists mainly of low-grade zones in simple serpentinized ultramafic lenses. They appear to be roughly conformable intrusions, a few kms long and several hundreds of metres thick. Grade of the deposits is usually 0.4 to 0.7% and tonnage in the tens or hundreds of millions range. The mineralized zones are located centrally within the ultramafic rather than at its base and consist of disseminated rather than massive or matrix sulphides. Grain size of original olivine averages 2 to 5 mm. Ultramafic flows occur nearby, but their genetic relationship to ore, if any, is not clear. The Mount Keith deposit is one of a series of such mineralized bodies strung out over a strike length of more than 90 kms along a strong fault lineament. The Dumont deposit of the Abitibi belt is the best known Canadian example.

2. The Perseverance deposit: a possible exploration target in the Abitibi belt? The Perseverance (Agnew) deposit occurs in one of the serpentinites of the Mount Keith belt described above, and has many of the characteristics of sill type deposits. However it differs from the usual sill type in that it is richer (more than 40 million tons at greater than 2% nickel), and the ore zone is a marginal (basal?) segregation of massive and heavily disseminated sulphides (Martin and All-

church, 1973). In these two respects it resembles the vent type deposits, but no close relationship to ultramafic flows is apparent.

The Dumont serpentinite is one of a series of ultramafic lenses strung out along a strike length of 120 km in northern Quebec from Barraute township in the east to LaSarre township in the west (Dugas, et al., 1967). Volcanic flow features have not yet been reported from these ultramafic bodies. It seems, therefore, that the Dumont belt bears certain important similarities to the Mount Keith belt. Consequently, some ultramafic body in the Dumont belt could be expected to contain a "Perseverance type" of deposit, a very worthwhile exploration target.

3. Archean stratigraphy. There are at least two, probably three, cycles of basic volcanism, each containing ultramafic sequences (Sofoulis, 1966; Williams, 1969; Kriewaldt, 1969) in the Kalgoorlie region of Western Australia. At least two of the ultramafic sequences contain nickel occurrences. However, deposits are obviously concentrated in both time and space. Attempts (Williams, 1973; Gemuts and Theron, in press) have been made to relate these concentrations to structural subprovinces, presence of sulphide or oxide iron-formation, abundance of calc-alkaline volcanism, and different potential of individual ultramafic sequences. Documentation of Barberton Mountainland in South Africa (Viljoen and Viljoen, 1969) has demonstrated strong chemical breaks in the volcanic stratigraphy, with attendant control on distribution of ultramafic rocks. These avenues of investigation are of obvious interest and are having an impact on the continuing study of Canadian nickel deposits.

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Project 720097

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This project is one more step in research to develop methods for regional mineral resource appraisal through combined geological and mathematical procedures. It is a co-operative effort by members of the Appalachian, Geomathematics and Mineral Deposits Geology sections. Each of three major inputs, namely the regional geological data-base, geomathematical methodology, and the mineral deposits data-base, is developed with the other two in mind.

The regional geological data are converted into computer-processable form. In earlier projects the regional geological base was restricted to data that could be quantified directly and consistently from available maps. The input parameters were thus limited to those applicable to the least detailed map from which input was required. The present project was designed to get away from this limitation and to use additional information gained from reports, document files, better-grade maps and geologists' first-hand knowledge.

The geological base legend combines lithological facies and age-spans so as to represent natural litho-age groupings and it thus has strong tectonic connotations. There are about one hundred litho-age units. The input includes also information on structural style, metamorphic grades, the nature of intrusive contacts and certain unconformities and stratigraphic contacts. In coding these data for computer processing, the project area (the Canadian Appalachian geological province) was divided into about 3600 "standard cells" 10 km by 10 km, laid out on a UTM-based grid. The proportion of each cell occupied by each litho-age unit was determined by point-counting, using a grid that subdivides each standard cell into four hundred $\frac{1}{4}$ km^2 sub-cells. Linear features are recorded on a km/cell basis and "spot" features by frequency per cell.

The mineral deposit data-base includes information on commodities present, quantitatively when possible, and on mineralogy, morphology, immediate host rocks and positions relative to certain variables of the geological data-base.

During this project, results of mathematical analyses of the inputs will be compared with interpretations reached by non-mathematical methods.

Project 670029

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A mild revival of interest in exploration for uranium took place in certain parts of Canada, and visits were made to several areas in which sufficient mineralization had been exposed or drilled to permit assessment of the type and environment of such deposits, and sampling for mineralogical examination.

In Bancroft area, Imperial Oil Limited, jointly with Mandarin Mines has trenched and drilled a zone of radioactive calc-silicate rocks in marble that are intruded by erratically distributed red pegmatites. This property is in the southeastern part of Glamorgan township. A short distance to the east, in Monmouth township, Northern Nuclear in 1968 and 1969 blocked out a deposit of uraninite in calc-silicate rock on the former Wadasa Gold property, which was reported (Northern Miner, 17 April, 1969) to average about 1 lb. U_3O_8 per ton.

Near Bissett, Manitoba claims owned by Dome Exploration (Canada) Limited were visited and occurrences of uranophane and finely divided pitchblende (?) that form concentrations in quartzite of the Archean San Antonio Formation were examined. No associated minerals or alteration were detected.

In Berard Lake area, west of Fort Chimo, Quebec, on mining concessions being explored by Imperial Oil Limited, uranium occurs in irregular bodies within pebbly arkose with scattered boulders up to 8 inches in diameter. These beds are part of the Aphebian Chioak Formation. The uranium minerals boltwoodite and uranophane have been identified in the GSC laboratories. Calcite is apparently the only visible mineral that seems to be associated with the mineralization.

An examination of Permo-Carboniferous red beds in the Maritime Provinces was made in part to determine whether reduzate zones indicating migration of uraniferous solutions, are present. In about one quarter of the outcrops examined some evidence of reduzate action was seen. The most spectacular of such evidence was seen in the outcrop on the northwest side of the former bridge over French River near Tatamagouche, and a sample contained 70 ppm U.

In Mont Laurier area, Quebec, A. Boyer of the Geological Survey visited the properties of Mont Laurier Uranium, Inc., and Scandia Mining and Exploration Limited, and examined diamond-drill core from the property of Gulf Minerals (Canada) Limited. On the Mont Laurier property, which is in Perodeau and Leman townships, four zones have been explored by trenching and drilling at intervals over a distance of eight miles along the strike of a metamorphic terrain composed of granitic gneiss, hornblende gneiss, quartzite and marble, and pods of white pegmatite. The four zones range in width from 10 to 100 feet and in length from 20 to 600 feet. Uranium mineralization occurs in pegmatites and in metasomatized quartzite, and is concentrated within crystals and clusters of biotite. Variable amounts of magnetite, pyrite, chalcopyrite, pyrrhotite, and molybdenite occur as accessory minerals. Uranophane is visible in some trenches.

Diamond-drill core from the property of Gulf Minerals, in Franchère township, is similar to that from the Mont Laurier property.

The Scandia property, in Joliette 60 township near Mitchinamecus reservoir, is underlain by hornblende gneiss and amphibolite. Three red pegmatite dykes that strike east across the trend of these metamorphic rocks have been trenched and drilled, and a zone of discontinuous white pegmatite that strikes north-northwest has been trenched. The red pegmatites are 6 to 30 feet wide and at least 300 feet long, and contain much magnetite, hematite, and minor biotite. The white pegmatite contains more biotite and less magnetite. Radioactive minerals in the pegmatites are uranothorite, uraninite, thorite, and gummite. Zones elsewhere on the property were not examined.

An area that on theoretical grounds might be favourable for sedimentary uranium deposits is that underlain by Paleozoic rocks west of Bear Structural Province in the District of Mackenzie. Some 200 bore holes have penetrated to basement in this area and gamma logs of these wells were examined by W. S. Mackenzie and G. K. Williams of the Institute of Sedimentary and Petroleum Geology, Calgary, and 5 zones of highest radioactivity were delineated and sampled. The samples were analyzed by gamma ray spectrometer in the laboratories of the Geological Survey, and ranged from 0.2 to 6.0 ppm U. This tends to confirm the opinions of the stratigraphers that the source of the basal Paleozoic rocks is from the west.

In northern Saskatchewan the writer visited the Fay and Hab mines of Eldorado Nuclear Limited. The ore of the latter, which is of relatively high grade, is expected to be exhausted early in 1974. Visits were also made to the small high grade deposits known as the Gully, Intermediate, and Lost Vein, which from time to time have supplied some ore to the mill from surface operations.

On the property of Mokta (Canada) Ltd. in the vicinity of Cluff Lake, three separate deposits are being explored. The D zone, which is of very high grade, lies at the south edge of the Carswell circular structure, and was described previously (Little, 1972; Mokta (Canada) Ltd., Geology Dept., 1972). It is currently being drilled at close centres to determine accurately its size and shape. A second deposit, the N zone, lies about a mile north-easterly from the D zone. It is larger and of lower grade than the D zone. A third deposit, the Claude, still in the early stages of exploration, is about two miles northwesterly from the D zone. Samples from all these deposits resemble those of the

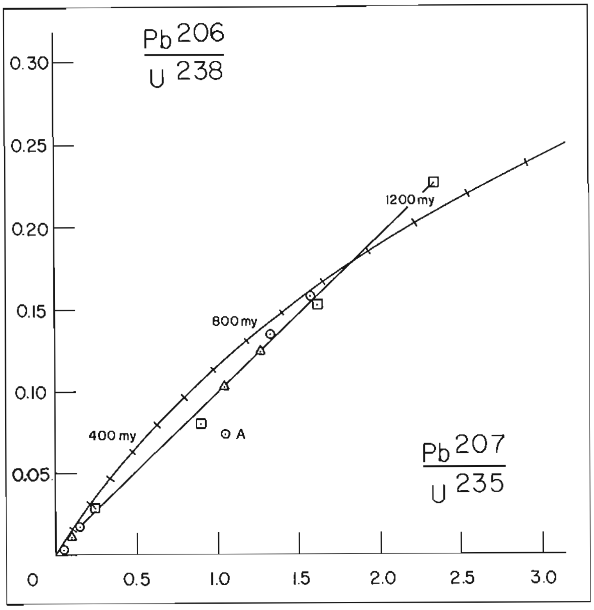

Figure 1. Concordia diagram showing lead/uranium ratios of pitchblende from Rabbit Lake deposit. Circles represent 5 samples analyzed in Geological Survey laboratories; squares represent 4 samples analyzed in Gulf laboratories; triangles represent 3 samples analyzed in University of Alberta laboratories.

pitchblende veins of the Beaverlodge area in that pitchblende is the predominant mineral although pyrite and pyrrhotite may be locally abundand. Micro sariat à l'Energie Atomique, has shown the presence of clausthalite, gold, gold telluride, chalcopyrite, cobalt-nickel arsenides, and uraniferous bitumen, similar to Beaverlodge ores (Robinson, 1955).

Permission was kindly granted by Gulf Minerals (Canada) Limited to examine all the drill core of the deposit and to sample it for mineralogical study. Recent papers (Knipping, 1971; Derry, 1973) have suggested a supergene origin for the deposit, and a word on another possibility is in order. Although the close spacial relationship between the deposit and the Athabasca unconformity cannot be denied, it may be the result of the Athabasca Formation acting as a trap for hydrothermal solutions that percolated upward through the breccia zone. The paragenetic sequence: colloform pitchblende, white quartz and calcite, euhedral quartz, sooty pitchblende and coffinite, followed by boltwoodite, sklodowskite, and uranophane, has been established by Knipping. A. Boyer has confirmed this sequence (except for sklodowskite), and in addition has found transparent dolomite that is earlier than the colloform or massive pitchblende, and calcite and minor dolomite, siderite, marcasite, sphalerite, and thucholite that followed euhedral quartz, and has identified tyuyamunite among the secondary minerals. Thick sections tested on a heating stage by Boyer showed that the dolomite was deposited at 245^{o}C without compensating for the effect of pressure, but it is possible that this early dolomite is unrelated to mineralization and may be related to an earlier metamorphic event such as the Hudsonian orogeny. The temperature of filling of fluid inclusions in the euhedral quartz, also determined by Boyer, is 135 to 160^{o}C. Allowing for effects of pressure, the actual temperature of formation of the euhedral quartz, for a filling temperature of 135^{o}C is 180 to 225^{o}C (Smith, 1963), depending upon the salinity which was not determined. It is evident, therefore that dolomite, massive or colloform pitchblende, white quartz and calcite, and euhedral quartz were all deposited under hydrothermal conditions.

Knipping (1971), in his address to the Canadian Institute of Mining and Metallurgy, suggest that surface waters containing uranium leached from the granites and gneisses of the basement circulated through the breccia zone in which the uranium was precipitated. Because such solutions are extremely dilute, a uranium content of 5 parts per billion being comparatively high, a very powerful precipitating agent would have been necessary - carbonaceous material, H_2S, or bacteria, of which there is no evidence in the environment of the deposit. It is difficult to conceive of massive or colloform pitchblende being concentrated in places to grades of 10 or 15 per cent U_3O_8 from cold, dilute solutions without a strong precipitating agent. Furthermore, Knipping, from ages derived from U-Pb isotope data obtained in the Gulf laboratory in Pittsburgh, states that the colloform pitchblende was formed 1200 m.y. ago, and was remobilized several times at later periods. These basic data, and additional data determined in the University of Alberta laboratories and kindly supplied by Gulf Minerals, and some obtained in the Geological Survey geochronology laboratory were plotted on a concordia diagram (see Fig. 1). Except for one determination (sample A), all points fall close to a chord which indicates the time of initial mineralization was 1075 m.y. ago.

Even if the initial age of the deposit was 1200 m.y., its accumulation could not be a surface phenomenon because the Athabasca Formation is at least 1250 m.y. old. This is based on the fact that paleomagnetic measurements prove that a diabase dyke that cuts the Athabasca Formation on the shore of Lake Athabasca is of the Mackenzie swarm (Fahrig, W.F., oral comm., 18 October, 1973). It might be argued that, if uranium had accumulated prior to deposition of the Athabasca Formation and then 1075 m.y. ago had been completely remobilized to form the present deposit, almost complete separation of uranium from its earlier decay products could have occurred. Support for this conjecture might be claimed in sample A (Fig. 1) which yielded a Pb 207/Pb 206 age of 1610 m.y., but a later analysis of material from the same minute sample when plotted falls on the chord. Furthermore, the sample consisted of sooty, rather than colloform pitchblende.

In the light of the foregoing evidence, the writer favours the theory that 1075 m.y. ago, hydrothermal solutions at temperatures exceeding 180^{o}C deposited massive and colloform pitchblende, quartz, and calcite. Such temperatures would be expected in a continental area (where the average geothermal gradient is 35^{o}C per kilometre) at depths of 15,000 to 20,000 feet, a thickness unlikely to have been attained by the Athabasca Formation. Consequently the solutions were probably generated at greater depth, and migrated upward until trapped beneath the Athabasca Formation, where colloform and massive pitchblende were deposited, followed by white quartz and calcite, and finally euhedral quartz. Finally, supergene processes brought about deposition of sooty pitchblende, coffinite, calcite, and minor marcasite.

The Aphebian-Helikian unconformity is widely used as a guide in uranium exploration in many other parts of the world. In Canada, a close spacial relationship between this unconformity and uranium mineralization is evident in such deposits at Rabbit Lake, Cluff Lake, certain parts of Beaverlodge area, and Baker Lake area. The relationship is not as close in other deposits in Beaverlodge area (such as Gunnar and Hab). At Rayrock, Amer Lake, and Makkovik, the Aphebian-Helikian unconformity has not been found within 50 miles of the deposits, and at Port Radium within 30 miles. Thus, the unconformity in some areas appears to control deposition of uranium deposits, perhaps by serving as a trap for hydrothermal solutions, but in the writer's opinion, epigenetic uranium deposits should be sought elsewhere as well.

Boyer and the writer acknowledge with thanks the hospitality and co-operation of the owners and personnel of the properties visited.

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Project 650056

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Sulphide deposits containing lead and/or zinc sulphides were examined in the Grenville, Superior, Cordillera, Interior, Churchill, and Innuition regions as part of a continuing geological study of Canadian lead-zinc deposits. Of these, two are described here and a third area is covered in a joint report by Sangster and Kirkham elsewhere in this volume.

1. Argentia Mines Ltd., Beaverdell, B.C. (NTS 82E/6)

Presently under option to Riocanex, the property is exposed in good outcrops and several dozen pits and trenches. According to company geologists, the geological succession on the property is as follows:

youngest
↑
Hornblende-feldspar porphyry dyke
Porphyritic granite
Quartz-monzonite porphyry
Granodiorite
Anarchist volcanics (andesite)

Surface mineralization appears to be confined to the altered portion of the granodiorite adjacent to the later porphyritic granite. In hand specimen, alteration appears to have been sericitization, kaolinization, and chloritization. This is currently being checked by thin section examination. Sulphide minerals observed were pyrite, sphalerite, and pyrrhotite. Sphalerite was by far the most common sulphide seen in hand specimen although all rocks in the mineralized zone were heavily iron-stained, suggesting that the fresh, unweathered rock may contain a higher pyrite (and probably sphalerite) content. For the most part, sulphides occur as disseminated grains within the altered portion of the granodiorite. Sphalerite, the most common sulphide observed, occurs as discrete pin or match-head sized grains or loose aggregates. This texture, together with the alteration described above, suggests that the Argentia occurrence is a rather uncommon example of "porphyry zinc" mineralization.

Although porphyry copper and porphyry molybdenum deposits are far more common than porphyry zinc, the reason for this is not at all clear. Copper and molybdenum contents of intermediate to acidic intrusive rocks are about ½ and 1/10, respectively, that of zinc in the same rock types and yet the hydrothermal systems operating appear to be infinitely more efficient for Cu-Mo than for Zn. Percentage grades of metal on the Argentia property, 0.5 to 2% Zn, are comparable to porphyry copper deposits and strengthen the analogy with the latter type.

As a matter of interest, an occurrence of disseminated lead-zinc mineralization has recently been described in a Miocene intrusive-extrusive sequence in Colorado (Young and Segerstrom, 1973). Average zinc content of this deposit was calculated to be 0.06%.

2. Arvik Mines Ltd., Cornwallis Island, N.W.T. (NTS 68H)

This company was formed by Cominco Ltd. to develop the lead-zinc deposit of Bankeno Mines on Little Cornwallis Island. With about 5,000 feet of underground development completed and approximately 5,000 tons of ore stockpiled at the mine site, the operation, at 75°30' latitude is probably the most northerly mining venture in the world. Official reserves have not been released but the gross metal value has been determined to be in excess of $1.5 billion, thereby qualifying it as one of the more significant lead-zinc deposits in the world (Northern Miner, Apr. 12, 1973).

Mineralization, consisting of pyrite, sphalerite, and galena, is confined to the top quarter of the Ordovician Thumb Mountain Formation dolomite and limestone (Thorsteinsson and Kerr, 1968). The deposit is stratigraphically beneath, and spatially close to, a major disconformity separating the Thumb Mountain-Irene Bay (shale) formations and the overlying Silurian-Devonian Cape Phillips shale. In every aspect, the deposit is of the so-called "Mississippi Valley" type probably controlled by karst solution caverns and breccias in a manner popularized by Callahan (1964) and Bernard (1973). Fluid-inclusions in sphalerite have been found to homogenize in the range 52-105°C (Jowett, 1972), in good agreement with similar studies on other Mississippi Valley type deposits in the world.

Low-grade mineralization is largely in the form of sulphides accompanying white dolomite veining and irregular "soaking" of the Thumb Mountain dolomite. High-grade mineralization consists of massive sulphides in a wide variety of textures of which botryoidal to massive sphalerite and crystalline galena is the most common.

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DISSEMINATED BASE METAL MINERALIZATION ALONG THE WOLLASTON LAKE FOLD BELT, SASKATCHEWAN

Projects 650056 and 700059

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Several disseminated copper, lead, and zinc occurrences have been found in highly metamorphosed and deformed Proterozoic quartzofeldspathic sediments over a distance of about 150 miles along the Wollaston Lake fold belt of northern Saskatchewan. Descriptions of some of these occurrences have been presented by Pyke and Partridge (1967), Rath and Morton (1969) and Beck et al. (1972). The deposit at George Lake, containing several million tons of zinc mineralization, has been described by Karup-Møller and Brummer (1970). Money (1968) has published a summary of the regional geology in the Wollaston Lake fold belt.

Host rocks for the disseminated base metal mineralization consist of highly metamorphosed arkosic sandstones and conglomerates. Most, if not all of the occurrences examined, probably belong to the Daly Lake Group or its equivalents as defined by Money (1968).

Mineralization along the belt consists of disseminated pyrite, sphalerite, galena, chalcopyrite, bornite, chalcocite and native copper. In most cases, copper and lead-zinc are found in separate occurrences; although in the Kaz Lake area in the central part of the belt, boulders containing both galena and chalocpyrite have been found. In spite of the high metamorphic grade and intense deformation, mobilization or concentration of sulphides into fold axes or fractures does not appear to be a major control of mineralization. Sulphides seem to be most abundant in those portions of the metasandstones that contain a minimum of pelitic material i.e. the "cleaner" quartzites contain the mineralization. The disseminated nature of the sulphides and the lack of extensive veining or fault control strongly suggest to the authors that the base metals were emplaced in the quartzites and meta-arkoses before they lost their primary porosity. One characteristic of these occurrences (except George Lake) is that individual mineralized zones in most cases, cannot be traced for any significant distance along strike in spite of the fact that the host rock lithology is laterally continuous without apparent change beyond the mineralized zones. George Lake is exceptional in that mineralization has been intersected along strike in excess of 2,000 feet. The down-dip extension, however, is less than 400 feet and, with an average width in the order of 100 feet, the deposit could probably be best described as pencil- or blade-like in form. If this shape is true for other occurrences in the Wollaston Lake fold belt, then a random section through such a body would likely be of very limited strike-length and exploration drilling might be better directed down dip rather than along strike of the surface mineralization.

Blade- or pencil-shaped mineralized zones in rocks which were probably deposited as sandstones with presumed good porosity, suggest that the original control to mineralization may have been related to permeability channels and/or "pinch-out" traps in the sandstones. At the Marina Pb-Zn showing near Johnson Lake the mineralization occurs in discontinuous "clean" quartzite lenses along a contact with a granitic body which could possibly be Archean basement.

Money (1968, p. 1493) has stated that the presence of abundant arkose in the Daly Lake Group suggests that deposition "took place in close proximity to a land mass or landmasses consisting in part of granitic rocks" and that the depositional environment resembled that of a miogeosyncline. Since volcanic rocks are rare or absent in the Daly Lake Group, a problem remains as to the probable source of the metals. One distinct possibility is that the metal source was the same granitic landmass that was the source of the material for the arkoses, conglomerates, and quartzite host rocks themselves in a manner analogous to that described by Samama (1968) for lead and by Garlick (1961) for copper. Crucial to this modelling for the disseminated mineralization in the Wollaston Lake fold belt is the relationship of the metasedimentary host rocks to the granitic rocks of the belt. In the few places where a granite-sedimentary rock contact was examined by the authors, even though the contact is sharp, because of intense deformation evidence as to the intrusive or erosional nature of the relationship is equivocal. Money (1968) recognized basement granites in a few places but stated further that (p. 1491) "a granitic basement may be present elsewhere along the fold-belt system, particularly in view of the common occurrence of arkosic rocks within the system and of the possibility that some intrusive granitic rocks actually represent remobilized basement". Detailed mapping and age-determinations are obviously required to solve the problems which are crucial to a proper assessment of the future potential of this mineralized belt.

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56. RED WINE ALKALINE PROVINCE, LABRADOR

Project 680071

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Reconnaissance mapping of an area of about 350 square miles containing major occurrences of agpaitic alkaline rocks was completed during the 1973 field season.

Regional Setting

The alkaline plutons occur as elongate, sinuous to irregular, tectonically deformed pods, enveloped by rocks of the Letitia Lake Group or metamorphosed equivalents (Currie, 1973).

In contrast to low greenschist grade rocks from the Seal Lake belt to the northeast, the rocks in the area mapped are of a much higher grade, though it appears to vary irregularly and facies-specific assemblages are rare. The assemblage sillimanite-biotite-magnetite-muscovite-alkali feldspar has been identified in close proximity to the Red Wine alkaline rocks, and granulite facies basic rocks occur south and southeast of the area (Stevenson, 1969).

The Letitia Lake Group of quartz-feldspar porphyries and minor intercalated sediments together with the overlying, possibly conformable, Seal Lake Group, extends southwest in the northern part of the Red Wine province, then sweeps south, incorporating the southern Red Wine alkaline rocks. The termination of this extension has not been found, but is critical to the understanding of the boundary between the Grenville and Nain structural provinces.

Structure

The disposition and configuration of the alkaline rocks is a function of folding and accompanying elongation. At least two periods of deformation are recognized, succeeded by faulting. A crenulation cleavage superimposed on the foliation is observed in many exposures of the alkaline rocks. Transposition of foliation accompanied by extreme limb attenuation is observed on outcrop scale in the enveloping gneisses. East-west foliation dominates in the southern pluton and north-south foliation in the northern ones.

Competent gabbroic bodies, and some pods of massive, coarse-grained alkaline rocks are arranged *en echelon* about north-northeast trending faults. Rocks from the Letitia Lake Group vary from schistose augen gneiss to massive, banded quartz-feldspar rocks showing little evidence of deformation. By contrast, the alkaline rocks show a wide range of textures, from rodded schists, through strongly gneissic types, to massive or blastophitic varieties. Pegmatitic 'sweats' and ptygmatic veinlets are widespread. The transitions from one texture to another may be very sharp.

Petrology

The alkaline rocks have been provisionally divided into melanocratic, mesocratic and leucocratic gneisses (all generally resembling amphibolites), massive malignites and syenites, lujavrites (nepheline-amphibole-pyroxene-feldspar rocks, possibly originally of cumulate origin), and hybrid gneisses or syenites containing a significant metasomatic component.

The essential constituents of the alkaline rocks are microcline, albite, arfvedsonite, and/or alkali pyroxene, with at least accessory amounts of nepheline. Aenigmatite and eudialyte occasionally reach significant proportions, and apatite, lamprophyllite and ramsayite are common accessories.

A variety of other rare minerals have been identified, but are uncommon. They appear to be concentrated in zones marginal to the main intrusions, and also occur in an elongate mass of alkaline gneisses on the north edge of the province, apparently a deformed dyke (Brummer and Mann, 1961).

Truly syenitic rocks are not rare, but appear to occur only as masses of feldspar-amphibole pegmatite 'sweated' out of the rocks. More mafic pegmatite masses however form spectacular, though volumetrically insignificant masses, commonly rich in eudialyte.

A variety of hybrid rocks, commonly syenitic, occur as very irregular though often extensive aureoles around the plutons. These rocks are characterized by pale colour, granular texture, and the common presence of small amounts of eudialyte, acmitic pyroxene, alkali amphibole, hematite, aenigmatite and mica. Trace amounts of these minerals are found at considerable distances, measured in miles, from the plutons. The widespread distribution of these minerals is possibly due to the dispersal of metasomatic fluids by metamorphism and tectonic deformation.

The most significant mineral variation occurs in the pyroxene group where compositions range from almost pure acmite and acmite-jadeite in marginal zones, to aegirine, aegirine-hedenbergite, and a unique titanian omphacite (Table 1) within the plutons. The latter is ubiquitous, and although commonly characterized by a startling blue pleochroism may also appear green or almost colourless.

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TABLE 1

	1	σ	2	3	4	σ
SiO_2	55.3	6.0	52.52	46.47	54.17	0.08
Al_2O_3	12.73	2.53	13.66	13.06	7.80	1.16
FeO*	12.31	5.10	8.99	13.39	12.14	1.31
CaO	2.57	1.84	3.27	5.72	9.40	1.45
MgO	0.70	1.22	0.29	3.52	3.19	0.62
TiO_2	0.73	0.64	0.49	1.98	3.49	1.67
Na_2O	8.77	1.46	8.42	8.76	9.19	0.70
K_2O	4.35	1.44	5.52	4.13	0.13	0.07
MnO	0.32	0.17	0.76	0.27	0.36	0.04
P_2O_5	0.33	0.49	0.07	1.40		
ZrO_2	0.287	0.291	1.60	0.075		
CO_2	0.06	0.04	0.18	0.12		
$H_2O\pm$	0.86	0.54	2.44	1.30		
	99.32		98.21	100.20	99.87	
atomic Fe_2/Fe_3	2.34		0.14	5.47		
atomic Na+K/Al	1.50		1.50	1.43	1.68	

L.W. Curtis, analyst

1. Mean and standard deviation of fourteen Red Wine alkaline rocks SiO_2, Fe_2O_3, P_2O_5, CO_2 and H_2O analyses by Loomis Laboratories.
2. Nimroc standard lujavrite, NIM-L, medium value reported by Russell et al., 1972.
3. Mean of two 'omphacite' bearing dyke rocks, Red Wine Complex.
4. Mean and standard deviation of nine electron probe analyses of blue 'Fe-Ti omphacite' from the dyke rocks.

* Total Fe reported as FeO.

Chemistry

The alkaline rocks are distinguished by their rather high Si content, high Fe and low Ca and Mg contents, together with high Na+K/Al and low oxidation ratios. Relative to other agpaitic complexes, these agpaitic alkaline rocks are distinctly mafic, and approximate in average composition the chemistry of a lujavrite (Table 1). The absence of leucocratic agpaitic rocks, particularly sodalite-rich varieties may be a consequence of original magma composition, level of exposure, metamorphism and metasomatism, or some combination of the three.

Apart from the typical concentration of Zr in these rocks, Nb and Ce appear to be high, and Ba, Sr, Cl and F are low relative to other agpaitic complexes. Separate Ba, Nb, Be and REE phases are rare and are concentrated in hybrid or marginal zones.

Investigations of the Red Wine alkaline province are continuing at the University of Toronto on EMR Grant 1135-D13: 4-17/73.

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Project 670003

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Regional and Economic Geology Division

Approximately nine weeks were devoted to completing the field investigation of the Harp Lake complex in central Labrador. Most of this work was concentrated in the southeast quadrant of the complex.

Amphibolite facies gneisses of presumed Archean age lying east of the Harp Lake complex are upgraded to granulites within one-half to three-quarters of a mile from the contact. This is similar to the contact metamorphic effects that have been observed in Aphebian gneisses north and south of the complex.

Fine- to medium-grained gabbro and diorite are present along much of the eastern margin of the complex in the vicinity of Shapio and Mistinippi lakes. In part the rocks show intrusive relations toward coarse anorthosite, leucogabbro and leuconorite. Masses of fine- to medium-grained olivine gabbro, gabbro and norite occur in coarse anorthositic rocks at a number of localities well within the complex.

Much new layering has been mapped in anorthosite, leucogabbro and leucotroctolite. Although a coherent structural interpretation of the entire complex is elusive it is evident that layering has dominantly low dips (less than 30 degrees). A few localities have layering with highly irregular attitudes or with very steep dips but these are rare.

Adamellite dykes are common in the southeastern part of the complex and cut anorthosite and leucogabbro. The dykes range in thickness from a few inches to 20 feet or more. Most are tabular and have fairly consistent trends at any one locality. It is clear that they were emplaced after the anorthositic rocks were sufficiently solidified to fail by brittle fracture.

As reported last year Kennco Explorations has been actively exploring the Harp Lake complex. During the summer the company kindly provided the opportunity to visit several showings that have been opened up by blasting and trenching. Disseminated chalcopyrite and pyrrhotite are the chief sulphide minerals and geophysical surveys were underway to test the extent of some of the occurrences. There is little doubt that the sulphides are syngenetic and some occurrences can be shown to be related to layered structures. Whether any of the mineralization has economic potential remains to be determined. Nevertheless, the widespread presence of chalcopyrite and pyrrhotite within the complex suggests that careful exploration of some large anorthositic masses may prove to be rewarding.

Additional sampling of the complex and country rocks for paleomagnetic studies was carried out. These studies, when completed, should provide useful data bearing on recent paleomagnetic interpretations of rocks of central Labrador (Fahrig and Larochelle, 1972; Roy and Fahrig, 1973).

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ULTRAMAFIC AND GABBROIC ROCKS IN THE AIKEN LAKE AND McCONNELL CREEK MAP-AREAS, BRITISH COLUMBIA

Project 650288

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This study, which was carried out in conjunction with Operation Finlay, represents an extension of earlier work on the Polaris ultramafic complex in the Aiken Lake area (Irvine, 1966, 1968). About 3 weeks were devoted to supplementary mapping of the Polaris complex, to mapping and sampling of a peridotite body south of Wrede Creek in the McConnell Creek area and of a pyroxenite body northwest of Tutizzi Lake in the Aiken Lake area, and to spot examination of four other ultramafic-gabbroic bodies near the boundary of the two map sheets (Fig. 1). Four weeks were spent mapping a layered gabbro intrusion in the Axelgold range at the southeast corner of the McConnell Creek area.

Polaris Ultramafic Complex

This complex, described originally by Roots (1954), is a northwesterly-trending body about 9 miles long and 1-3 miles wide situated in the Lay Range, north of Aiken Lake (Fig. 2). It consists of dunite and peridotite (wehrlite) with subordinate olivine clinopyroxenite and minor hornblende-magnetite clinopyroxenite and hornblendite, a combination of lithologies that establishes it as an Alaskan-type (or so-called "concentric" or "zoned") ultramafic complex (Irvine, 1968). The country rocks are dark tuffaceous sediments and basic lavas which in early work were classed as Permian or older (Roots, 1954) but which may, on the basis of recent work, be Triassic Takla Group rocks lying beneath a thrust plate of Permian strata (J.W.H. Monger, pers. comm., 1973). The ultramafic complex has steep to vertical contacts around most of its perimeter but shows a domical roof at the northwest end (Roots, 1954, Fig. 8). It is largely fringed by a contact metamorphic-metasomatic aureole of amphibolite, 200-500 feet wide.

The ultramafic rocks are almost entirely cumulates but show little distinguishable layering. The hornblende-bearing units occur mainly on a high ridge along the southwest side of the body and appear to form a cupola. Some of the olivine clinopyroxenite borders the edges of the complex, giving a suggestion of concentric structure, but most of it is scattered through the interior, partly as grossly tabular bodies that appear to be stratigraphic units, and partly as roughly equant, angular blocks, many of which are cut by dykes of dunite and peridotite. The dykes are generally less than a foot wide; a few are 20-50 feet across. The dunite and peridotite locally contain small deformed and broken layers of chromite (e.g. Roots, 1954, Figs. 6, 7), and are cut by numerous thin veins of clinopyroxene (augite). They are everywhere partly serpentinized.

The complex is intruded by at least 6 small bodies of syenite and is locally cut by veins of ferrodolomite that are probably byproducts of serpentinization. The writer was unable to find the corundum-bearing "plumasite" reported by Roots (1954). The only rock seen that would fit the description occurred in a small carbonate vein and proved to be composed of vesuvianite.

The petrology and structure of the ultramafic complex suggest that it formed as thickly stratified accumulations of olivine plus minor chromite and augite plus subordinate olivine fractionated from a much larger body of magma, and was then intruded into its present host rocks while still in a semi-solid state. During intrusion, the pyroxene-rich layers were broken and intruded by the olivine-rich crystal mush, and the small chromite layers were deformed and fragmented. The magnetite-bearing clinopyroxenite and other hornblende-rich rocks appear to have formed later from residual magma.

Other Ultramafic Bodies

The Wrede peridotite body is roughly on strike with the Polaris complex (Fig. 1) and is the same type of ultramafic body. It is about 3 miles in diameter and consists of coarse dunite and peridotite with olivine clinopyroxenite and feldspathic hornblende clinopyroxenite around the east and north sides. It is emplaced in Takla volcanics and is bordered by a narrow contact aureole of amphibolite.

The Tutizzi Lake pyroxenite (Fig. body C) appears to be a tabular body, 3-1/2 miles long and 1,000 -1,500 feet thick. It consists mainly of altered olivine clinopyroxenite and hornblende clinopyroxenite with some magnetite clinopyroxenite and gabbro. It is emplaced in Takla augite porphyry, to which it bears considerable similarity, and is intruded by several small bodies of syenite. At its western end it is truncated and severely metamorphosed by the Hogem granitic batholith and is cut by numerous quartz veins. Ultramafic body D in Figure 1 is similarly composed of olivine clinopyroxene.

A small ultramafic body just south of Kliyul Creek, denoted E in Figure 1 is composed of dunite, peridotite and minor olivine clinopyroxenite that are identical to rocks in the Polaris complex. The body is situated on the crest of a ridge above what appear to be amphibolitized Takla volcanics. Body F in Figure 1, situated just north of Kliyul Creek, consists of clinopyroxenite where it was seen by the writer. Body G, which is east of Croydon Creek, is mostly fine- to medium-grained

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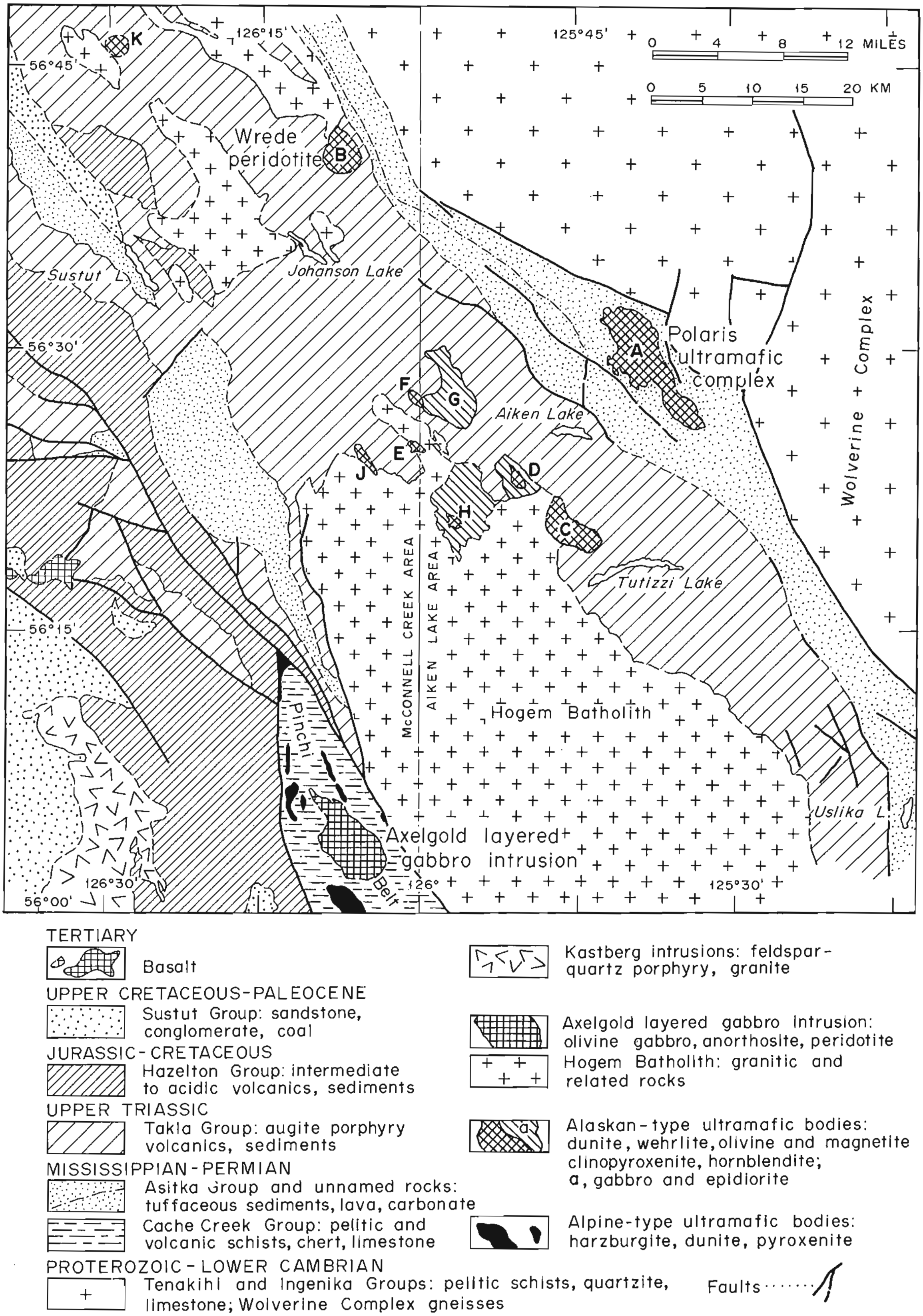

Figure 1. Geology of parts of the McConnell Creek and Aiken Lake areas showing the locations of the ultramafic and gabbroic rocks examined in this work. Geology generalized and slightly modified from Lord (1948) and Roots (1954).

epidiorite. It intrudes Takla augite porphyry and is cut on the east by a small syenite intrusion. The only rock-type seen in body H, located on the headwaters of Abraham Creek, was highly metamorphosed gabbro. The writer has not had opportunity to examine bodies J and K. J was described by Lord (1948) as peridotite. K is a newly discovered body reported by mining companies to be magnetite pyroxenite. It underlies the strongest aeromagnetic anomaly in the McConnell Creek area (G.S.C. Maps 5266G-5273G).

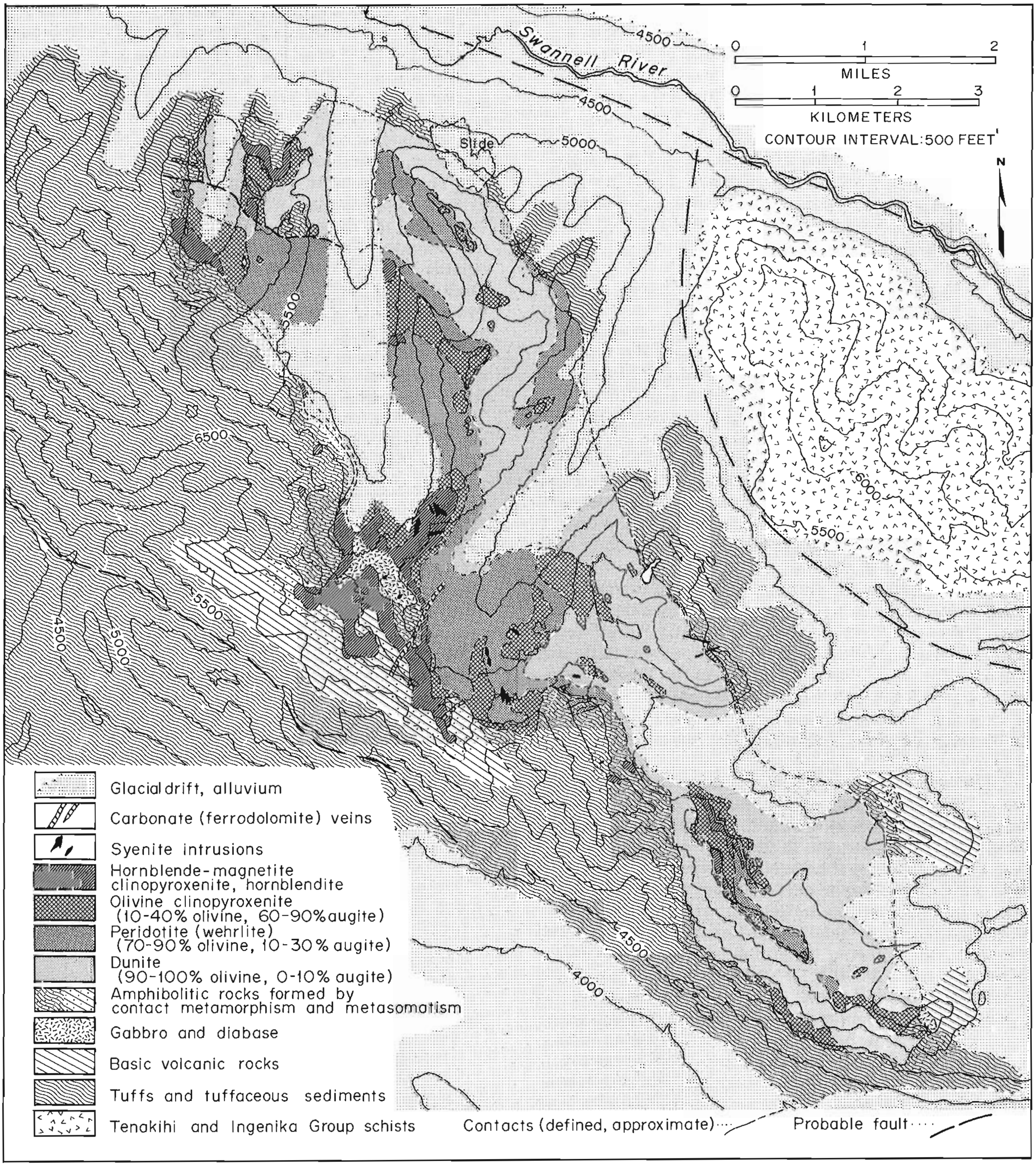

Figure 2. Geology of the Polaris ultramafic complex.

A main point to be made from these observations is that the described ultramafic bodies are a petrographically consanguinous group, younger than and distinctly different from the alpine-type peridotite that forms the so-called "Trembleur intrusions" in the Pinchi Belt of Permian oceanic crust that extends southward from the McConnell Creek area to Fort St. James and beyond. In early mapping, the Polaris complex was classed as a Trembleur intrusion, and the other bodies in the Aiken Lake area were grouped with the Hogem batholith. However, from present knowledge, it seems more likely that they are all in some way related to the Takla volcanics. One possibility is that they represent high-temperature differentiates of Takla magma that were fractionated in subvolcanic intrusions. As such they would be expected to mark the general location of volcanic centres, information that may be of interest in mineral exploration work.

Axelgold Layered Gabbro Intrusion

This intrusion is a tear-shaped, north-trending body, about 7-1/2 miles long and 3 miles wide, exhibiting prominent layering closely resembling bedding in sediments. It is emplaced in a complex assemblage of pelitic schist, ribbon chert, limestone, amphibolitic metavolcanics, and alpine-type peridotite in the northern tip of the Pinchi Belt (Fig. 1). Its age is unknown, but it is exceptionally fresh and almost undeformed and is clearly much younger than its Permian host rocks. A K-Ar age is currently being determined at the Geological Survey on a sample of biotite from the body submitted by J. W. H. Monger.

The contacts of the intrusion are steep to vertical everywhere they are exposed, and the layering has a basin form structure, dipping inward at 30^{o} - 60^{o} from the perimeter on the east, north and west and flattening to the south. The visible thickness of the layered series is 4, 000-5, 000 feet, but its base does not appear to be exposed, and the top has been removed by erosion, so the total original thickness may have been much greater.

The main rock type in the intrusion is olivine gabbro, a cumulate of plagioclase, clinopyroxene and olivine. Prominent peridotitic and anorthositic units, 10-40 feet thick, are common to the lower part of the layered series and thin anorthositic layers occur sporadically through the upper part. Almost the whole intrusion is layered, but the individual stratification units pinch and fade over relatively short distances. Viewed from afar, the layering is defined by strata a few feet to 10 or 20 feet thick that in places exhibit vague cyclic repetition. Close at hand, it is distinguished mainly by a discontinuous lamination of olivine and clinopyroxene in plagioclase. A few layers are well graded from olivine-rich at the base to plagioclase-rich at the top; many outcrops show faint crossbedding and some show winnowing structures, indicating that the layering was produced by sedimentation from magmatic currents.

At the south end of the intrusion there is a 3-square-mile area of biotite-rich dioritic rock that was combined with the gabbro on G. S. C. Map 966A and described by Payne (1970) as part of the intrusion. The writer's impression, however, is that this is a distinctly older, metamorphosed rock belonging to the Pinchi Belt.

The country rocks adjoining the intrusion are generally hornfelsed through an aureole 300-500 feet wide, and those within 50-100 feet of the contact are commonly rusty due to slight enrichment in sulphides. Some of the same rock types can also be seen as xenoliths within the intrusion, generally as blocks 20-200 feet on a side resting in the more steeply dipping parts of the layered series. Several prominent examples consist of marble with small skarn zones of diopside, tremolite, hornblende and epidote.

The intrusion is cut by many dykes of dark, fine-grained gabbro, some with phenocrysts of plagioclase. In general the dykes are 6 inches to 2 feet wide, trend north-south, and dip steeply. They were not found outside the intrusion and so would appear to be genetically related to it. The intrusion is also cut by a dyke-like body of grey rhyolite, about 10 feet wide and 300 feet long, and by two syenite intrusions. One of the syenite bodies is a steep, bottle-shaped pipe about 40 feet in diameter; the other is a dyke, 2-3 feet wide, extending for 500 feet.

Sulphide minerals are lightly disseminated throughout the intrusion, and slight concentrations occur locally in the layered series and contact aureole. Small amounts of chromite were seen in the peridotitic layers and several podiform segregations of ilmenite, one extending over an area 20 feet by 30 feet, were found in gabbro. There are signs that the area has been extensively prospected, but no claims were seen.

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59. PENRHYN GROUP METAMORPHIC COMPLEX, MELVILLE PENINSULA, DISTRICT OF FRANKLIN

Project 710053

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During the field season, about two and one-half months were spent in the Penrhyn Group metasediments and the underlying basement granodiorite and granitic gneisses (Heywood, 1967). The work was concentrated along the boundary between NTS map-sheets 46 N and 46 K, with some work in the southwest corner of 46 O, P. A metamorphic age of about 1750 m.y. is indicated by a Rb/Sr isochron on Penrhyn metasediments and on a hornblende (K/Ar) from basement granodiorite gneiss. A $^{207}Pb/^{206}Pb$ age from granodiorite gneiss is about 2600 m.y., indicating an Archean age for the gneisses that are basement to the Penrhyn Group.

Metamorphic rocks of the Penrhyn Group consist of a well-differentiated, well-bedded sequence ranging from orthoquartzite, marble, and calcium silicate gneiss to schist, paragneiss, and impure quartzite. In spite of a high grade of metamorphism throughout the area examined, as well as evidence for three episodes of folding, a rude structural-lithological sequence can be recognized. The granodiorite-granite gneiss of the basement is in many places followed by a thin white orthoquartzite unit 35 metres or less in thickness. This is followed by a thin schist and then by a coarse-grained calcite marble. This is in turn followed by a biotite-quartz-feldspar paragneiss and schist with some feldspathic grey quartzite. This unit is commonly characterized by small, white, quartzofeldspathic segregations arranged parallel to the compositional layering and the foliation defined by micaceous minerals. The succeeding unit is characterized by calcium-silicate gneiss with minor marble, some schist and some biotite-quartz-plagioclase paragneiss. This unit is again followed by biotite-quartz-plagioclase paragneiss, schist and grey feldspathic quartzite. Although the 'stratigraphic' relations are not so far known, a few thin beds of magnetite iron-formation associated with a grey fine-grained biotite-feldspar quartzite and amphibolite layers has been found at scattered intervals, striking diagonally across map-sheet 46 N-3 from the northeast to the southwest corner.

Particularly within map-sheets 46 N-1 and 46 N-2 are rusty graphitic schists and sheared quartzofeldspathic rocks. Brilliant colours of hematitic red or limonitic yellow characterize these gossan-like horizons. Locally they are characterized by massive pyrite and rarely may contain a little chalcopyrite. They occur at various stratigraphic horizons commonly not far from basement gneiss or granitic contacts.

Pelitic gneisses commonly contain the assemblages biotite-garnet-cordierite-quartz-sillimanite and biotite-garnet-sillimanite-potassium feldspar, as well as biotite-quartz-feldspar. Assemblages in marble and calcium-silicate gneisses consist of calcite-diopside-graphite, calcite-serpentine-diopside, calcite-quartz-diopside, calcite-humite group-spinel-graphite, diopside-quartz-scapolite-calcite, diopside-forsterite-calcite. Thus the level of metamorphism throughout the area examined lies in the uppermost amphibolite facies.

An east-northeast-trending structural culmination centred within map-sheets 46 N-1 and N-2 has resulted from the interfolding of basement and cover rocks. The folding is characterized by broad doubly plunging anticlinal zones of basement gneiss with narrow, tight, synclinal infolds of cover metasediments. This extensive deformation of basement and cover rocks is attributed to a second phase of folding, and evidence for extensive diapiric movement of basement gneiss into cover rocks has not been found.

An earlier phase of folding is attested in part by abrupt terminations of metasedimentary units within the succession with no evidence of faulting, and in part from refolding of layers (thrust slices?) of basement gneiss within the metasediments by second phase folds. On the other hand, a third phase of folding is evident and is best developed in areas peripheral to the 'domal' culminations. They are well developed in map-sheet 46 O-4 to the east of the culmination and there have a northeast trend. They are similarly well-developed northwest of the culmination in 46 N-3 and are here trending northwestward where they result in preservation of metasediments with northeast-trending second-phase folds in northwest-trending synformal depressions and in exposure of basement gneiss in antiformal culminations.

Granite and granite pegmatite are found not only in regions dominated by basement gneiss, but throughout areas of metasediments as well. Granitoid bodies are in places structurally controlled and occur in sheets parallel with dominant compositional layering or in axial zones of large second-phase folds. It is not uncommon for such granitoid units to be concentrated in zones of great structural complexity. Pegmatites are commonly boudinaged and in places foliated. Thus the emplacement of these granitoid rocks was closely associated with the second phase of folding.

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60. VOLCANIC STUDIES IN THE CAPE SMITH-WAKEHAM BAY BELT, NEW QUEBEC

Project 730038

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Two sections across the Cape Smith—Wakeham Bay Belt were mapped and sampled in detail and a third section was partly completed. The locations of the sections are shown in Figure 1. The geology of the belt to date is known largely from a series of reports by the Quebec Department of Natural Resources (Bergeron, 1957, 1959; Beall, 1959, 1960; DeMontigny, 1959; Gelinas, 1962; and Gold, 1962) which covered chiefly the central part of the belt. The entire belt and the region to the north forming the crown of the Ungava Peninsula were mapped during the current season by F. C. Taylor of the Geological Survey (this report).

The Cape Smith—Wakeham Bay Belt forms part of the Circum-Ungava geosyncline of Aphebian age. It is composed in large measure of mafic volcanic rocks intruded by numerous mafic and ultramafic sills. Along the southern border of the belt a thin strip of sediments rests unconformably on gneisses of the Archean basement. The northern boundary is less well defined. A major east-west fault marks the northern limit of rocks

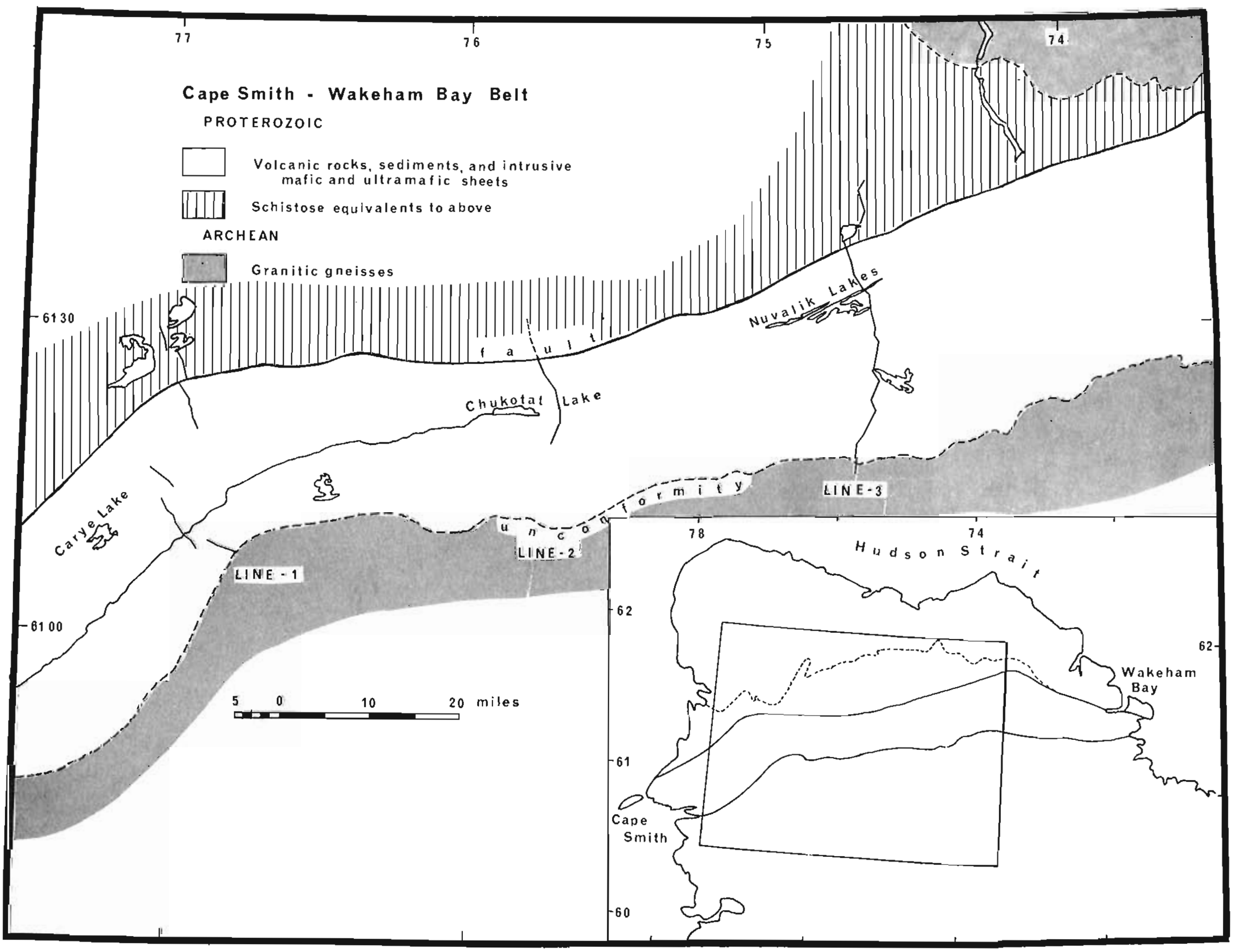

Figure 1. Sketch map of the Cape Smith—Wakeham Bay Belt showing the location of the section lines mapped. The outlines of the geology are from Bergeron (1957).

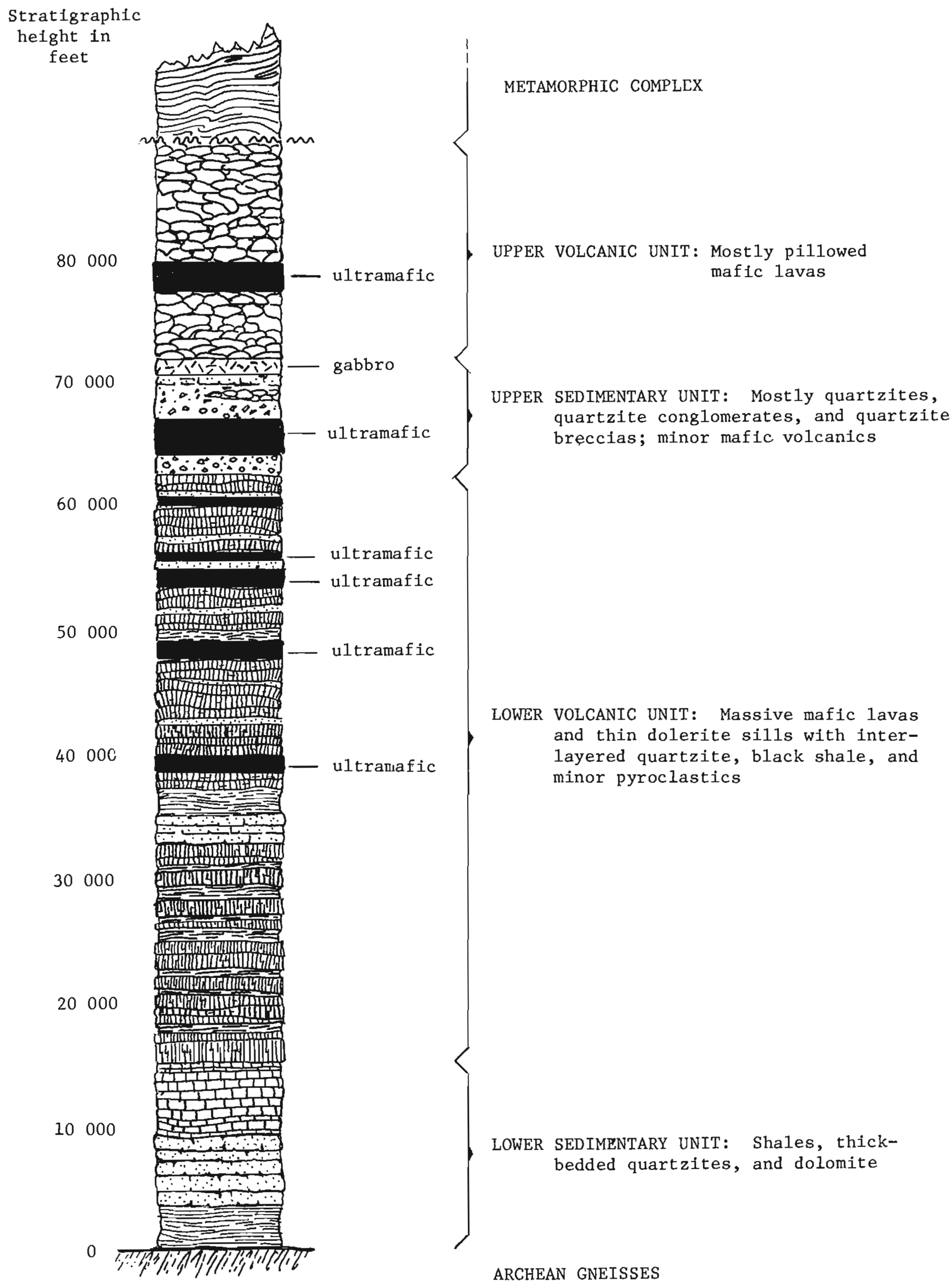

Figure 2. Simplified geological column of section line 3.

of relatively low metamorphic grade; beyond this fault schistose rocks of equivalent age continue northward into gneisses of uncertain derivation.

Lines 1 and 3 cross the low-grade segment of the belt and extend into the schists to the north of it. Line 2, which was not completed owing to the shortness of the season, spans only the northern part of the low-grade zone. The lines were run by chain and compass and elevations determined at 300-foot-intervals by aneroid barometer. The geology was mapped on the resulting profiles at a scale of 400 feet - 1 inch. Chip samples of volcanic and subvolcanic rocks were taken at stratigraphic intervals of about 500 or 600 feet. In the metamorphic terrane north of the fault where stratigraphic control is lacking samples were taken less regularly. All samples will be analyzed for 13 major and 15 minor elements.

Figure 2 is a simplified stratigraphic section of line 3. The major stratigraphic divisions of this section can also be recognized in modified form in line 1 and as far as it goes, in line 2. Broadly speaking they are: 1) a lower sedimentary unit of quartzites, dolomites, and shales that rests unconformably on Archean gneisses; 2) a lower volcanic unit comprising massive volcanic flows with interbedded shales and quartzites invaded in part by a profusion of thin (10 to 50 feet) dolerite sills; 3) an upper sedimentary unit composed of quartzites, quartzite breccias and conglomerates and/or shales and minor volcanic breccia and pillow lava; and 4) an upper volcanic unit consisting chiefly of pillowed mafic lavas.

Although represented in Figure 2 as a stratigraphic column about 90,000 feet thick it is unlikely that the units were ever completely superimposed. Rather, the succeeding units probably represent facies changes from south to north or from landward to seaward in a geoclinal basin. On the landward side are shelf deposits of sediments which become increasingly mixed seaward with shallow-water, massive mafic flows and high-level sills. At the edge of the shelf steep inclines and frequent volcanic disturbances may have been responsible for the formation of the breccias and conglomerates contained in the upper sedimentary unit. Finally, pillowed lavas of the upper volcanic unit may be attributed to extrusion in deep waters beyond the marginal shelf. In support of this view it may be noted that massive lavas of the lower volcanic unit are commonly amygdaloidal whereas pillow lavas of the upper unit are essentially devoid of amygdules.

This interpretation differs somewhat from that of Bergeron (1959) and Beall (1959, 1960). They divided the succession into a lower unit of massive flows and sediments (Povungnituk Group) and an unconformably overlying unit of pillow lavas (Chukotat Group). The conglomerate-breccia formation was interpreted as the basal conglomerate of the upper unit.

Metamorphosed rocks north of the major fault include mafic schists and metasediments which might reasonably be interpreted as the metamorphosed equivalents of the rocks to the south. In addition coarsely fragmental rocks consisting of felsite porphyry fragments in a more mafic groundmass outcrop for several miles north of the fault along line 1. This is particularly notable in that acidic rocks are rarely observed elsewhere in Circum-Ungava geosyncline and have been assumed to be essentially absent (Dimroth et al., 1970). Extending the previous interpretation to include these acidic rocks one might postulate that they are part of an island-arc assemblage fringing a deep inter-arc basin.

Leopard rock, which is a characteristic intrusion of the Labrador Trough but not reported elsewhere in the Circum-Ungava geosyncline, was found within the pillowed assemblage in the northern part of line 1 where it occurs as a sill at least 300 feet thick.

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PARAGNEISSES OF THE PRINCE ALBERT GROUP

Project 720054

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The rocks of the Prince Albert Group are lithologically subdivided into two sequences:

Greywacke sequence
1) Greywacke - (quartz-plagioclase-biotite/amphibole-magnetite gneiss)
2) Iron-formation - (magnetite-quartz-garnet gneiss)
3) Meta-ultrabasics - (serpentine-talc-magnetite gneiss)

Quartzite sequence
1) Quartzite - (quartz-muscovite/phlogopite/fuchsite gneiss)
2) Knotted Quartzite - (quartzite with sillimanite porphyroblasts)
3) Greywacke (minor) - (quartz-plagioclase-biotite/amphibole-magnetite gneiss)

The quartzite appears to structurally overlie the greywacke sequence, but as no top determinations were possible, it is uncertain which is younger. The base of the greywacke sequence is indefinite, but a conglomerate which is very close to gneissic granodiorite may define the base of the Prince Albert Group. This conglomerate is recognized at only one locality, and thus the evidence is extremely tenuous. Due to the effects of repeated folding of the group, the true thickness is unknown.

The iron-formation in the greywacke sequence occurs at a number of structural/stratigraphic positions but it is uncertain whether or not they are repeated by folding. The increased number of thin iron-formations in the east suggests a primary origin. The thickest iron-formation occurs in the western part of the area, where one unit is approximately 120 m thick; the normal thickness is less than 6 m.

There appear to be two iron-formation associations; the first invariably occurs associated with the meta-ultrabasic rocks, and the second only with metasediments. The association with the ultrabasic rock is interpreted as a primary rheological control, as there is scant evidence to indicate that the ultrabasics are extrusive.

In both the eastern and western parts of the area an iron-formation is either in contact with, or very

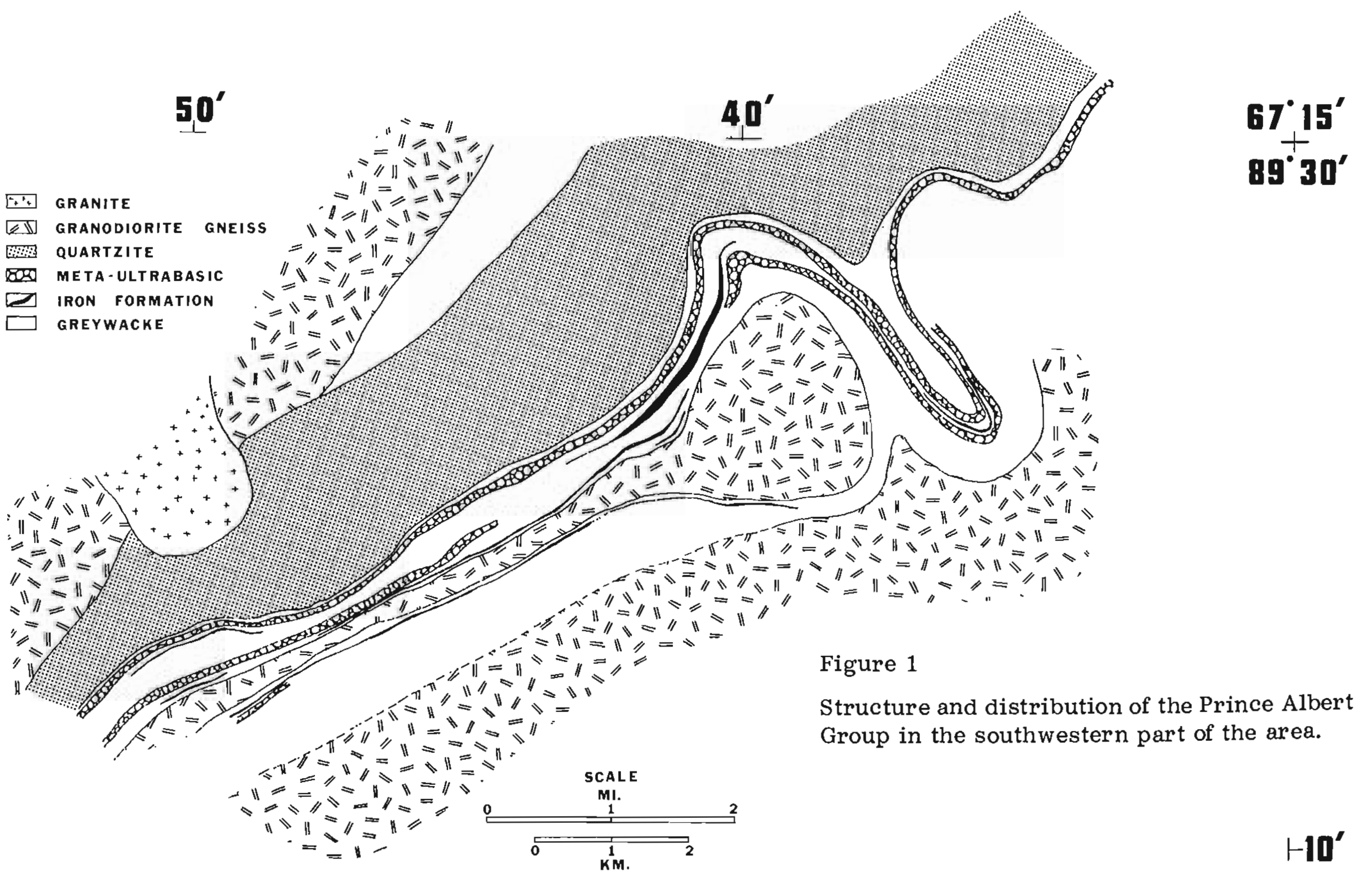

Figure 1

Structure and distribution of the Prince Albert Group in the southwestern part of the area.

close to, granodiorite gneiss. In the east, iron-formation is underlain (?) by a pebble conglomerate. The conglomerate contains much flattened and stretched clasts of quartz and possible gneissic granodiorite. It is adjacent to, but not in contact with, a gneissic granodiorite, which may be remobilized basement, as it appears to be intrusive elsewhere in the vicinity.

Meta-ultrabasic rocks occur as continuous sills up to 70 m thick throughout the western and central parts of the Prince Albert Group. They do not occur in the eastern part of the area. They display all phases of deformation recognized in the metasediments, and locally contain inclusions of quartzite and iron-formation. Possible spinifex texture was noted at two localities. An ultrabasic pseudo-breccia is exposed for approximately 4 km in the western part of the area, and is interpreted as blocks of a slightly older sill incorporated in a younger sill. The composition of the "matrix" is sufficiently different from the blocks to produce a breccia-like appearance. Locally, thin veinlets of magnetite are a common alteration product, and fibrous, stiff, asbestiform amphibole up to 30 cm was noted at one location.

Meta-ultrabasic rocks also occur well outside the main "belt" of Prince Albert Group rocks. Where they are associated with metagreywacke, the rocks are identical to those in the group, except that the iron-formation is sulphide, rather than magnetite variety, and that there is minor greenstone. Elsewhere, the meta-ultrabasic rocks are completely surrounded by well-foliated granodioritic gneiss. The meta-ultrabasics trend north-south, and appear to strike into the main sequence of Prince Albert Group rocks. However, the two are separated by faults, and relations are thus unclear.

The lack of any appreciable amount of quartzite in the eastern part of the area is interpreted as a combination of deformation and facies change. The quartzite sequence is folded between two large masses of granodioritic gneiss, and may completely surround the westernmost of the two bodies. The increased number of thin iron-formations in the eastern part of the area suggests a facies change - from quartzite/greywacke in the west to greywacke in the east.

The Prince Albert Group has been affected by at least three phases of deformation. As no top determinations are possible, the form of the resulting fold pattern is unknown. The first recognizable period of folding is represented by tight, overturned, isoclinal folds which plunge shallowly to the southwest, and in some cases, to the southeast. An axial plane foliation is commonly associated with this event, and is defined as the S_2 foliation. However, the S_1 and the S_2 foliations can be distinguished only in the fold noses, and the form of the folds which produced the earliest (S_1) foliation is unknown. The second period of folding produced the tight major and minor, isoclinal, upright to overturned, northwesterly trending folds. On a minor scale these are best displayed in the iron-formation; on a major scale, they are well developed in the western part of the area around a granodiorite gneiss core (see Fig. 1). There is no recognizable planar fabric associated with this phase of folding. A fourth period of folding is inferred from the attitude of the minor folds in the fold nose shown in Figure 1. There, the minor kink folds have divergent plunges, at steep angles, as though the fold was refolded about a northeast-trending axis.

Isolated paragneiss remnants, surrounded by magnetiferous granodioritic gneiss, together with the gradational contacts between the Prince Albert Group rocks and the granodioritic gneiss, suggest that the gneiss has in part been derived from the Prince Albert Group. In the eastern part of the area, the Prince Albert Group rocks are nearly horizontal, and outcrop at the tops of the hills. They are both under- and overlain by sills of granodioritic gneiss. These sills become much thinner in the main part of the belt, where the only intrusive rocks are the ubiquitous pegmatites and younger diabase dykes.

62. WATTERSON LAKE (65G, WEST HALF) AND FERGUSON LAKE (65I, WEST HALF) MAP-AREAS, DISTRICT OF KEEWATIN

Project 680085

K.E. Eade and F.W. Chandler
Regional and Economic Geology Division

The continuation of this project, a study of the stratigraphic and structural relations of the Precambrian rocks in the southern District of Keewatin, is intended to enhance the knowledge of the Precambrian geology and to assess the mineral potential of areas previously mapped on a scale of 1 inch to 8 miles (Wright, 1967). The mapping, for publication on a scale of 1: 250, 000, combined helicopter and ground traversing.

Ferguson Lake map-area

West and north of Imikula Lake, in the south-central part of the map-area, Aphebian Hurwitz Group rocks consist for the most part of impure quartzite to subgreywacke or quartz-mica schist probably correlative with the uppermost unit of the Hurwitz Group in the area to the south (Eade, 1964). Dolomite, phyllite, and orthoquartzite of the Hurwitz Group occur in only a few places, close to Imikula Lake.

The southeast part of the map-area consists of a mixed assemblage of granodiorite gneiss and paragneiss, probably of Archean age, in part migmatized and partially assimilated by quartz monzonite of probable Aphebian age.

Metavolcanic rocks, ranging in composition from basalt to rhyolite are present in a northeastward-trending band approximately four miles wide in the southern part of the map-area intersecting the south end of Yathkyed Lake. Cherty-magnetite iron-formation and chert-pyrite beds are associated with the metavolcanic rocks. To the south of the southwest corner of Tyrrell Arm of Yathkyed Lake, close to the southeast boundary of the metavolcanic rocks, chert-pyrite beds with total thickness ranging from 50 to 80 feet have been traced over a strike length of four miles. Metabasalts occurring on islands in the northern part of Yathkyed Lake are part of a separate band of metavolcanic rocks.

To the northwest of the main metavolcanic band are northeast-trending quartz-feldspar-biotite paragneiss to migmatite, in part garnetiferous, with some accompanying bands of amphibolite. Numerous small zones of pyrite and pyrrhotite mineralization occur in the amphibolite bands. A small pluton of adamellite intrudes these rocks near the east boundary of the map-area.

An east-west fault at 62°45'N is the north boundary of the paragneiss and migmatite bands. To the north of this fault the major rock type is hornblende-biotite gneiss ranging in composition from granodiorite to quartz diorite and trending east to northeast. Within the gneiss are some amphibolite bands, derived at least in part from metavolcanic rocks. Metagabbro dykes and sills intrude the gneisses.

These gneisses are bounded on the north by another east-trending fault at approximately 62°52'N latitude. North of this fault and extending to the north boundary of the map-area is a mixed assemblage of gneisses of granodiorite to quartz diorite composition, with some amphibolite, cut by a diorite to quartz diorite pluton and some small plutons of syenite to monzonite composition. The syenite and monzonite are probably equivalent to the Martel syenite occurring in the map-area to the east (Bell, 1971).

Watterson Lake map-area

Hurwitz Group rocks are restricted to the southern half of the map-area, in a north-south elongated basin, centred on Watterson Lake and in a north-south striking belt in the extreme southwest. The stratigraphy in the basin, in ascending order is as follows: (a) greywacke paraconglomerate of very restricted distribution; (b) white orthoquartzite; (c) phyllite and paper slate, intruded by a metagabbro sill; (d) cream weathering dolomite; (e) shale, slate, phyllite, siltstone; (f) rusty weathering dolomite; (g) fine-grained, cleaved greywacke; (h) light grey arenite. The axial plane of the basin dips westward and lower units are partly faulted out on the west side of the basin.

The southwestern belt of Hurwitz Group rocks is bounded on the west and north by faults and continues southward out of the map-area (Eade, 1973). Units (a) to (c) above are recognizable but the upper part of the section is represented by undivided biotite schist, biotite metasandstone, hornblende-bearing calc-silicate rock and minor magnetite iron-formation.

Sedimentary rocks of probable Aphebian age, occurring near Bate Lake in the eastern part of the map-area, consist of dolomite and phyllite overlying arkose to subgreywacke. The dolomite and phyllite are contiguous with that mapped in the area to the east (Eade, 1966) but the arkose to subgreywacke was not found there. A similar succession, arkose to subgreywacke, dolomite and phyllite, and their metamorphosed equivalents, occurs to the south, about six miles north of Watterson Lake. There, they are close to the Hurwitz Group rocks but the stratigraphic relations are unknown.

A band of basic metavolcanic rocks, five miles northeast of Watterson Lake is a continuation of those rocks from north of Griffin Lake in the map-area to the east (Eade, 1966). On the north side of the band in this map-area, a zone of ultrabasic composition, with spinifex texture was recognized. These rocks have some associated pyrite and pyrrhotite mineralization.

The metavolcanic band south of Sutcliff Lake, on the reconnaissance map (Wright, 1967), which extends to the east north of Bate Lake (Eade, 1966) continues to the west and northwest as a band 1½ to 2 miles wide. It passes three miles north of Boland Lake and then swings to the northwest and north, crossing the north boundary of the map-area at longitude 99°45'W. The rocks range in composition from metabasalt to rhyolite but there are more rocks of acid to intermediate composition in this band than are found in the other volcanic bands of these map-areas. Small occurrences of pyrite and pyrrhotite mineralization are abundant in these rocks.

In the north part of the map-area, around longitude 99°15'W, lies a northeast-trending band of metagreywacke of probable Archean age. To the east, the greywacke passes gradationally into paragneiss but on the west it is intruded by a north-trending body of fresh anorthosite approximately 1½ miles wide. To the west of the anorthosite, occurs paragneiss with some amphibolite bands.

The north-central part of the map-area, east of Boland and Hicks lakes consists of biotite granodiorite gneiss and quartz-plagioclase-biotite paragneiss intruded by plutons of quartz monzonite to granite. These plutons are, in part at least, of Aphebian age.

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63. GEOLOGICAL STUDIES IN THE PRINCE ALBERT HILLS, WESTERN MELVILLE PENINSULA, DISTRICT OF FRANKLIN

Project 720070

Thomas Frisch
Regional and Economic Geology Division

Investigations were confined almost entirely to the Prince Albert Hills between Mackar Inlet and Erlandson Bay. This 800-km^2 area includes excellent exposures of a wide variety of Precambrian rocks of at least four ages, including the Prince Albert Group metavolcanics (Heywood, 1967).

Granitoid and associated metabasic rocks

The following mappable units were distinguished:

1. Generally poorly foliated, grey-weathering quartz monzonitic to granodioritic rocks with numerous amphibolite dykes. The granitoid rock varies from diorite to leucoquartz monzonite but most commonly has a colour index of ~30. The amphibolite dykes are dark green to black, unfoliated, generally discordant to the foliation of the host rock, commonly sheared along their margins, and trend southwesterly. Some of the dykes show such relict igneous features as fine-grained borders and ophitic centres. In places, the dykes are veined by the granitoid host rock - the "Sederholm effect" (Mehnert, 1968, p. 311) - and may even be severely fragmented. However, most dykes are traceable for several kilometres and one can be followed for at least eleven, cutting both granitoid and Prince Albert group rocks.

2. Granitoid rock similar to (1) with abundant lenses, blocks and small fragments of amphibolite, metasediments and (?) metavolcanics. This unit outcrops in part adjacent to the Prince Albert Group and, as many of the inclusions resemble rocks found in the latter, may represent disrupted and intruded Prince Albert Group.

3. Well-foliated granitic gneiss with interlayered amphibolite. This unit is not abundant in the area studied.

4. Pink, medium- to coarse-grained biotite-quartz monzonite. A major unit in the area, this rock in places is clearly intrusive and then postdates all other granitoid rocks; elsewhere it appears to grade into them.

The remaining granitoid rocks, including gneisses, augen gneisses, migmatites, unfoliated rocks and associated amphibolites, have not been differentiated.

5. Metabasic rocks. These include concordant masses, up to 2 square kilometres in size, ranging from hornblendite through metagabbro to metadiorite, which are veined by granitoid gneiss and by the quartz monzonite (4). Zonation and layering in some of these bodies suggest they are of igneous origin. Sulphides are commonly disseminated in them.

Prince Albert Group

In work on this unit, emphasis was laid on mapping the contact with surrounding rocks, tracing-out iron-formation, and outlining an area of acid metavolcanics discovered this summer.

Granitoid rocks in contact with the Prince Albert Group commonly appear to be intrusive. This applies as much to the gneisses as to the quartz monzonite. Without exception, the contact is concordant with the foliation in the granitoid rocks and no evidence of an original depositional contact was found. Ultramafic rocks, generally peridotites altered to talc-carbonate rocks, are particularly common at or near the contact.

Numerous extensions of previously known occurrences of magnetite- or hematite-quartz iron-formation were found in the Prince Albert Group.

A 6-square-kilometre area within the Prince Albert "Belt" was found to be underlain by metarhyolite and metarhyolite porphyry with quartz porphyroblasts. This is the first reported occurrence of significant volumes of acid volcanics in the Prince Albert Group.

Late Precambrian metasediments

These rocks constitute unit 16 of Heywood (1967) and cover a larger area than previously recognized. The basal rocks of this unit and their contact with older rocks are well exposed at a number of localities and were studied in detail.

The lowermost 20 to 50 m of this unit typically comprises the following succession (from bottom to top):

(i) Quartz- and granite-pebble conglomerate (pebbles are 1 to 5 cm long) with scattered magnetite crystals.

(ii) Green sericite schist with 1 to 2 mm euhedra of magnetite in some layers.

(iii) Purple-weathering, hematite-rich quartzite, locally with massive specularite and rarely minor magnetite. The thickness of this bed is generally ~2 m but reaches 4 m in places.

(iv) Dark-weathering sericite schists, commonly with quartz lenses, becoming increasingly calcareous upward.

(v) Tremolite-marble conglomerate with pebbles of jasper, marble, granitic rocks and quartz (pebbles are up to 60 cm long but most are ~2 cm) in a pale grey marble matrix rich in green tremolite.

(vi) Marble with scattered pebbles grading upwards into pebble-free marble. Both the marble and marble conglomerate vary considerably in thickness over short distances, probably as a result of deposition in restricted, shallow-water basins. Calcareous rocks in the succession increase in abundance to the southwest.

(vii) Calcareous quartzite becoming less calcareous upward.

(viii) Relatively pure, commonly crossbedded quartzite, which is by far the predominant rock of the entire unit. F.H.A. Campbell briefly examined this part of the section and reports: "Tabular crossbedding up to 1 m is best developed in the quartzites and shows a uniform bimodal transport direction from the east and northeast. Slump folds, common in calcareous quartzite, indicate the same direction of transport. Rare ripple marks, sand-filled scours, and well-crossbedded sheet sands are also present".

The above sequence rests with pronounced angular unconformity on steeply dipping granitoid and Prince Albert Group rocks. In general, the dip of the metasediments becomes gentler with distance from the contact. South of Folster Lake, a regolith, at least 10 m thick and consisting of granitoid boulders up to 2 m across and lenses of calcareous schist in a matrix of sericite schist, underlies the conglomerate (i).

The relative abundance of calcareous rocks and hematite and scarcity of magnetite in this unit contrasts markedly with the older rocks, where no primary carbonate was found and vast quantities of magnetite iron-formation exist (Wilson and Underhill, 1971).

Diabase dykes

In contrast to the amphibolite dykes described above, diabase dykes in the area weather brownish and trend northwesterly. They cut all but Paleozoic rocks.

Structural and age relationships

The Prince Albert Group and the granitoid rocks apparently intrusive into it are severely deformed into isoclinal folds plunging steeply southwest. The amphibolite dykes being much less deformed, their intrusion must have occurred later but prior to deposition of the late Precambrian sediments, as no metadykes nor granitoid rocks cut these rocks. It seems probable that the metamorphism which affected the latter also caused the amphibolitization of the dykes. The late Precambrian metasediments are thrown into open folds about northeast-trending axes.

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GEOLOGY OF THE INDIN LAKE AREA (86B) DISTRICT OF MACKENZIE

Project 720052

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Introduction

During the 1973 field season geologic mapping was carried out in the Grenville Lake and Cotterill—Snare Lakes area (Fig. 1). Structural studies at 3, 000 feet to the inch were conducted in the Chalco—Ranji Lake area and in the Arseno Lake (west-half) map-area. Several cross-sectional areas were mapped in detail to study contact relationships between rock units (for locations see Fig. 1). In addition, preliminary results of geochronological work on samples collected during the previous field season (Frith, 1973) by Rosaline Frith in the Isotopic Laboratory at McGill, under the supervision of Professor R. Doig are reported.

The Indin Lake map-area lies along the Bear—Slave Province boundary between latitudes 64° and 65°N and longitudes 114° and 116°W. In the Slave Province a north-south belt of supracrustal rocks belonging to the Yellowknife Supergroup occurs throughout the map-area. The preservation of abundant primary structures in the low-grade metamorphic central part of this belt, between Hewitt Lake and the eastern margin of Indin Lake, made it possible to unravel the structural history and fold geometry of this area. At present, the boundaries between the supracrustal rocks of the Yellowknife Supergroup and the adjacent granitic gneisses can be interpreted as faults, as along the eastern margin, or in the case of the western margin, as intrusive contacts along which the supracrustal rocks are separated from diapiric granitic intrusions by a migmatitic zone (Smith, 1966 a, b). The nature of the faulted boundaries was studied in some detail and much of the accumulated field evidence suggests that areas of granitic rocks occurring along parts of the eastern margin of the supracrustal belt may represent a pre-Yellowknife Supergroup basement. Gneiss domes occurring immediately to the west of the Bear—Slave boundary, in the Arseno Lake (west-half) map-area (Frith, 1973) are surrounded by metasedimentary rocks of the Aphebian Snare Group. Structural relationships in and around some of these domes were studied in detail.

Geochronology

The following six Rb-Sr whole rock age determinations are pertinent to the area covered in this report. At this stage of the investigation the age data must still be considered as preliminary and may be subject to revision. The disintegration constant used for Rb^{87} is $1.39 \times 10^{-11} y^{-1}$. Errors are expressed as one standard deviation. Locations 1-6 are shown on Figure 1.

(1) Arseno Lake (W½). Granitic core of gneiss dome; 2712 ± 89 m.y. with an initial ratio of 0.7014.

(2) Arseno Lake (W½). Alaskitic granite intruded into Snare metasediments; 1808 ± 43 m.y. with an initial ratio of 0.7142.

(3) Arseno Lake (W½). Porphyroblastic (porphyritic?) biotite granite intruded with frozen contacts into Snare metasediments, between 1335 and 2316 m.y. with initial ratios between 0.700 and 0.728.

(4) Mesa Lake (E½). Biotite granitic gneiss interstratified with hornblende gneiss forming a rock unit adjacent to Yellowknife metavolcanic rocks; 3002 ± 20 m.y. with an initial ratio of 0.6997.

(5) Grenville Lake (W½). Muscovite granite pegmatite with no apparent deformation fabric; 1935 ± 75 m.y. with an initial ratio of 0.7248.

(6) Strachan Lake (W½). Granodiorite cutting Yellowknife Supergroup rocks but with a N-S deformation fabric (S_2); 1928 ± 73 m.y. with an initial ratio of 0.7021.

Arseno Lake (W½)

In this area gneiss domes occur within Aphebian Snare Group sediments which in turn are sandwiched between two granitic bodies of higher relief, the Archean to the east and a Proterozoic (?) plutonic body of porphyritic (porphyroblastic?) granite of wide extent to the west (see also Lord, 1942, and Ross and McGlynn, 1965). More detailed mapping was carried out in order to determine the age and origin of the domes.

Field and age determination work outlined the following rock units:

(1) Gneisses forming the basement to the Snare Group metasediments consist mainly of medium-even-grained biotite gneiss of granodioritic (McGlynn and Ross, 1966) to granitic composition. Locally these gneisses are migmatized and cut by pegmatites.

(2) The mantling gneisses are metasedimentary rocks of the Snare Group which locally contain quartz-pebble conglomerates (basal and intraformational) sandstones, and dolomite, but for the most part consist of rusty weathering biotite gneiss.

(3) Alaskitic-pegmatitic granite of limited extent occurs within the Snare metasediments. Isotopic data suggests that the granites were formed *in situ* during the Hudsonian orogeny.

(4) Coarse-grained porphyritic (porphyroblastic?) granite, possibly a high level intrusion that shows frozen contacts with the Snare metasediments along the eastern margin.

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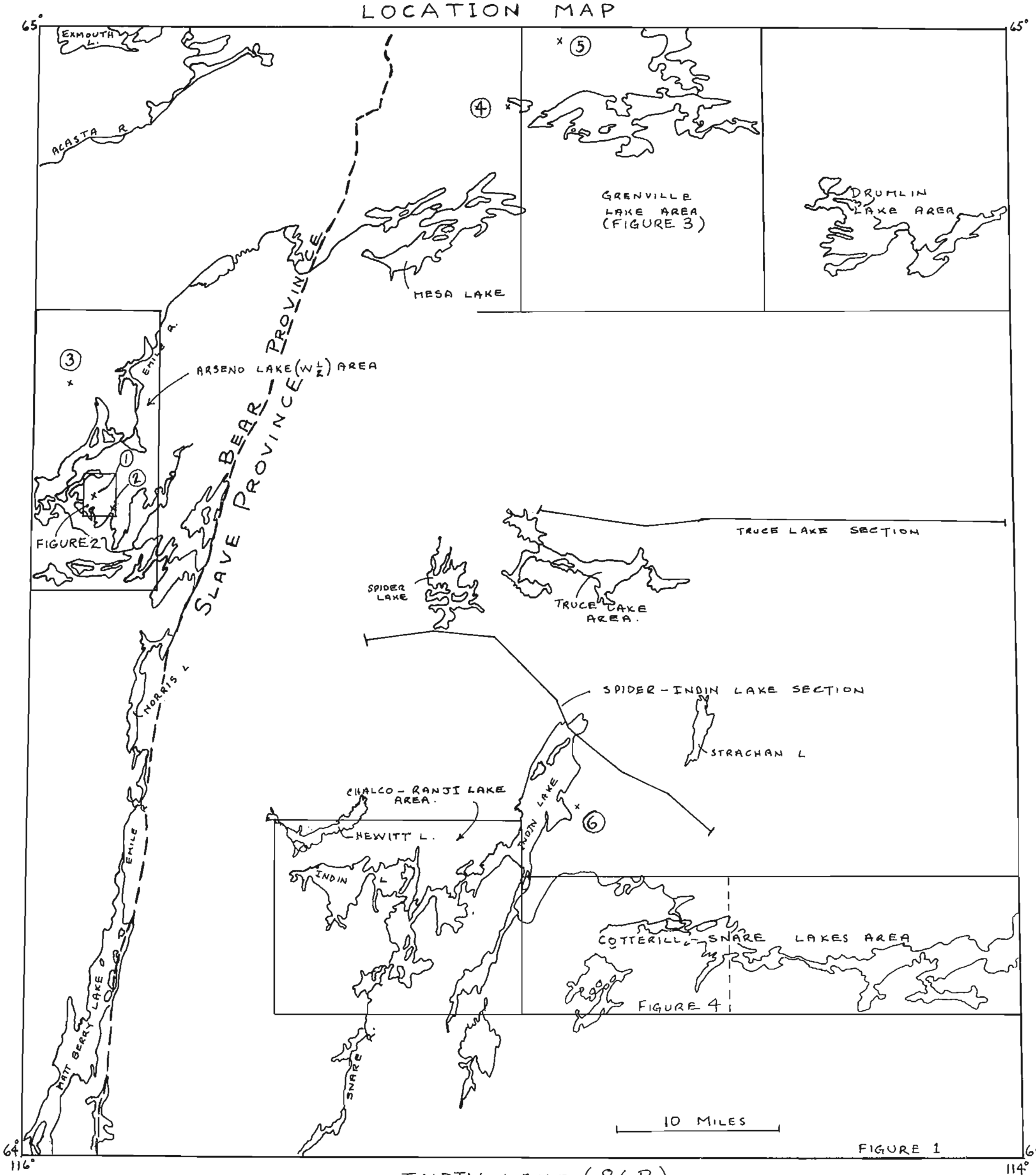
The core of the central dome (Fig. 2) is massive and was dated by a Rb-Sr whole rock isochron at 2712 m.y. The gneissosity of the mantling gneisses is generally concentric and increases in intensity and dip toward the margins. Close to the dome margin, hypabyssal granites of Aphebian age (1808 m.y.) occur in the surrounding gneisses, which contain sillimanite, garnet and cordierite.

Intraformational conglomerate marker beds can be used to outline the macroscopic geometry around the gneiss domes fold. Their distribution is controlled by the higher topographic level of the dome areas.

Two major folding phases can be distinguished: phase 1 caused isoclinal folds which are in part recumbent. Phase 2 folds are tight to open and have north-south trending axial planes. Phase 1 folds are present

LOCATION MAP



INDIN LAKE (86B)

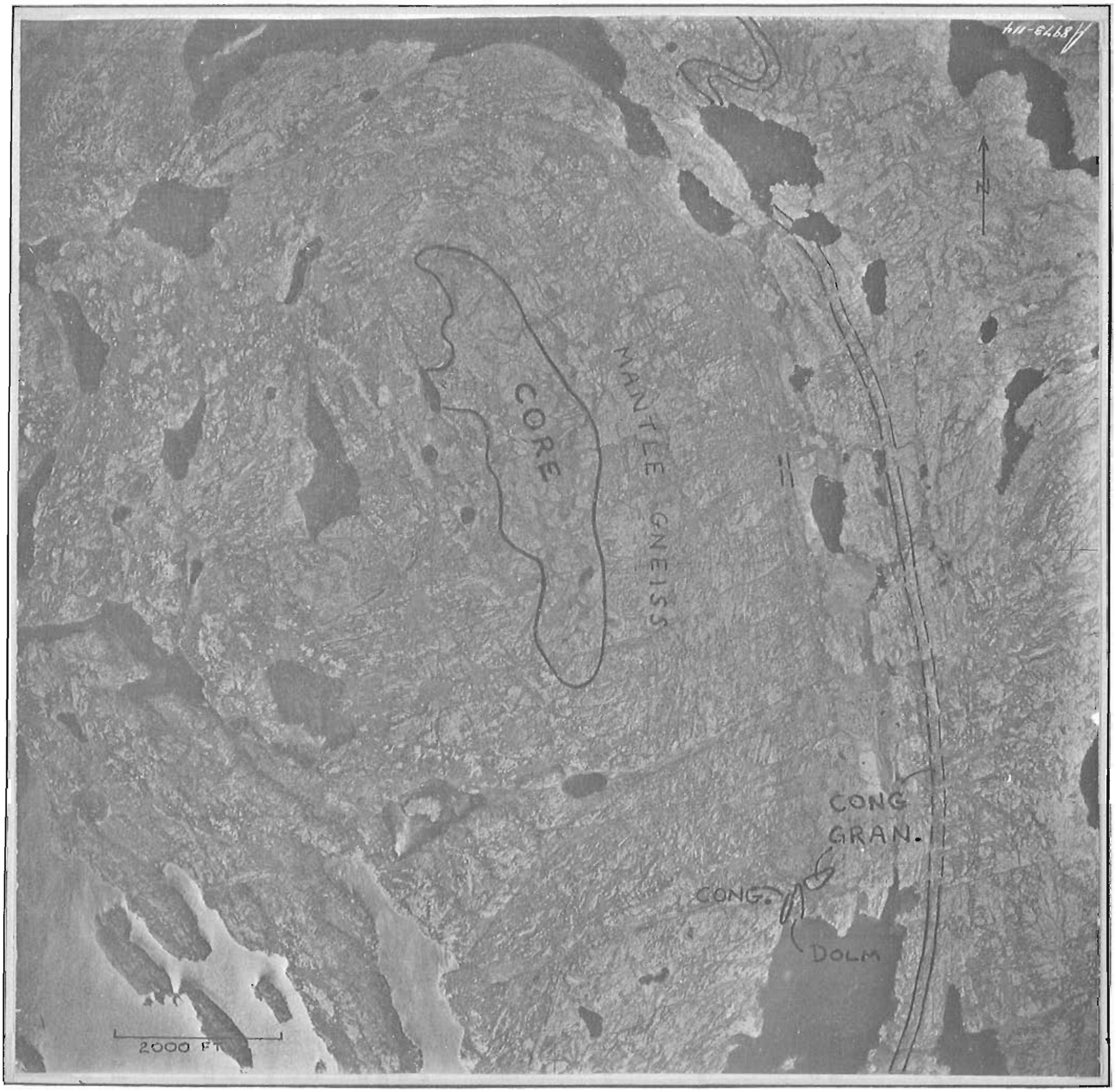


Figure 2. The central gneiss dome showing the core, mantling gneisses, basal conglomerate and dolomite along with interlayered biotite granite. An intraformational conglomerate horizon runs north-south along the eastern margin. (EMR Photo 8973-114.)

throughout the area, whereas phase 2 folds are poorly developed in the southern part of the Arseno Lake map-area. They are quite strongly developed in the central dome areas and are also present south of the Arseno Lake map-area in the Castor Lake area.

Three hypotheses were entertained in explaining the gneiss dome area: (1) ancient topographic highs (2) superposed fold structures and (3) mobilization and gravitational emplacement into the overlying meta-sedimentary rocks. Further work is in progress to determine whether the deformation within the cores and the mantling gneisses is compatible with a vertical gravitational rise of the domes.

The Grenville Lake Area

During the 1972 field season, rocks in the north-west corner of the Grenville Lake map-area were found to be remarkably similar to biotite-plagioclase-gneisses from the Grenville Province, Quebec, which were dated

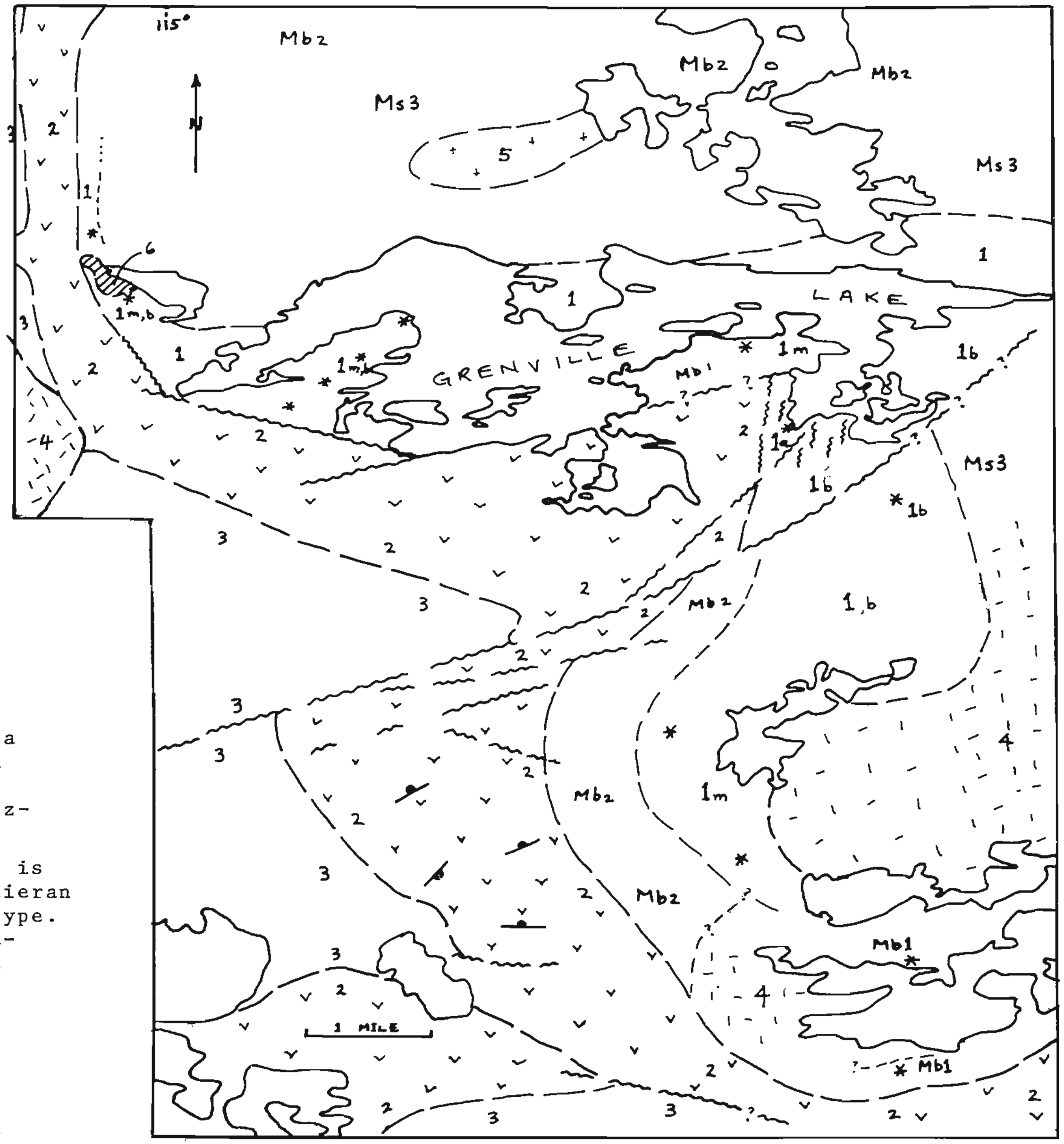
LEGEND

6	Muscovite-bearing pegmatitic granite no penetrative fabric observed
5	Alaskitic granite similar to the mobile phase of the adjacent migmatites
4	Biotite-granite-gneiss, massive in places
3	Yellowknife Supergroup metasediments
2	Yellowknife Supergroup metavolcanics
1	Unnamed gneiss complex. la is a quartz-dioritic gneiss, lb is a hornblende metagabbroic gneiss and lm is a metasomatized quartz-dioritic gneiss
M	Migmatite undifferentiated. Mb is the banded type, Ms is the schlieran type, Mm is the metasomatized type. Numbers refer to the above rock-units that occur as the restite phase of the migmatite

Fault

Strike and dip of pillow

* Quartz-dioritic gneiss observed



THE GRENVILLE LAKE AREA

FIGURE 3

COTTERILL - SNARE LAKES AREA

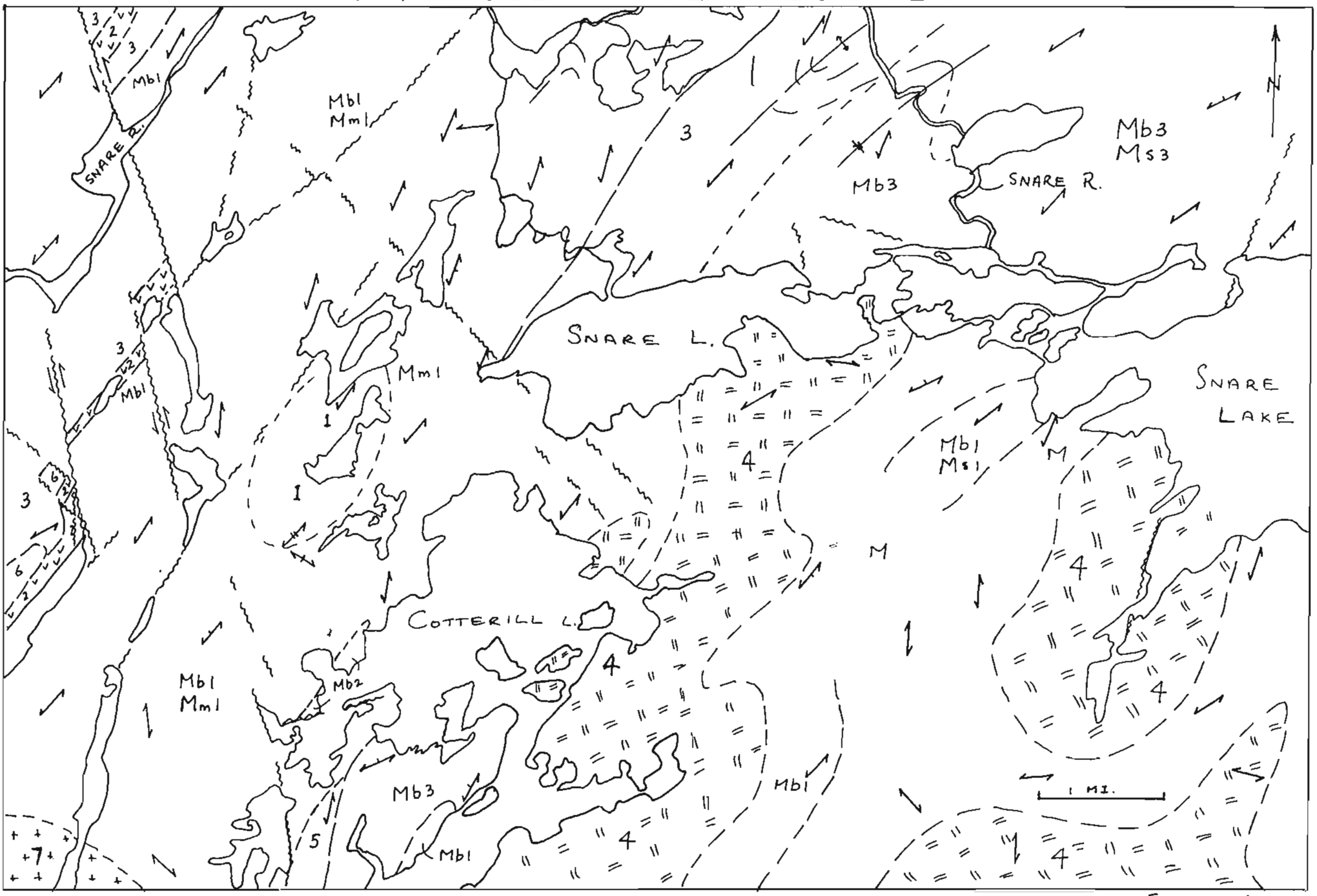


FIGURE 4

LEGEND

7	Biotite granodiorite intruded along the contact of the Yellowknife supracrustal rocks and the granitic rocks to the east
6	Biotite syenite intruded into 1 and 2
5	Biotite granite similar to the mobile phase of the adjacent migmatite
4	Porphyritic (porphyroblastic?) biotite granite with gradational contacts with the surrounding migmatites
3	Yellowknife Supergroup metasedimentary rocks
2	Yellowknife Supergroup metavolcanic rocks
1	Biotite-quartz-plagioclase gneiss with generally less than 35% alaskitic pegmatite
M	Migmatite undifferentiated. Mb is banded type, Ms is the schlieren type and Mm is a metasomatized type. Numbers refer to the above rock units that occur as the restite phase of the migmatite

Foliation (S1, S2)

Fault

Rock contacts (probable to assumed)

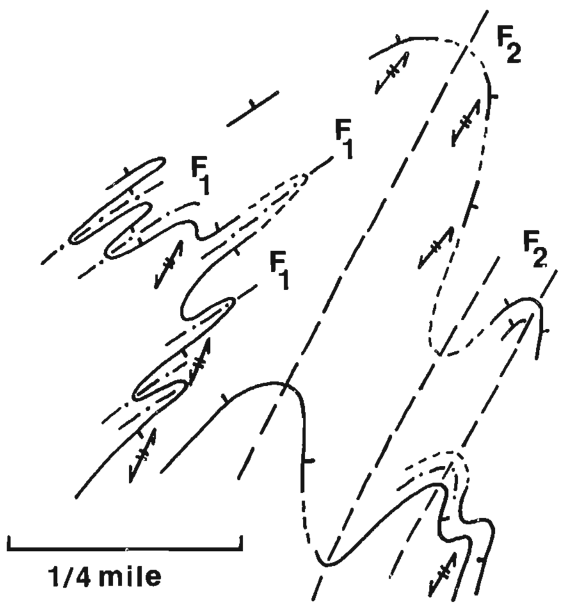


Figure 5. Interference pattern between F_1 and F_2 folds in vertically dipping greywacke-slate sequence at Indin Lake, east of Float Lake.

at 3021 ± 146 m.y. (Frith, 1971). A preliminary age of 3002 m.y. of the Grenville Lake rocks locality 4, Figure 1 shows that they probably represent an older basement to the Yellowknife Supergroup. Extensive mapping (1973) at 1/50,000 to outline this rock tvpe (Figs. 3 and 4) showed that the rock is highly deformed and closely associated with hornblende-gneiss interlayers. The rock is essentially a quartz-diorite, but in most places shows potash metasomatism by later pegmatitic phases. The extent of the basal unit (1) is shown in Figure 3. On the east side of Grenville Lake this rock unit is deformed in an east-northeast—west-southwest direction that can be related to a similar direction of deformation within the Yellowknife Supergroup rocks.

Studies along the Truce Lake section south of Grenville Lake (Fig. 1) showed that these older rock types are absent, but large areas of migmatite of suspected Yellowknife supracrustal parentage were outlined.

The Cotterill-Snare Lakes Area

The area was mapped at 1/50,000 and an attempt was made to subdivide the granitic rocks that comprise most of the area. Migmatites are defined here in a descriptive sense. For mapping purposes, where the origin of the restite is known or suspected, map-units were proposed. In most cases the mobile phase can be demonstrated as secondary and introduced. Migmatites were found to be the most abundant rocks and their mobile phase was found to be related to extensive porphyritic (porphyroblastic?) granites and in some areas to finer grained biotite alaskitic granites, It was possible to subdivide the migmatites into those derived from (1) biotite-quartz-plagioclase gneiss, (2) metasedimentary and (3) metavolcanic rocks. Mappable areas of older restite quartz dioritic gneisses were found along the eastern margin of the Yellowknife belt, as outlined in Figure 4.

The Chalco-Ranji Lake Area

The grade of metamorphism in the rocks of the Yellowknife Supergroup belt in the Chalco-Ranji Lake Area increases from greenschist facies in the centre to the upper amphibolite facies in the margins. The structural-metamorphic sequence recognized in this belt is as follows:

1. First period of deformation (D_1)

Structures resulting from this period of deformation are approximately east-west trending, steeply plunging folds (F_1) on the mesoscopic and macroscopic scales. A penetrative schistosity (S_1) which is axial planar to F_1 is well developed only in the higher grade metamorphosed marginal areas not greatly affected by D_2.

During a late to post-D_1 thermal event, porphyroblasts of sillimanite or andalusite and cordierite overgrew S_1. These porphyroblasts were retrogressively altered during further movement along S_1. In the final phase of this deformation garnet formed and can be seen to have overgrown retrograded porphyroblasts as well as their pressure shadows.

2. Second period of deformation (D_2)

The second period of deformation was responsible for the northeasterly lithologic trends in the central parts of the Yellowknife Supergroup belt. Effects of this period of deformation are greatest and best recognized in the lower grade rocks of the centre of the belt where primary sedimentary structures are abundant. Tight and steeply plunging, northeasterly trending folds (F_2) overprint and in part obliterate earlier F_1 folds causing Type 3 interference patterns (Ramsay, 1967) (see Fig. 5). Mesoscopic F_1 and F_2 folds have parallel axial planes and are co-axial on the limbs of macroscopic F_2 folds. A penetrative S_2 cleavage is axial planar to the F_2 folds. In the centre of the belt, where S_1 is virtually absent, S_2 is a slaty cleavage which represents the most pronounced tectonic fabric in the rocks. In volcanic rocks, S_2 is present as schistosity of varying intensity. At the margins of the belt the effects of D_2 are less evident in the supracrustal rocks. F_2 folds are open and generally evident only on the mesoscopic scale and S_2 is locally developed as crenulation cleavage further obliterating the porphyroblasts of the post-D_1 thermal event. S_2 is also recognized around and within granodiorite intrusions along the eastern margin of the belt. Within small round plugs of this granodiorite in the Strachan Lake area (see No. 6, Fig. 1) S_2 overprints a concentric cataclastic fabric probably related to late stage movements during emplacement. This granodiorite yielded an absolute age of 1929 ± 7.3 m.y., hence establishing a maximum age of S_2.

Possibly related to or slightly postdating D_2 are large north-northwesterly striking faults with apparent left-handed displacements. A locally developed, late fracture cleavage (S_3) strikes more or less parallel to these faults.

Conclusions

1. Possible Pre-Yellowknife Supergroup basement was recognized in the eastern part of the map-area.
2. Two major periods of deformation have affected the Slave Province part of the map-area. The first of these was closely followed by diapiric emplacement of granitic plutons about 2570 m.y. ago (McGlynn, 1972) immediately to the east of the Bear–Slave boundary. The second period of deformation postdates the emplacement of the approximately 1930 m.y. old granodiorite intrusions (loc. 6, Fig. 1). It indicates that this part of the Slave Province was affected by extensive and penetrative post-Kenoron deformation.
3. It is possible that the large northwest faults in the Slave Province and the early diabase dykes (approx. 2000 m.y.) are closely related in time to the second period of penetrative deformation.
4. Although considerable crustal shortening may have occurred during the two periods of deformation, the tectonic development of the area must have involved large vertical movements. Such movements are thought to have brought possible pre-Yellowknife Supergroup basement into juxtaposition with the supracrustal rocks along the eastern margin of the belt.
5. Archean basement was positively identified within the folded Aphebian rocks immediately to the west of the Bear–Slave boundary.
6. It is interesting to note that the gold occurrences in the Chalco-Ranji Lake area are confined to the low-grade metamorphic parts of the Yellowknife Supergroup. The gold-bearing quartz veins formed in fractures opened during the second period of deformation.

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VOLCANISM AND PLUTONISM, SLOAN RIVER MAP-AREA (86K), GREAT BEAR LAKE, DISTRICT OF MACKENZIE

Project 730039

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The 1973 field season was the first in a three year project to map, at 1: 250, 000 scale, the Sloan River map-area in the west-half of the Bear Province. The area is a small part of that mapped during the helicopter reconnaissance of the north-central District of Mackenzie (Fraser et al., 1960). In the current project, special emphasis is on the late Aphebian (1750 million-year-old) volcanic and plutonic rocks of the Great Bear Batholith (Fraser et al., 1972; Hoffman, 1973). They underlie all but the northwest corner and eastern boundary of the map-area. In 1973, mapping was concentrated in the largest volcanic belt (Fig. 1), extending for 50 miles from Dumas Lake west along the Sloan River to Great Bear Lake. Mapping was done by ground traverses from seven base camps during the unusually long season of fourteen weeks.

Volcanic Stratigraphy

The internal stratigraphy of the Sloan River volcanic belt was established, a task facilitated by its simple structure - a northeast-facing homocline with a few broad folds (see cross-section in Fig. 1). Thus, volcanics high in the stratigraphic sequence occur in the east and those lower in the sequence to the west.

The volcanic rocks are mainly rhyolitic to andesitic welded ash flow tuffs (ignimbrites) and make up a conformable sequence of great thickness (Fig. 2). The tuffs consist of broken phenocrysts of plagioclase, alkali feldspar, quartz, hornblende and biotite, scattered in a dense aphanitic groundmass. The field term "rhyolite" is used where the phenocrysts are dominantly alkali feldspar and quartz, "andesite" where dominantly plagioclase and hornblende. These identifications are supported by a limited number of chemical analyses of samples collected near Dumas Lake and Jaciar Lake.

The ash flow tuffs are unstratified and some are massive, but most contain fragments of porphyritic pumice, more or less recrystallized, strongly flattened parallel to the depositional surface (eutaxitic structure). The pumice fragments (fiamme) are equant, not elongate, in the plane of flattening, thus indicating that the flattening is due to compaction not flowage. A few of the tuffs contain unflattened pebble- to boulder-sized clasts of tuff or intrusive porphyry. In parts of the sequence, particularly on the west side of Doghead Peninsula (see Fig. 1), individual cooling units (Ross and Smith, 1961) can be distinguished by variation in the degree of flattening of the pumice fragments.

The sequence was divided into four formations (Units 2-5 in Fig. 1-2) and many members, to be formally defined in a later publication.

Unit 5: A diverse unit with well defined and consistent internal stratigraphy. Dominant are thick rhyolitic to rhyodacitic crystal-rich ash flow tuffs, eutaxitic in the lower part and massive above. The tuffs are mostly orange, pink or mauve and contain discontinuous crossbedded sandstones derived from them. Between the tuffs are conglomerates, composed of tuff, porphyry and basalt clasts; mudstones, with varve-like laminations and graded turbidites; basalt flows, commonly amygdaloidal, porphyritic and rarely pillowed; and laccoliths of porphyry containing alkali feldspar megacrysts. The porphyries were intruded during volcanism as they provide boulders to the conglomerates and, on the basis of phenocryst similarity, are interpreted to be intrusive equivalents of the ash flow tuffs.

Unit 4: A less diverse unit, lacking sedimentary rocks, but with a highly variable internal stratigraphy. The background component is red rhyolitic crystal-poor ash flow tuff with excellent eutaxitic structure, within which are *en echelon* shield volcanoes, many miles in diameter, of dark green andesitic crystal-rich ash flow tuff. The flanks of the volcanoes are strongly eutaxitic, the flattened pumice fragments commonly recrystallized to clear granophyre, whereas the centres consist of massive finely porphyritic andesite rich in biotite and unflattened pumice fragments. This unit, and those below, are intruded by discordant to pene-concordant masses of coarsely porphyritic dacite.

Unit 3: A weakly differentiated unit, mostly without sedimentary interbeds, of orange to purple, rhyolitic to dacitic ash flow tuff. Most of the tuffs are crystal-rich, many are strongly eutaxitic and others weakly so, and some are notable in having lithic clasts of tuff and porphyry.

Unit 2: This unit is most like Unit 5 in having thick sedimentary interbeds. Dominant are thick and thin, rhyolitic to dacitic, massive to strongly eutaxitic, crystal-rich ash flow tuffs, several with large clasts of red porphyry. The sedimentary rocks are conglomerate and crossbedded pebbly sandstone, with clasts of tuff, porphyry, hornfelsed sediment and granitoid rocks; laminated calcareous mudstone, with mudcracks and beds of stromatolitic dolomite; and silicified mudstone with turbidites. There are also thin intervals of basaltic flows, tuffs and breccia; laccoliths of coarsely porphyritic dacite; and discordant intrusions of finely porphyritic rhyolite. The internal stratigraphy is complicated by abrupt facies changes across high-angle faults active during volcanism.

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Basement Rocks and Nature of the Wopmay Fault

The Wopmay Fault (Hoffman, 1973) separates the volcanic sequence from the high grade Hepburn Metamorphic–Plutonic Belt (Fraser et al., 1972) of the east half of the Bear Province. The nature of the fault and the age relation of the volcanic sequence to the Hepburn gneisses, previously unknown, was determined east of Dumas Lake (see Fig. 1). There, the uppermost volcanic and sedimentary rocks of Unit 5 (see Fig. 2) overlap the fault trace and lie unconformably on granodiorite and migmatite of the Hepburn Belt. Thus, the volcanic sequence is younger than the Hepburn Belt and movement on the Wopmay Fault was complete before the end of volcanism. The fault must have provided great structural relief during volcanism in order to truncate the great thickness of volcanic rocks that project beneath the unconformity a few miles to the west (see cross-section in Fig. 1). West of the fault, basement to the volcanic sequence is not exposed in the area mapped.

Plutonism Not Coeval with Volcanism

Two generations of undeformed discordant epizonal plutons intrude the volcanic sequence (see Fig. 1). The older plutons are vertical-sided intrusions of granodiorite, commonly with central areas of alkali-feldspar-porphyritic quartz monzonite, and locally with quartz diorite in embayments into the country rocks. Distinctly younger are plutons of coarse-grained granite, the roofs of which are close to the present erosion surface. Trending southwestward from Spence Lake is a dense swarm of granitic porphyry dykes that issues from the roof of one of the granite plutons.

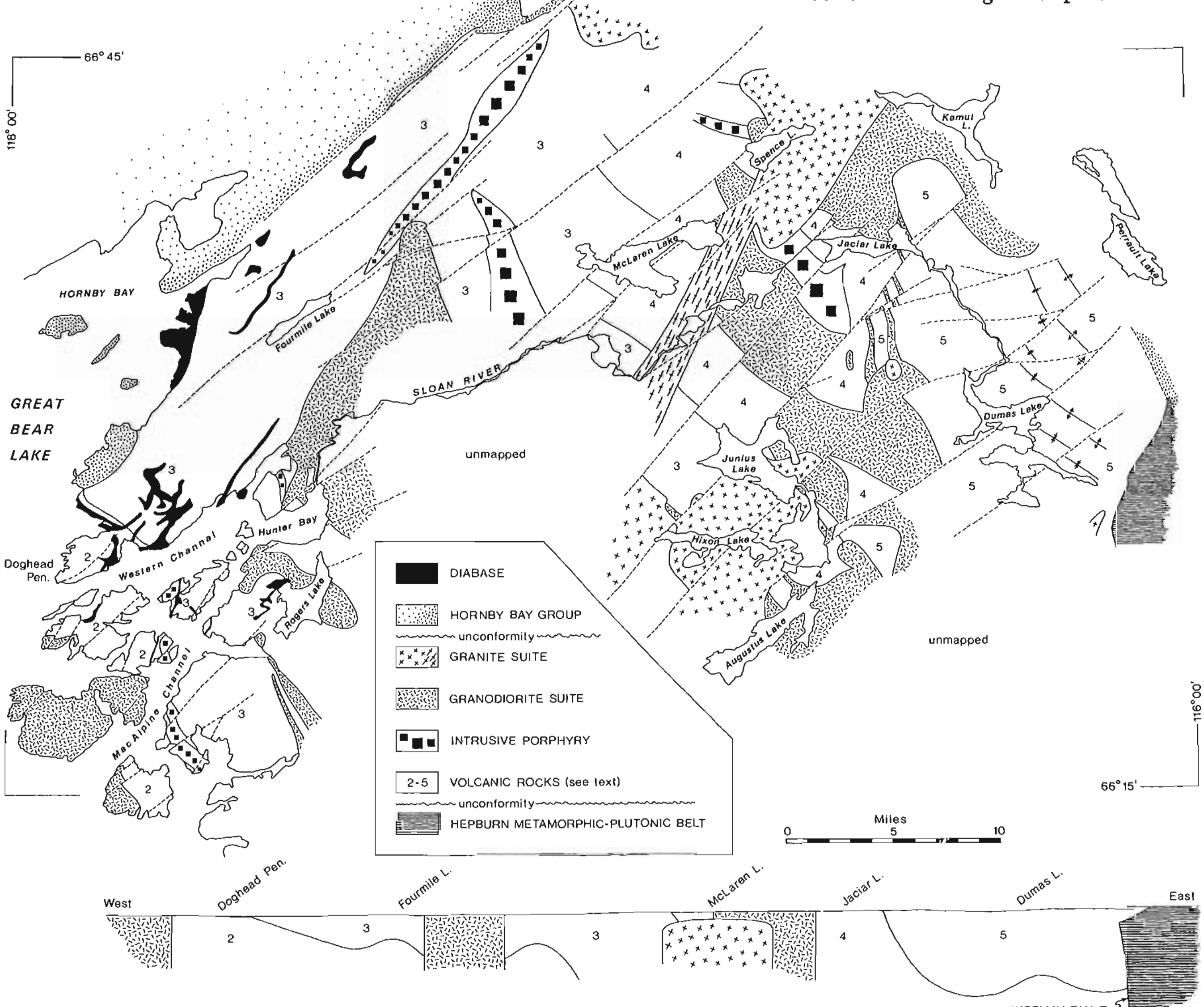

Figure 1. Geological sketch map and cross-section of part of the Sloan River map-area (86K). Many more units were mapped than are shown here.

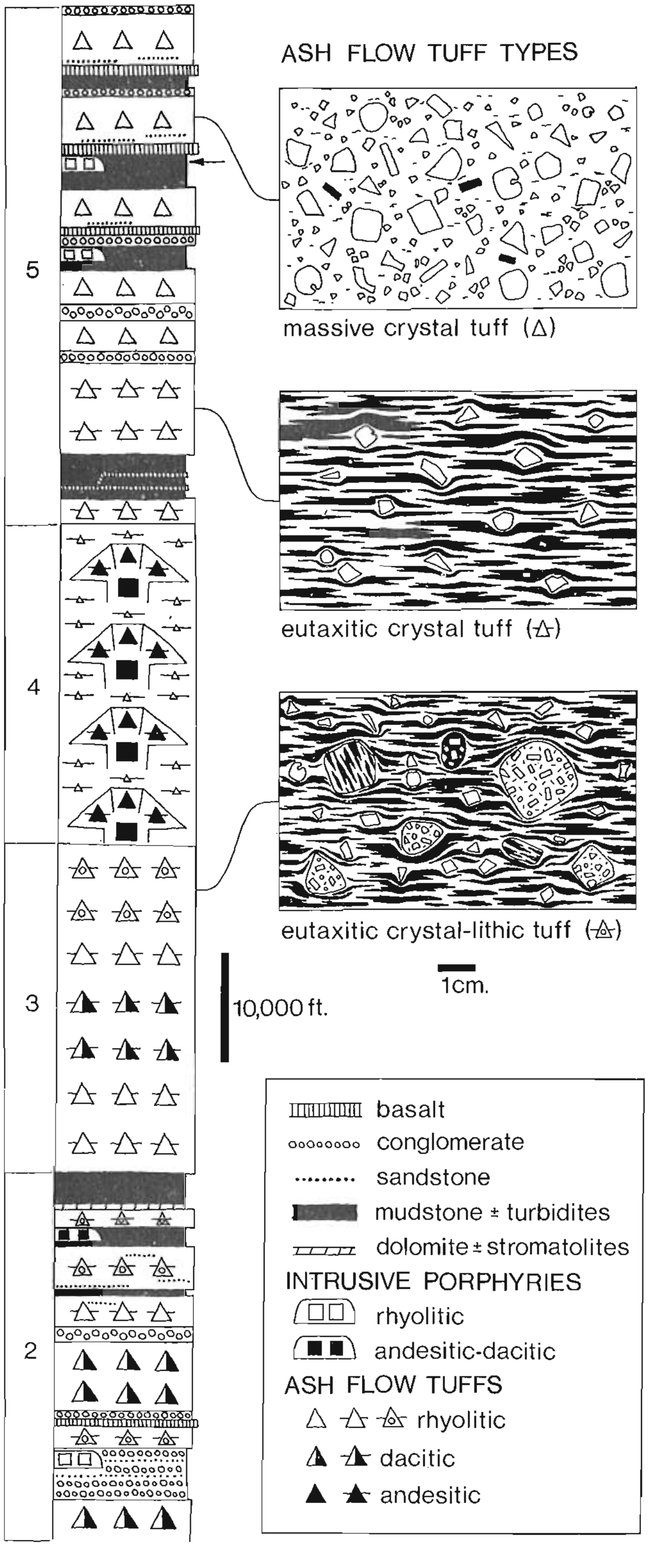

Figure 2. Aggregate stratigraphic column of the Sloan River volcanic belt. The arrow to the right of the column in Unit 5 indicates the level of the unconformity east of the Wopmay Fault. Insets show typical structures in the ash flow tuffs. Unit numbers are keyed to Figure 1.

The plutons and their host rocks must have been relatively dry as pegmatite, miarolitic cavities, explosion breccias, muscovite and hydrothermal alteration are lacking.

Although the compositional range of the plutons is similar to that of the volcanic sequence, there is no evidence that volcanism and plutonism were coeval. The two may be comagmatic but emplacement of the plutons clearly postdates deformation of the entire volcanic sequence. The only conglomerates to contain plutonic clasts are those in the lowest parts of the sequence, presumably derived from basement. The porphyry laccoliths of the volcanic sequence, common as clasts in the conglomerates, are texturally distinct from the porphyry dyke swarms related to plutonism.

Late Faulting

Map patterns are greatly complicated by late faults that displace the plutons and all older rocks (see Fig. 1). The faults strike northeast and have both right-lateral strike-slip and normal movement. The fault traces occupy lineaments commonly marked by quartz stockworks. Prominent north-striking lineaments have nò displacement and are probably recessive dykes, not faults.

Helikian Weathering Beneath the Hornby Bay Group

The gently dipping Helikian Hornby Bay Group (Baragar and Donaldson, 1973) has a basal unit of red polymictic conglomerate, mudstone and sandstone. The red beds are overlain by light grey friable kaolinitic crossbedded sandstone and conglomerate. Beneath the basal unconformity, the volcanic rocks of the Sloan River belt are weathered to a reddish brown earthy saprolite. The weathered rocks extend for miles from the trace of the unconformity in the region east of Hornby Bay and along the east shore of Great Bear Lake. Where deeply weathered, the subtle differences between the volcanic units are exceedingly difficult to map.

Great Bear Batholith Not an Andean-type Arc

The association of silicic volcanics and plutons prompted Hoffman (1972) and Badham (1973) to suggest that the Great Bear Batholith may be a volcano-plutonic arc of Andean-type generated above a subduction zone along a convergent plate boundary. There are major objections to this hypothesis. Andean arcs typically have greatly thickened crust and therefore, for reasons of isostasy, are regions of great uplift. Ancient Andean-type arcs, such as the Sierra Nevada Batholith of California (Hamilton, 1969a), are deeply eroded. In contrast, the unmetamorphosed volcanics and epizonal plutons of the Great Bear Batholith have not been deeply eroded. Rather, the great thickness of conformable volcanic rocks indicates profound subsidence during volcanism, subsidence not later countered by uplift.

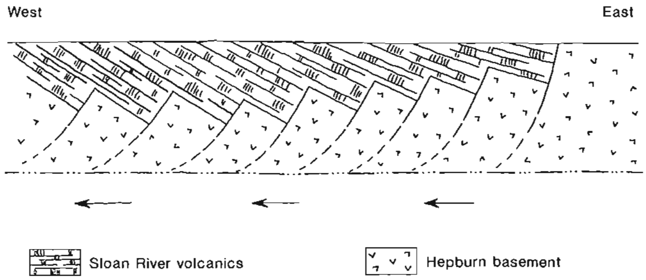

Figure 3. Tectonic model in which a homoclinal sequence of volcanic rocks is preserved in a region of crustal attenuation by slippage along listric normal faults. Arrows show direction of shear stress.

The foregoing requires an environment of crustal attenuation, whereupon the combined effects of volcanism and plutonism serve to restore the crust to normal thickness. Crustal attenuation can be accomplished by slippage of normal fault blocks during the early stages of volcanism. If the normal faults are predominantly west side down, as is the case of the Wopmay Fault, then a conformable homocline can be accommodated with an apparent thickness far in excess of what need be stacked in any one place (Fig. 3), a comfort in view of the outrageous thickness of volcanics represented by the stratigraphic column in Figure 2. Therefore, a better analogue than the Andes may be the Basin and Range Province of the western United States, a region of normal faulting, crustal attenuation and voluminous silicic ash flow eruptions in the Cenozoic (Hamilton and Myers, 1966).

It may be that the mesozonal batholiths of the Hepburn Belt, source of the flysch wedges in the Coronation Geosyncline (Hoffman, 1973), occupy the deeply eroded arc. For they have the same temporal relation to the Sloan River volcanics that the Sierra Nevada Batholith (Cretaceous) has to the Basin and Range volcanics (Hamilton, 1969b).

Absence of "Porphyry Copper" Mineralization

The intimate association of silicic volcanics, intrusive porphyries and epizonal plutons seems ideal for disseminated copper sulphide mineralization. Yet none was found, nor any of the intense hydrothermal alteration with which "porphyry copper" is intimately associated.

There is local copper mineralization in quartz stockworks associated with the northeast faults but this is minor and is not limited to the Great Bear Batholith. (There are similar occurrences in the east arm of Great Slave Lake). There is disseminated pyrite in an anomalously sheared area of rhyolitic ash flow tuff (Unit 5) southeast of Junius Lake (see Fig. 1).

Whether the lack of obvious mineralization is related to lack of water in the magmas and/or country rocks, the non-arc affinities of the magmas, the level or erosion, or other factors is an intriguing academic question. But unless other parts of the Great Bear Batholith are substantially different, estimates of its potential for large low grade copper mineralization should be revised downward.

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Project 730040

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Geological mapping of Archean volcanic rocks in the Hearne Lake map-area, begun in 1972 (Henderson et al., 1972), was completed this year. The belts were mapped on a scale of 1: 50, 000 with the aim of determining the stratigraphic and structural relations in the belt, the sequence and types of volcanic eruptions and their environment of deposition, and the relationship of mineral deposits to volcanic stratigraphy and volcanic processes.

Specific gravities of about 250 hand specimens were measured with the hope of correlating them with the chemical compositions of the volcanic rocks. Three sections across the belt, near Allan and Sunset lakes, were sampled at 500- to 1, 000-foot intervals for chemical analyses.

The work was carried out mainly by ground traverse with helicopter support for a two-week period.

Stratigraphy

The volcanic pile is divided into three major units (Fig. 1): basal mafic volcanics, including rocks of basalt and andesite compositions, metamorphosed to amphibole grade; middle intermediate volcanics, dominantly dacite with minor andesite; and upper salic volcanics, dominantly rhyolite but including some dacite.

Mafic volcanics are generally dark green, fine-grained amphibolites of basaltic composition that have specific gravities ranging from 2. 8 to 3. 15. They comprise pillow lava, pillow breccia, tuff breccia and tuff. Parts of the mafic volcanic succession (medium green, feldspathic amphibolites, with specific gravities ranging from 2. 75 to 2. 85), may be meta-andesites.

Intermediate volcanics are typically pale green, sparsely porphyritic pillow lavas and tuffs that have quartz or feldspar phenocrysts. These very fine grained to aphanitic rocks, that contain little or no visible amphibole, and with specific gravities ranging from 2. 68 to 2. 76, were called dacite in the field.

Salic volcanic units are white, pale grey and buff weathering rhyolite containing quartz and feldspar phenocrysts. They include crystal tuffs, ash-flow tuffs, and dykes, sills and lava flows. Specific gravities of these rocks range from 2. 6 to 2. 7. The salic volcanic units southeast of Trout Lake are dominantly massive and eutaxitic ash-flow tuffs. Near the contact with granitic plutons, some rhyolite units are very fine grained, and have well developed schistosity in contrast to the normal aphanitic rhyolite.

The contact between salic and mafic volcanic successions is conformable. The volcanic succession is overlain conformably by metasediments. At this contact sediments and volcanics are interbedded. Northeast of Webb Lake, where volcanics are in contact with granitic gneisses, considered by Davidson (1972) to be basement to the volcanic pile, gneissosity makes an angle of 30 degrees with the trend of flattening in the volcanic belt, indicating that the contact is an unconformity.

The stratigraphy varies considerably from one part of the belt to another. In the Cameron River belt the succession is dominantly basalt pillow lavas with minor andesite, dacite and rhyolite units as pods and discontinuous beds near the top of the succession. The pillow lavas are intruded by large amphibolite dykes and sills in the east and central parts of this belt. Between Ross and Victory lakes the volcanic belt pinches out southward.

The belt from Victory Lake to Tumpline and Turnback lakes contains subequal amounts of salic and mafic units. Near Sunset Lake the succession is mixed andesite and dacite pillow lavas and tuffs with minor rhyolite crystal tuffs, lava flows and sills west of Sunset Lake. Compositions become more mafic towards the eastern and western sides of the belt.

South of Payne Lake, the southeast-trending arm of the belt comprises schistose tuffs of intermediate composition, minor rhyolite and mafic pillow lavas, and water laid volcanic sediments.

Three miles north of Turnback Lake, 4 miles northeast of Turnback Lake and south of Detour Lake, the contact between salic volcanics and metasediments is marked by a dark grey weathering carbonate unit locally up to 250 feet wide. This unit can be traced intermittently around the belt to the vicinity of Ross Lake. Carbonate-bearing units also occur at the contact between salic volcanics and sediments southeast of Sunset Lake, as the matrix of a rhyolite boulder conglomerate and breccia northeast of Ross Lake, and as thin zones in intermediate tuff north of Sunset Lake. The carbonate unit contains up to 40 per cent rhyolite lenses, screens and in some cases complete small scale folds of rhyolite in a carbonate matrix. Layering in the unit is defined by preferred orientation of salic clasts, which generally have the same attitude as layering in the adjacent volcanic units. These carbonate units generally are not distinct beds, but are carbonate rich zones in salic volcanics that have boundaries gradational over distances of 1 to 20 feet.

Amphibolite dykes form massive medium- to coarse-grained bodies with steeply dipping mineral streaking defined by preferred orientation of hornblende crystals, and locally with layered margins. Specific gravities of these dykes generally fall in the range of 2. 95 to 3. 1. Amphibolite forms swarms of dykes and sills within the mafic and felsic volcanic successions. Dense swarms of amphibolite dykes penetrate granitic rocks notably along the southeast side of the Cameron River belt and along the northeast side of the Beaulieu River belt.

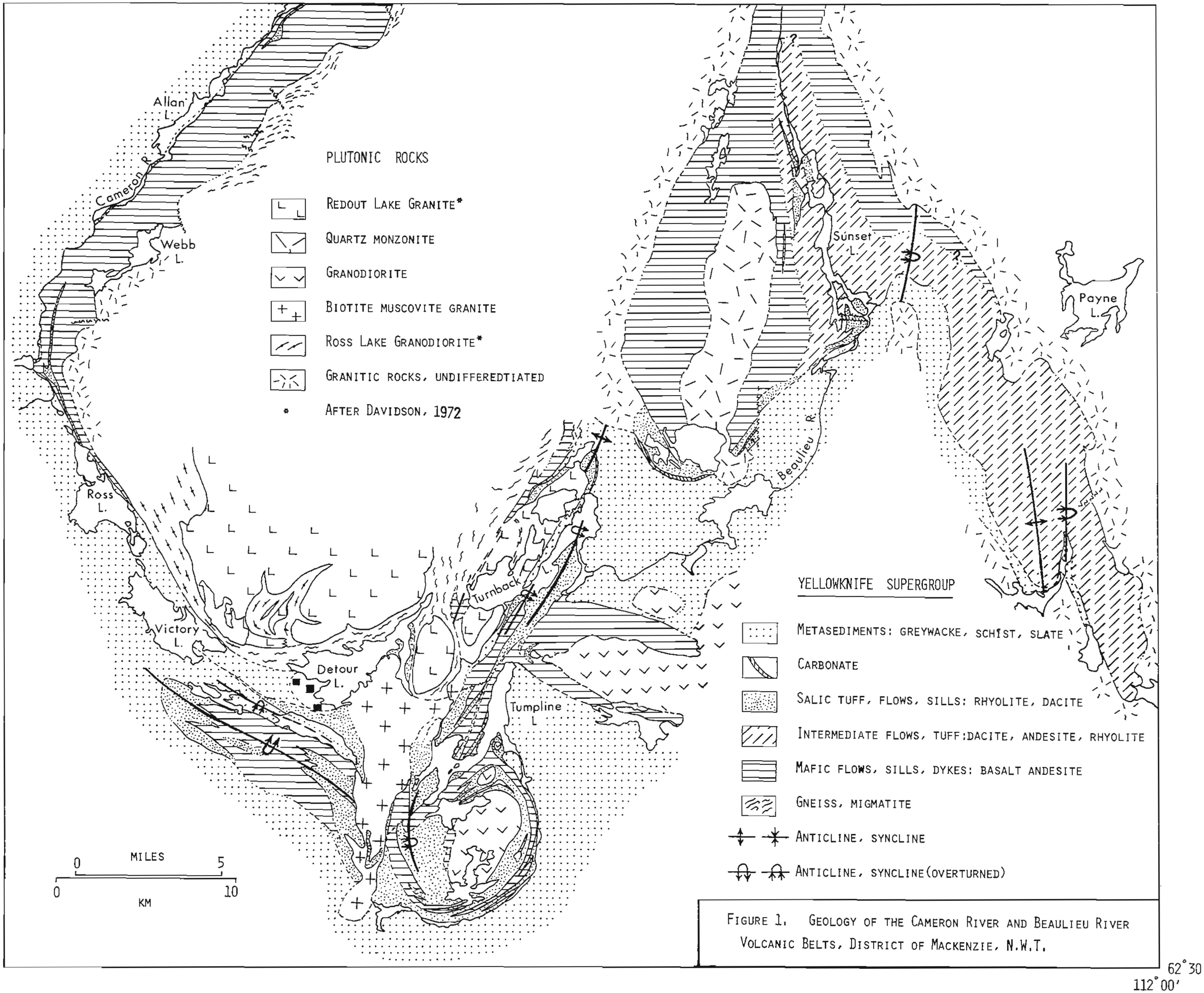

FIGURE 1. GEOLOGY OF THE CAMERON RIVER AND BEAULIEU RIVER VOLCANIC BELTS, DISTRICT OF MACKENZIE, N.W.T.

Fresh pyroxene diabase dykes cut across virtually all volcanic formations, following along the layering of the volcanic belt and cutting across it at high angles.

Structure

The contact between volcanic and sedimentary successions in the Hearne Lake map-area suggests that the volcanic belts outline a large scale anticline-syncline pair with an amplitude of at least 25 miles. The style of folding varies in different parts of the belt.

The Cameron River belt is essentially a northeast-trending homoclinal succession in which pillows are both flattened in a plane parallel to the trend of the belt and drawn out into steeply plunging rods. Phyllitic cleavages are developed parallel to the plane of pillow flattening. Southwest of Webb Lake, small scale folds in tuffs and gentle warps in the flattened pillows, have axial planes that make a high angle (azimuths ca. 340 to 360 degrees) to flattened pillows. Metasediments that lie to the west of the Cameron River belt, preserve delicate structures that indicate at least three periods of deformation. These features are rarely preserved in the more massive units of the volcanic belt.

South of Victory and Detour lakes the belt defines two northwest-trending tightly folded isoclines. Axial planes of these folds conform to the boundary of a large pluton (Davidson, 1972) that lies north of Detour Lake. Near Tumpline and Turnback lakes axial planes of major folds trend north-northeast, whereas near Sunset and Payne lakes they trend roughly north-south. Southeast of Turnback Lake the east-southeast trending arms of the volcanic belt may be parts of one or more isoclinal folds.

Several granitic plutons have intruded and deformed the volcanic belt. Southeast of Tumpline Lake, layering in the volcanic belt makes abrupt changes in trend to warp around two small plutons. The layering generally conforms to the margins of these plutons, but in detail the plutons cut across it. West of Turnback Lake, a large north-northeast trending pluton forms the core of a large anticline. The western and southern margins of this pluton contain slivers and screens of volcanic rock. Attitudes of layering within these inclusions is essentially the same as that in the adjacent volcanic units, and thus the inclusions outline the stratigraphy and at least two large folds in the intruded volcanic succession. West of Sunset Lake a large roughly north-south trending pluton has intruded along the centre of the volcanic belt.

Mineral Occurrences

No new deposits of economic significance were discovered. Sulphides, mainly pyrite, are ubiquitous but generally appear to be more abundant in the eastern and southern parts of the belt than in the Cameron River belt. In almost all parts of the belt sulphides are most abundant at the contact between salic volcanics and metasediments. This contact is almost always marked by a gossan zone, which tends to be best developed in the metasediments. These gossans are very prominent adjacent to the thick carbonate units near Turnback and Detour lakes. Garnet- and diopside-rich scarn zones, up to 25 feet wide occur at the contact of granitic bodies where they intrude the carbonate unit north of Turnback Lake.

Interpretation

The general stratigraphy indicates that there was one major cycle of eruption in which the composition of the magma changed from mafic to salic with time. Interbedded mafic and salic volcanics suggest either that magma of different compositions effused, penecontemporaneously from different eruptive centres, or that there were periodic fluctuations in magma compositions near the end of the cycle. That most of the volcanic succession was deposited in a subaqueous environment is indicated by extensive pillow lava successions. Local thick welded ash-flow tuff units, however, suggest that part of the volcanic pile, near the end of the cycle, emerged above the surface of the ocean. Carbonate units have features strongly suggesting that they are of exhalative origin.

The northwest-trending folds south of Detour Lake may be the noses of refolded isoclines. The sudden swing in trend of the belt in this vicinity may be due partly to superposed folding and partly to forcing aside of the volcanic and sedimentary succession by large granitic plutons that lie to the north of Detour Lake. Several smaller granitic plutons in the vicinity of Tumpline, Turnback and Sunset lakes, have forcefully intruded and wedged aside parts of the volcanic and sedimentary successions.

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VOLCANIC STRATIGRAPHY AND METALLOGENY OF THE KAMINAK GROUP, SPI LAKE AREA, DISTRICT OF KEEWATIN

Project 700052

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Fifty-seven chemical analyses of volcanic rocks from the Spi Lake area, not reported previously, are presented (Fig. 1; Table I). Detailed structural information collected principally during the field season of 1972 (Ridler, 1973) but augmented by a single day's activity during August, 1973, are also presented (Fig. 1).

Six fragments of sphalerite-rich massive sulphide exhalite were discovered on island "A" in Spi Lake (Fig. 1) by W.W. Shilts and two were analyzed (Shilts, this report). The outcrops on islands "A" and "B" were examined subsequently by the author in August.

Island "A" is composed of a medium-grained polymictic breccia of overall intermediate composition apparently correlative with the similar andesite unit defined by samples 12 and 13 on Figure 1. Zones a few feet thick containing a small percentage of fragments of massive sulphide are present locally. The largest sulphide fragment observed was one inch in diameter. Island "B" is predominantly a massive, quartz-eye-bearing rhyolite, apparently correlative with the similar rhyolite unit defined by samples 8, 9, 10, and 11 on Figure 1 and the similar rhyolite at the main Spi Lake showing (sample 3006, Fig. 1). The outcrop displayed tuffaceous

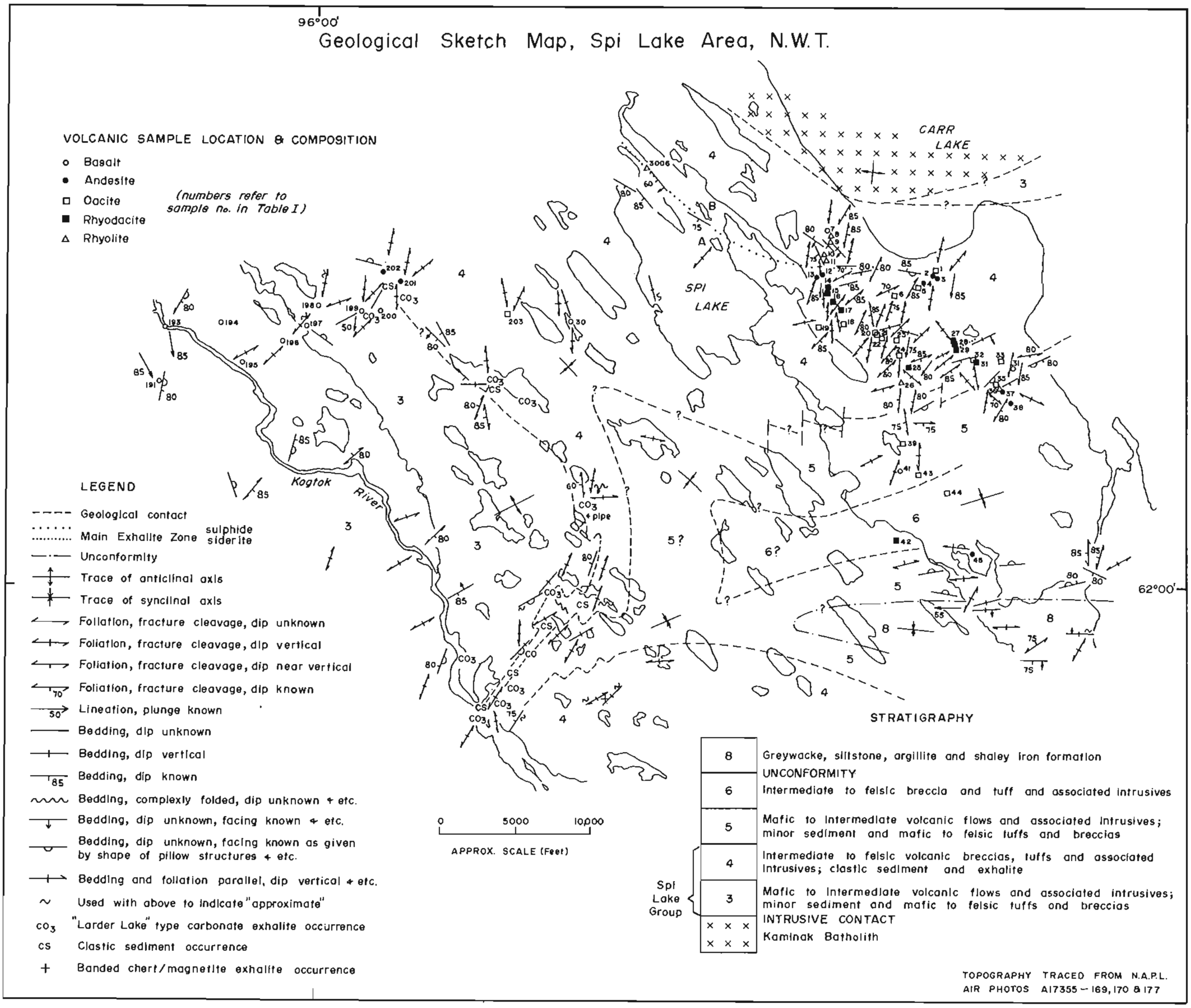

TABLE I Chemical Analyses of Volcanic Rocks, Spi Lake Area

Sample Number	Rock Type	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	FeO	Fe_2O_3	Na_2O	P_2O_5	CO_2	H_2OT	Total
1	Dacite Breccia	0.07	0.52	3.9	1.2	59.1	17.0	3.6	4.1	1.6	2.8	0.09	2.2	3.6	99.8
2	Andesite(?) Pillow Lava	0.10	0.75	7.1	1.4	56.9	15.9	2.5	5.1	1.7	1.3	0.13	4.7	3.7	101.3
3	Andesite(?) Breccia	0.11	0.82	4.9	0.3	51.5	15.1	5.5	6.9	2.4	3.5	0.12	4.3	4.1	99.5
4	Andesite(?) Breccia	0.13	0.73	8.5	1.3	51.9	15.0	5.4	5.1	2.2	2.1	0.13	5.6	3.4	101.5
5	Dacite Breccia	0.12	0.74	6.7	1.9	58.3	14.8	1.4	5.2	1.7	0.9	0.12	5.0	3.3	100.1
6	Dacite Breccia(?)	0.08	0.84	2.6	0.9	62.3	14.1	2.1	5.3	2.7	4.2	0.13	1.6	2.8	99.6
7	Basalt Pillow Lava	0.14	0.76	8.0	0.0	49.3	13.8	8.2	7.1	3.0	3.2	0.13	3.5	4.3	101.5
8	Rhyolite Tuff	0.05	0.22	4.4	1.8	71.8	12.8	0.8	2.2	0.5	0.7	0.04	3.3	2.0	100.6
9	Rhyolite Tuff	0.07	0.19	3.4	2.5	69.1	15.1	1.2	1.9	0.5	1.9	0.03	3.0	1.8	100.7
10	Rhyolite Breccia	0.06	0.31	2.2	2.2	72.4	14.0	1.2	3.0	0.2	1.3	0.06	1.7	2.2	100.8
11	Rhyolite Flow(?)	0.05	0.35	2.7	1.7	71.1	14.5	0.7	2.8	0.3	3.5	0.06	1.8	1.7	101.3
12	Andesite Breccia	0.14	0.74	7.7	1.1	53.5	15.4	4.8	5.5	2.0	2.3	0.12	5.2	3.4	101.9
13	Andesite(?) Breccia	0.10	0.69	6.0	0.7	56.4	16.8	4.2	6.1	0.9	2.9	0.08	4.6	3.7	103.1
14	Rhyodacite Flow(?)	0.06	0.69	3.2	1.3	66.1	15.3	1.4	4.4	0.6	3.1	0.12	2.6	2.7	101.6
15	Rhyodacite(?) Breccia	Initial analysis inaccurate													
16	Rhyodacite Breccia	0.03	0.68	1.9	1.3	65.5	15.7	2.2	4.6	1.1	3.0	0.12	1.6	3.2	101.0
17	Rhyodacite(?) Breccia	Initial analysis inaccurate													
18	Dacite Breccia	0.09	0.59	2.3	1.0	63.6	14.2	2.8	4.9	1.7	4.7	0.09	2.6	2.6	101.2
19	Dacite Flow	0.14	0.88	4.1	0.5	63.6	14.0	1.8	5.0	1.7	5.5	0.12	2.1	1.9	101.4

TABLE I (cont'd)

Sample Number	Rock Type	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	FeO	Fe_2O_3	Na_2O	P_2O_5	CO_2	H_2OT	Total
20	Dacite Breccia	0.09	0.58	1.9	0.6	59.4	16.5	5.5	4.4	2.5	4.9	0.09	1.7	3.0	100.3
21	Dacite Tuff	0.09	0.44	4.8	3.0	62.4	14.3	3.2	3.7	1.2	1.0	0.10	3.6	3.2	101.0
22	Dacite Flow	0.07	0.42	3.0	0.1	60.9	15.5	5.1	4.9	1.8	5.0	0.10	0.5	3.0	100.4
23	Dacite Breccia	0.15	0.45	5.0	2.7	60.1	14.3	2.2	4.8	1.6	0.9	0.10	4.5	3.4	100.3
24	Dacite Breccia	0.10	0.55	6.0	1.2	62.3	14.9	1.4	3.1	0.7	3.1	0.13	4.0	2.5	100.0
25	Rhyodacite Breccia	0.03	0.45	4.0	1.2	66.4	16.2	0.5	2.0	0.2	4.5	0.11	2.6	1.7	99.9
26	Rhyolite(?) Breccia	Initial analysis inaccurate													
27	Rhyodacite Flow	0.07	0.50	5.0	1.0	64.5	15.4	0.8	2.4	0.7	4.6	0.19	3.2	1.8	100.2
28	Rhyodacite Altered	Initial analysis inaccurate													
29	Rhyodacite Breccia	0.13	0.47	5.4	1.0	65.1	15.5	0.6	3.0	0.5	3.0	0.11	3.9	2.0	100.7
30	Basalt Breccia	0.16	0.70	8.0	1.2	47.5	14.7	9.1	5.7	2.3	3.7	0.11	4.5	3.7	101.4
31	Rhyodacite Flow	0.05	0.32	5.5	1.0	68.1	15.1	0.2	1.0	0.0	4.8	0.10	3.6	1.1	100.9
32	Dacite Breccia	0.15	0.50	3.7	1.0	61.8	17.4	1.0	3.9	1.6	4.2	0.12	3.1	2.4	100.9
33	Dacite Breccia	0.04	0.42	5.5	1.3	62.7	15.6	1.0	1.9	0.2	4.3	0.10	5.9	1.4	100.4
34	Basalt Pillow Lava	0.16	0.65	11.1	1.3	50.4	15.0	5.5	5.0	1.7	1.6	0.13	7.5	1.3	101.3
35	Dacite Pillow Lava	0.07	0.38	4.5	1.6	64.5	15.5	2.3	3.3	1.5	3.9	0.07	2.0	2.0	101.6
36	Rhyolite Flow(?)	0.01	0.09	1.7	2.8	74.6	13.8	0.4	1.4	0.1	3.2	0.00	1.2	1.2	100.4
37	Andesite Pillow Lava	0.13	0.92	5.7	0.9	53.5	16.0	3.4	5.7	2.8	3.5	0.23	5.0	3.2	101.0
38	Andesite Breccia	0.16	0.86	6.3	0.2	53.3	14.0	3.8	5.6	4.8	4.5	0.22	2.9	1.3	97.9

TABLE I (cont'd)

Sample Number	Rock Type	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	FeO	Fe_2O_3	Na_2O	P_2O_5	CO_2	H_2OT	Total
39	Diorite	0.10	0.85	5.0	0.6	60.5	14.2	3.7	6.0	2.5	4.4	0.19	0.6	2.9	101.5
41	Gabbro	0.17	0.69	5.6	1.0	51.6	13.3	10.5	8.5	2.8	2.6	0.13	0.2	3.8	101.0
42	Rhyodacite Breccia	0.12	0.93	3.1	1.4	65.6	14.7	1.7	5.7	1.2	4.3	0.26	0.2	1.8	101.0
43	Dacite Breccia	0.11	0.74	7.2	1.1	60.7	15.1	4.6	5.3	1.9	2.4	0.11	0.0	2.8	102.6
44	Gabbro	0.09	0.63	7.2	0.5	60.4	15.7	3.4	4.3	2.1	3.9	0.15	0.4	1.4	100.2
45	Andesite Pillow Lava	0.09	0.64	6.0	1.7	56.2	16.7	5.2	5.8	1.6	3.1	0.13	0.1	2.9	100.2
191	Basalt Pillow Lava	0.17	1.45	11.6	0.7	48.6	14.4	2.4	5.8	1.8	4.3	0.26	6.1	2.8	100.4
193	Basalt Pillow Lava	Initial analysis inaccurate													
194	Basalt Pillow Lava	0.22	1.03	12.7	0.0	41.5	12.7	7.1	8.8	3.3	2.5	0.07	5.5	4.3	99.7
195	Basalt Pillow Lava	0.29	1.05	13.8	0.1	41.5	13.4	5.7	9.1	2.4	2.2	0.06	7.1	4.7	101.4
196	Basalt Ropey Lava	0.26	1.62	11.7	0.5	42.6	13.0	4.4	8.6	3.4	4.2	0.12	6.5	3.2	100.1
197	Basalt Flow	0.32	1.19	10.8	0.0	40.9	12.6	7.2	10.9	3.3	2.9	0.08	6.0	4.3	100.5
198	Basalt Flow	Initial analysis inaccurate													
199	Basalt Pillow Lava	0.28	1.22	7.6	0.2	39.7	14.1	8.0	12.4	6.2	2.8	0.07	1.7	5.0	99.3
200	Gabbro	0.28	1.14	6.7	0.0	42.9	12.5	9.6	12.7	5.2	2.7	0.10	0.1	4.5	98.4
201	Andesite Breccia	0.13	1.50	6.0	1.1	52.5	15.2	3.1	7.3	2.8	3.9	0.41	3.6	3.0	100.5
202	Andesite Pillow Lava	0.14	1.59	6.0	0.9	52.6	14.3	2.9	7.1	1.9	4.7	0.37	5.8	2.4	100.7
203	Dacite Breccia	0.05	0.84	1.6	2.5	61.5	19.3	1.8	5.6	0.9	2.3	0.12	0.9	3.2	100.6
3006	Rhyolite Breccia	0.07	0.61	3.4	1.7	69.8	14.0	1.5	3.8	0.5	3.6	0.10	0.6	1.7	101.4

banding at only one locality on the southwest shore (Fig. 1). On the northeast shore is a small gossan developed on a network of veins of pyrite and minor chalcopyrite associated with quartz-eye-bearing chloritite. Just south of sample locality 10 (Fig. 1), towards the top of the rhyolite unit, is a zone of irregularly distributed pyritic mineralization. North-northeast trending diabase dykes intersect island "B".

The main exhalite zone thus appears to pass between the two islands as indicated on Figure 1. It lies towards or at the top of a prominent rhyolite unit which at the main showing and on island "B" possesses typical stratigraphic hanging-wall alteration. It is overlain by an andesite breccia unit and has probably contributed the sulphide fragments present in that unit. The fragments of massive sulphide found in the glacial drift on island "A" appear to have been plucked from the main exhalite zone by glacial action within a short distance up ice from where they were found.

The Spi Lake area has been extensively faulted. Offsets are to be expected along the diabase dykes and their associated fracture system. In addition, the prominent north-south fracture cleavage axial planar to the anticline east of Spi Lake has been the locus of faulting. Dextral offsets of the older, north 60° east, mineral foliation and bedding have been observed but sinistral offsets may also be present (Fig. 1). Thus, correlation across the axial zone of the anticline is difficult and apparent thicknesses of the major stratigraphic units are only approximate. The siderite exhalite zone in the vicinity of samples 28 and 29 (Fig. 1) may not be correlative with the main Spi Lake zone, as was originally thought, but lie several thousand stratigraphic feet above it. A prominent zone of highly foliated rocks, perhaps a mylonite zone, occurs in the vicinity of samples 195 to 200 on Figure 1. The zone strikes approximately north 45° east and lies exactly along strike from the Kaminak Lake–Quartzite Lake trough of the Hurwitz Group. It may well be a member of the fault system controlling the disposition of the trough and undoubtedly adds to the structural complexity of the area. Considering these factors, it is possible that a block containing the main exhalite zone north of island "A" has been faulted south in the vicinity of the southeast end of the island such that the newly discovered massive sulphide fragments may be within a few feet of their source.

The fold pattern shown on Figure 1 is an attempt to accommodate the diverse and complex relations observed using an "interference" type of fold model. In this case the syncline indicated is a "first" fold and the two anticlines are "second" folds. Regardless of whatever model is used to interpret the folding, the observed pattern is very complex and bedding orientations may be expected to be extremely diverse. More detailed mapping will undoubtedly modify the preliminary pattern.

The chemical analyses (Table I) speak for themselves. The Spi Lake area is obviously one of the world's major concentrations of Archean intermediate to felsic volcanic rocks.

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VOLCANIC ROCKS OF THE PRINCE ALBERT GROUP, DISTRICT OF KEEWATIN

Project 720062

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Detailed mapping of the distribution of the basic remnants of the highly but variably deformed Archean or lower Proterozoic supracrustal rocks which now form the Prince Albert Group was started in NTS 56 J, K. Exemplary assistance was rendered by S. W. Campbell (senior), G. Campbell, L. deBie and P. Marchand (juniors). Base camp was established between June 17 and August 24 on the Hayes River, approximately 156 miles west of Repulse Bay.

The results of most interest include the locating and shipping of soapstone suitable for carving to Repulse Bay and the discovery of sparsely disseminated molybdenite and chalcopyrite in seriate to porphyritic granitic rocks. The establishment of the probable presence of gneissic basement, the presence of a thin ultramafic complex whose areal dimensions must approach that of the Bushveld Complex, and the recognition of areal variation in structural style and metamorphic grade constitute the important geological results.

The rocks of the Prince Albert Group are thought to rest upon a basement of diverse character. One kind of basement gneiss is a foliated and gneissic tonalite. Another kind is a schist-pegmatite complex in which "dent de cheval" up to 10 cm are common and in which at least 4 differently folded sets of pegmatite dykes are emplaced. Other kinds of gneisses, although not easily distinguished from later gneiss, are also thought to be basement. Contacts between Prince Albert Group rocks and basement are not usually exposed or they are masked by ultramafic sills. In one place the unconformity is exposed. Here, vertically foliated tonalite grades over 10 m into well-layered vertically dipping metasedimentary rock. Flattened discs (pebbles?) of felsic material are found in the above interval. One hundred metres away, within a metagreywacke rare crossbeds and ripple-marks indicate the gneiss must underlie the sediment. Indirect evidence that some gneisses are basement is given by the fact that ultramafic dykes traverse them as well as the Prince Albert Group. In younger gneisses the ultramafic dykes have been tectonically disrupted.

Rocks of the Prince Albert Group are mainly schist with only a few rocks preserving primary sedimentary structures. About a third are chlorite or actinolite schists, another third are phyllite, biotite schists, or gneissic metasedimentary rocks. Of the remainder, metamorphosed iron-formations and very pure quartzites are approximately equally abundant. Greenstones and amphibolites constitute a tenth of the belt and limy rocks account for less than 1 per cent of the total. Primary volcanic features noted include cobble and pebble breccias, local tuff horizons as well as quartz and feldspar porphyry dykes. Sedimentary structures are exceedingly rare but crossbedding and ripple-marks have been seen in metagreywacke. The stratigraphy has not yet been solved. Iron-formations structurally underlie metavolcanic rocks and rest upon quartz-rich metasedimentary rocks, yet indicators within the sequence suggest that quartzite is younger than greenstone and iron-formation.

Ultrabasic rocks were emplaced as sills and dykes in the Prince Albert Group near iron-formations and along the unconformity with the gneisses. The ultramafic units vary in thickness from a few metres to hundreds of metres and the lateral extent of the complex is in excess of 300 km (see F. H. A. Campbell, this publ.). Temporally associated but somewhat spatially removed is a thick sill and thin dykes of doubly folded meta-anorthosite with ovoid gabbro emplaced in the Prince Albert Group and basement gneiss. The presence of spinifex texture in the khaki-coloured actinolite biotite bearing dyke rock which cuts the above ultramafic complex but is probably genetically related to it, suggests that the ultramafic complex was emplaced near the surface. The low grade of metamorphism of the ultramafic rocks in NTS 56 K is similar to that noted at Rankin Inlet but no sulphide accumulations were noted.

Gabbro occurs as irregular stock and dyke complexes associated with the metavolcanic rocks. Other gabbro bodies are also commonly found near or cutting ultramafic bodies. Finally, gabbro dykes traverse the region. An older set is sheared and folded; a younger set is fresh diabase and is thought to be part of the Mackenzie swarm.

Metamorphism and intensity of deformation vary in the two map-sheets. Rocks are of low metamorphic grade and are deformed by open but complex and refolded folds in the southwest, whereas rocks are of high metamorphic grade and are deformed by tight refolded isoclinal folds in the east. Kyanite is found in the southwest whereas sillimanite is found farther east. Whether these variations were due to a lateral increase in temperature or due to differential uplift is not certain, but north-south faults whose east side moved up have been mapped in the area. Some of the Prince Albert Group rocks are now gneisses. Attempts to provide criteria which are useful in subdividing gneisses are continuing. Preliminary cluster analysis of specific shape and compositional parameters of gneisses yield statistically significant but geologically complex results.

Within the basement gneisses in a region (91°13'W, 77°56'N) where porphyritic to seriate granite and gneissic granite are the most abundant rock-types, sparse molybdenite and chalcopyrite are found disseminated near, as well as localized on, shear surfaces. The area is small and attempts to define a geochemical halo by testing (by cold extraction) stream silts, and bogs were unsuccessful. Nevertheless, the presence of economically interesting sulphides should renew interest in the granitic rocks in this region. Locally abundant arsenopyrite and pyrite, located near a contact but in a (altered) porphyritic quartz monzonite (93°17'W, 66°14'N) reinforces this notion.

OPERATION NUVILIK, NEW QUEBEC AND NORTHWEST TERRITORIES

Project 720039

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The northernmost portion of Quebec, that is all the area north of latitude 61°N, and the offshore islands of the Northwest Territories, were mapped using helicopter traversing techniques. Although parts of this region had been previously mapped by Quebec government geologists (Beall, 1959, 1960; Bergeron, 1957, 1959; De Montigny, 1959; Gelinas, 1962; Gold, 1962), the entire region was examined to establish uniformity in nomenclature and to assist in correlation and interpretation.

A base camp was established in mid-June in the western part of the map-area and traversing at 4-mile spacing was commenced in those parts of the map-area at low elevations as snow cover at that time of the year was extensive at elevations over 1, 000 feet above sea level. Two Bell G4A helicopters and a DHC_3 Otter equipped with over-size wheels were employed throughout the summer. Excellent weather conditions in New Quebec during the field season aided immensely in the successful completion of the project. The co-operation of the officials and staff of Asbestos Corporation is gratefully acknowledged in particular that of members employed at Asbestos Hill and Deception Bay. Without their unfailing co-operation logistical problems would have been overwhelmingly complex.

The bedrock in the region is entirely Precambrian and the region forms parts of both the Superior and Churchill structural provinces. The Archean rocks are confined chiefly to the southern part of the area. They are primarily granodioritic gneisses and granitic intrusive rocks with local remnants of metasedimentary and metavolcanic rocks. The Archean rocks in the eastern part of the area commonly contain many northwest-trending diabase dykes. Dyke orientations other than northwest also occur but are less common. Structures in the Archean rocks have predominantly northerly trends and commonly are intersected at steep angles by the younger, overlying Proterozoic rocks.

Archean rocks are also present in the Joy Bay–Wakeham Bay region where they are intimately associated with Proterozoic strata. There the Archean rocks have been reworked so that structures in both rock units are commonly parallel. Other granitic gneissic rocks north of the Cape Smith fold belt may include some reworked Archean rocks (Beall et al., 1963) but for the most part are considered to be of Proterozoic age.

The rocks of the Churchill structural province include those forming the Cape Smith fold belt and the gneissic terrain to the north. The Cape Smith rocks form a band of basic volcanic and to lesser extent sedimentary rocks about 50 miles wide. On the south side the contact between the Proterozoic Cape Smith rocks and the Archean rocks is largely an unconformity although locally faults separate these two major rock units. As previously indicated, at the east end of the belt the Archean rocks have been remobilized during the deformation of the Proterozoic strata but the presence of iron-formation in the Proterozoic rocks permits their recognition despite a common structure.

The rocks comprising the Cape Smith fold belt have been divided by Bergeron (1959) into two groups on the basis of a suggested unconformable relationship. According to Bergeron the lower Povungnituk Group lies unconformably on the Archean and the upper Chukotat Group lies unconformably on the Povungnituk Group.

As indicated above the existence of an unconformity between the rocks forming the lower part of the Cape Smith fold Belt and the Archean is well established, however, the present survey did not confirm the presence of an unconformity within the Cape Smith fold belt rocks, that is between the Povungnituk and Chukotat groups. Bergeron (1957) reported the presence of a terrestrial conglomerate at the base of the Chukotat Group on a cliff face about 400 feet above the level of the Chukotat River. A re-examination of this locality indicated that this conglomerate is of very recent, post-glacial origin, and that it contains fragments of twigs, (probably from shrubs) imbedded in a dominantly limonitic matrix. Similarly, re-examination of other localities, shown by Bergeron (1959) as unconformities such as that east of Chukotat Lake and at Lac Beauparlant, shows no evidence of such a relationship. Therefore it is recommended that the division of these rocks into two groups be dispensed with as they do not form separate mappable units. It is further suggested that use of the two group names be discontinued.

The rock types comprising the Cape Smith fold belt are described by the various Quebec government geologists previously referenced and do not, for the most part, require repeating in this short note. However, a few lithologies not previously reported were mapped particularly in the central part of the belt to the south of Nuvilik Lakes. There rhyolite and rhyolite breccia locally form discontinuous bands up to 300 feet thick in the basic volcanic rocks. Rhyolite also occurs approximately 5 miles north of Lac Allemand near the base of the Cape Smith belt. East of Chukotat Lake several outcrops of volcanic breccias, in part containing phenocrysts of biotite up to 2 inches in diameter, occur associated with chert, jasper, tuff and dolomite. Angular fragments of dolomite are locally present in the breccias. These breccias are considered in part at least to be of explosive origin. Somewhat similar breccias occur sporadically to the east-northeast as far as Esker Lake but only near Chukotat Lake are they known to contain biotite phenocrysts.

Rocks comprising the Cape Smith belt show a progressive increase in metamorphic grade from south to north and also from west to east in the vicinity of Wakeham River so that amphibolites, schists and paragneisses form the bulk of the rocks along the northern and eastern parts of the belt. Of particular interest is an extensive area of metamorphosed rhyolite 7 miles west of Lake Watts lying within an area underlain chiefly by amphibolite.

The rocks to the north of the recognizable Cape Smith belt strata consist chiefly of granitic gneisses, paragneisses, amphibolite and granulite. The contact with the rocks to the south is variously a fault or gradational.

The rocks of the belt proper generally trend east-northeasterly to easterly but locally a second trend is apparent with a northwesterly to northerly direction. This second trend is particularly prominent along parts of the northern extremities of the belt.

At the present time the only mineral production is from Asbestos Corporations asbestos property at Asbestos Hill. However, in the past extensive exploration for base metals, particularly nickel, has been carried out. The present survey, disclosed the existence of numerous gossans, many of which do not appear to have been sampled. Extensive zones of carbonatized basic volcanic rocks occur to the north of Nuvilik Lakes and these zones may be worth prospecting.

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COLLECTION OF SAMPLES FOR RADIOCARBON DATING, U.S.S.R.

Project 570148

W. Blake, Jr.
Terrain Sciences Division

In August 1973 samples for radiocarbon dating were collected at three sites in the western U.S.S.R. The collections were made during the course of a trip arranged under the auspices of the Canada-U.S.S.R. General Exchanges Agreement. The sampling on the Kola Peninsula was carried out as a contribution to the developing program of co-operation in Arctic Science, and the collections in the Estonian S.S.R. were made to provide new material for the Geological Survey's continuing program of inter-laboratory age determinations for cross-checking purposes. Both the Kola Peninsula and Estonia were within the boundaries of the Scandinavian Ice Sheet during the last glaciation.

Kola Peninsula

In conjunction with Dr. S.A. Strelkov, Institute of Geology, Kola Branch of the Academy of Sciences of the U.S.S.R., Apatity, and Dr. M.G. Grosswald, Institute of Geography, Academy of Sciences of the U.S.S.R., Moscow, seven days were spent in travelling along the White Sea coast of the Kola Peninsula (Fig. 1). The trip between Kandalaksha and Umba was made by regular coastal steamer, the coast between Umba and Varzuga was traversed by jeep. Two sections were examined, as outlined below.

Kuzreka

About 2 km north of Kuzreka (66°39'N, 34°48'E) two collections of marine molluscs were made from a silt-clay unit which is believed to be of early postglacial age and which overlies coarse boulder gravel interpreted as outwash. The molluscs were collected within 3 m of river level and less than 5 m above high tide level. At present, to the best of my knowledge, the oldest radiocarbon date on postglacial marine molluscs in the western part of the White Sea is one of 9330± 120 years (MGU-IOAN-27; Kaplin et al., 1971; Grosswald, 1972; date quoted as 9530±120 in the latter report). The shells used for this determination were from a depth of 150 to 196 cm in a core taken near the northern part of the Solovetskiy Archipelago, in 17 m of water. It is hoped that determinations on the new samples, which were taken along a coast adjacent to the deep water trough leading to Kandalaksha, will provide useful data about the pattern of deglaciation of White Sea, parts of which are believed to have opened up as early as Alleröd time (cf. Armand and Grave, 1966; Medvedev and Nevesskiy, 1971; Hyvärinen, 1973).

Varzuga

Approximately 90 km to the east-southeast of Kuzreka, and some 2 to 3 km downstream along the Varzuga River from the village of Varzuga (66°24'N, 36°38'E), a section was investigated in which marine deposits are overlain by till. A sample of marine molluscs was collected from a compact clay-silt unit exposed at river level. This unit is believed to be more than 40,000 years old, and it is one of the westernmost localities known from the Kola Peninsula where marine deposits predating the last glaciation occur along the

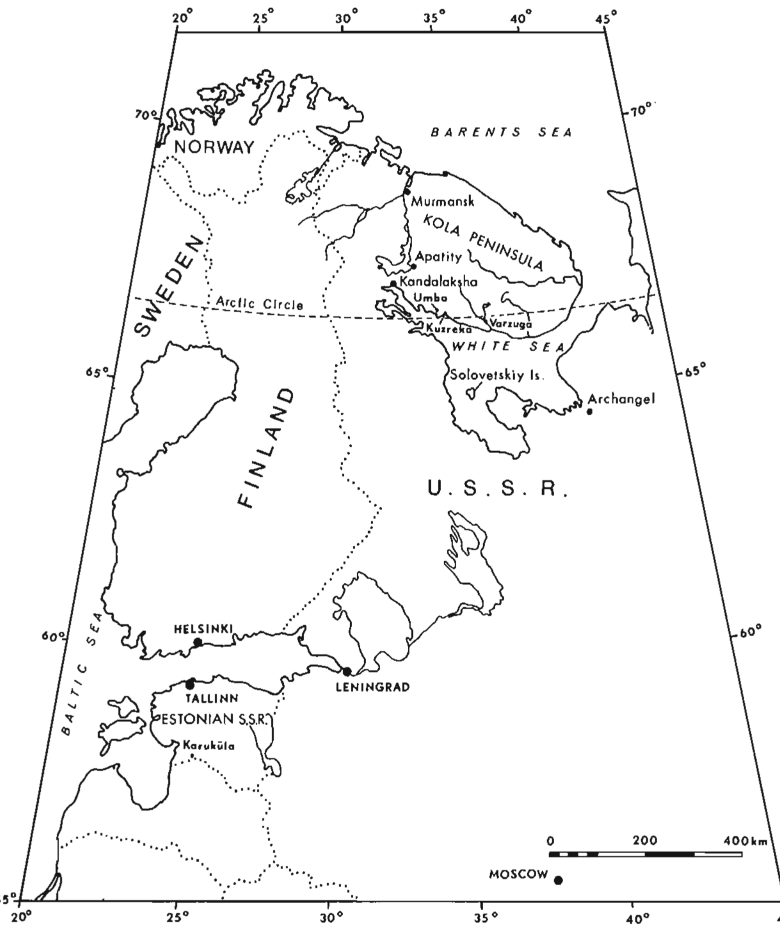

Figure 1. Location map

south coast (Evzerov et al., 1972). At the time of our visit two molar teeth and assorted pieces of bone, believed to be of mammoth, were found in marine silt a few metres above river level.

Estonian S.S.R.

Together with Drs. J-M. Punning and A.V. Raukas of the Geological Institute, Academy of Sciences of the Estonian S.S.R., Tallinn, a one-day visit was made to the Karuküla Interglacial site (58°04'N, 25°00'E) in southwestern Estonia, some 7 km south of the village of Kilingi-Nõmme (Fig. 1). Samples of both wood and the underlying peat were collected from the organic layers at 160 to 190 cm depth, beneath the surface till. The ages of both types of material will be determined by two or three radiocarbon dating laboratories. Previous age determinations on the organic deposits at this site have been done mainly by the laboratory at Tartu University, Estonia. Finite dates of 33,450±800 years (TA-99; Punning et al., 1968) and 40,800±700 years (TA-275; Kajak et al., 1970) have been obtained on the wood, but the samples used for TA-275 have also been dated at >48,750 years by Birmingham University (Birm-249; Shotton and Williams, 1973). Most dates on the underlying peat also have been finite in the 46,000 to 50,000 year-range although a determination made at the Vernadskiy Institute of Geochemistry and Analytical Chemistry in Moscow was >33,000 years (Mo-375; Vinogradov et al., 1968) and a determination on clayey sapropelite beneath the peat was >45,000 years (TA-106; Punning et al., 1968; Kajak et al., 1970).

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Project 690044

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Terrain Sciences Division

An exposure of the Beaufort Formation on Meighen Island (Fig. 1) was investigated by the author in 1968, and collections were made from the organic layers which overlie a sand unit and underlie coarse gravel (Fig. 2; Table 1). The "lower peat horizon", which proved to be richest in macrofossils, yielded the following taxa.

HEPATICAE

Porella sp.

MUSCI

Sphagnum sp. cf. *recurvum* B. Beauv.

Pogonatum alpinum (Hedw.) Rohl.

Polytrichum juniperinum Hedw.

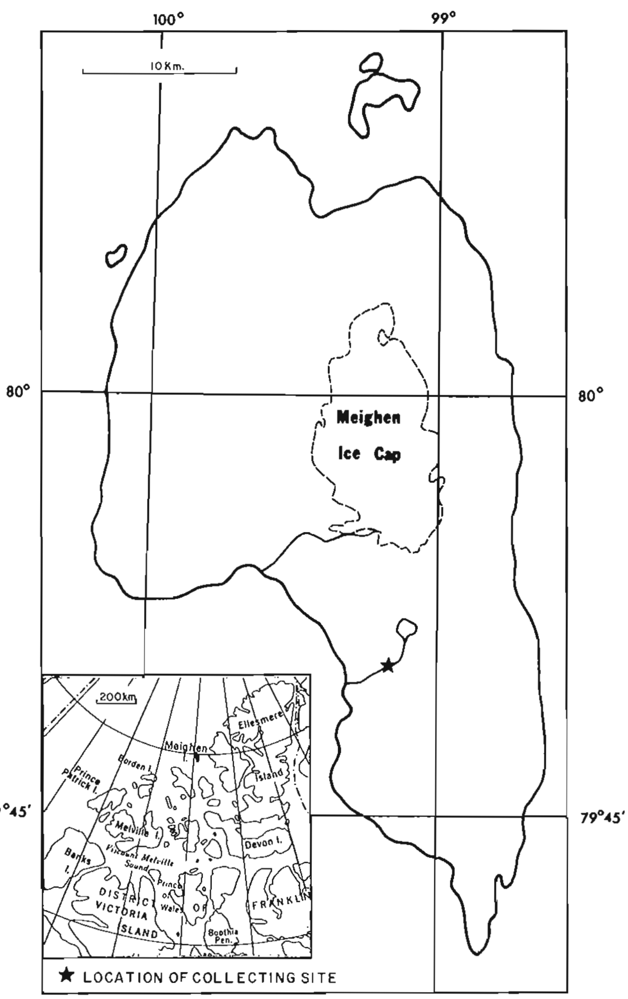

Figure 1. Location of collecting site on Meighen Island, N.W.T.

Ditrichum flexicaule (Schwaegr.) Hampe

Oncophorus wahlenbergii Brid.

Dicranum leioneuron Kindb.

Grimmia apocarpa Hedw.

Rhacomitrium microcarpum (Hedw.) Brid.

Mniobryum wahlenbergii (Web. et Mohr) Jenn.

Pohlia nutans (Hedw.) Lindb.

P. cruda (Hedw.) Lindb.

P. sp. Sect. *Eupohlia*

Bryum pseudotriquetrum (Hedw.) Gaertn. Meyer et Scherb.

Mnium marginatum (With.) Brid.

M. affine Bland.-sensu latissimo

M. cinclidioides Hub.

M. hymenophyllum B.S.G.

Cinclidium latifolium Lindb.

Aulacomnium palustre (Hedw.) Schwaegr.

Paludella squarrosa (Hedw.) Brid.

Meesia uliginosa Hedw.

Philonotis tomentella Moll.

Timmia austriaca Hedw.

T. norvegica Zett.

Climacium dendroides (Hedw.) Web. et Mohr

Myurella tenerrima (Brid.) Lindb.

Thuidium abietinum (Hedw.) B.S.G.

Drepanocladus uncinatus (Hedw.) Warnst.

D. revolvens (Sw.) Warnst.

D. exannulatus (B.S.G.) Warnst.

D. lycopodioides (Brid.) Warnst.

Campylium polygamum (B.S.G.) C. Jens.

Calliergon giganteum (Schimp.) Kindb.

C. richardsonii (Mitt.) Kindb.

C. aftonianum Steere

C. orbicularicordatum (Ren. et Card.) Broth.

Tomenthypnum nitens (Hedw.) Loeske

Brachythecium sp. Sect. *Velutina*

Pleurozium schreberi (Brid.) Mitt.

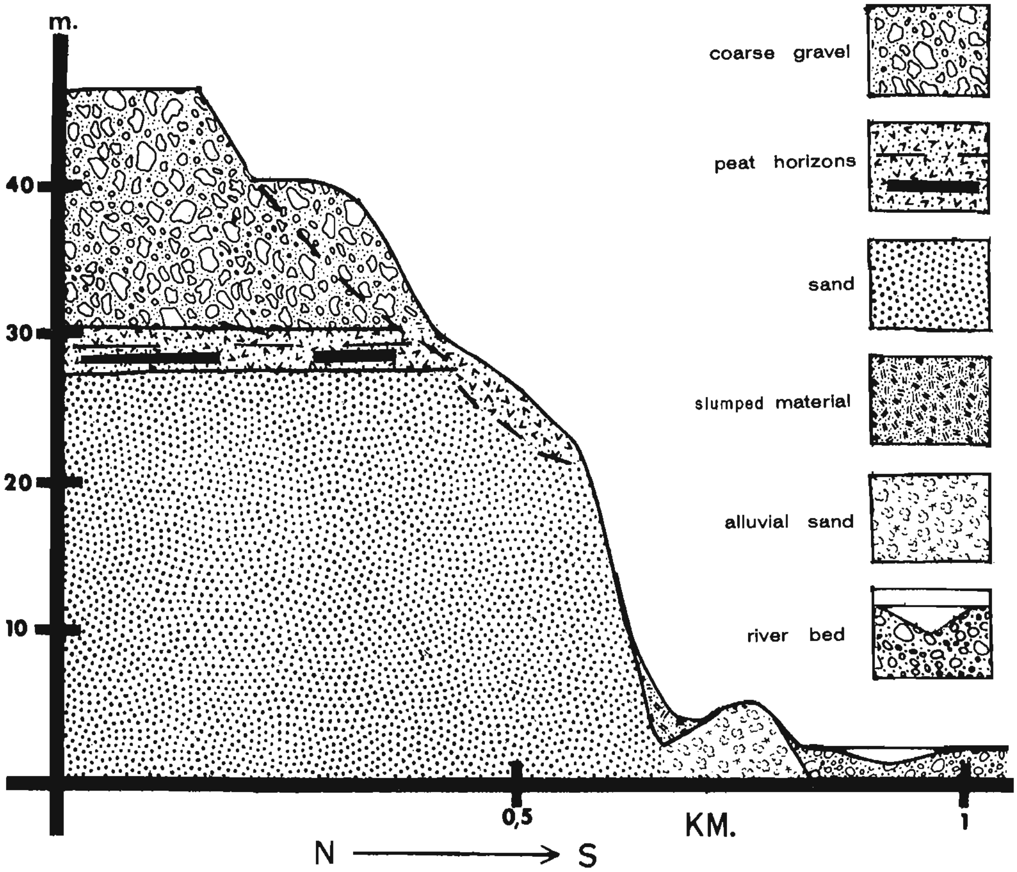

Figure 2

Schematic profile of strata studied. Vertical scale is in metres above river level.

Hypnum hamulosum B. S. G.

H. sp.

Hylocomium splendens (Hedw.) B. S. G.

SPERMATOPHYTA

Coniferae (parts of logs, chips of wood, branches, etc., belonging to more than one species)

Salix sp. (branches, leaf parts)

Dryas sp. (leaves)

Carex sp. (perigynia, rhizomes)

Gramineae (undeterminable leaf parts)

MISCELLANEOUS

Ostracoda, Insecta, plankton

This flora, excluding the critical taxon *Calliergon aftonianum*, does not contain extinct species. All taxa are representatives of the present-day circumboreal vegetation. *Porella* sp., *Dicranum leioneuron*, *Mnium cinclidioides* and *Climacium dendroides* do not grow now in the Canadian Arctic Archipelago. *Sphagnum* sp., *Paludella squarrosa*, *Thuidium abietinum*, *Drepanocladus lycopodioides(?)*, *Calliergon orbicularicordatum*, *Brachythecium* sp., and *Pleurozium schreberi* are rare plants of the Archipelago; they occur in isolated localities mainly in the southern parts. Other mosses are more or less common components of tundra growth.

The paleoecological significance of the fossils listed above indicates the boreal forest character of the vegetation. Communities included a forest dominated by coniferous trees, moss-bogs composed of species now representative of several gradients of wet tundra, *Sphagnum* peats, and dry habitats, including bare rock.

Table 1

Lithological data for the profile shown in Figure 2

Thickness in metres	Deposit	Distribution of plant macrofossils
17	Coarse gravel: rounded pebbles and occasional angular boulders	Occasional fragments of compressed and uncompressed logs and chips of wood irregularly distributed in the upper parts of the layer
2	Two peat horizons interbedded with silt and gravel	
	A - Upper peat horizon: fibrous, brown, woody, more or less compressed; continuous strata	Mostly well preserved stems of *Calliergon* and Drepanocladus with thin woody twigs and rare, compressed, brown log fragments
	B - Lower peat horizon: indistinctly fibrous, black, shiny when wet, strongly compressed, woody, slightly humified and silty; flat lenses or discontinuous strata	Mainly mosses of various ecological groups, mixed with thin, woody branches and occasionally associated with black, strongly compressed and deformed log fragments coated by peat
28	A sequence of fine-grained, grey, yellow and greenish sand with thin lenses of clay and thin discontinuous strata of plant detritus	Amorphic, strongly compressed, black detritus. Amount of organic material increases upwards. Fragments of wood absent

POLLEN ANALYSIS OF SURFACE SNOW FROM THE DEVON ISLAND ICE CAP

Project 690064

Sigrid Lichti-Federovich
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Introduction

Six samples of snow from the upper 0.5 m of the Devon Island Ice Cap, collected by Dr. R.M. Koerner (Polar Continental Shelf Project, Department of Energy, Mines and Resources) in June 1973, were submitted for pollen analysis. The sampled layer represents one year's snow accumulation. The results are of interest in relation to Arctic pollen dispersal and phenology.

The Devon Island Ice Cap, occupying the eastern portion, comprises about one third of the island area, and ranges in elevation from 600-1885 m a.s.l. (Koerner, 1970). The samples were taken from the centre of the ice cap at Summit Station, which is at 1885 m a.s.l.

Sampling and Laboratory Techniques

The upper 60 cm of snow were sampled by pooling subsamples from each 10 cm interval, covering a horizontal extent of ca. 5.5 square metres. The aggregate meltwater for each of the six 10-cm units was then filtered. Each of the aggregate samples yielded 30 to 35 kg of water. This was passed through 5 micron gauge 25 mm cellulose triacetate filters. The filters and residue were treated with cold HF (50%) overnight, glacial acetic acid, acetolysis mixture and glacial acetic acid; the preparations were then mounted in glycerine for microscopic examination.

Regional Features

Devon Island is in the High Arctic, both in its climatic and biogeographical characteristics. The vegetation and flora of the Truelove Lowland region, on the north coast immediately to the west of the ice cap, have been described by Barrett and Teeri (1973) and by Bliss (1971, 1972). The extensive lowland areas with saturated soils in summer, are occupied by continuous sedge-meadow communities dominated by *Carex stans, C. membranacea, C. misandra, Eriophorum triste, E. angustifolium, Arctagrostis latifolia* and *Salix arctica*. Numerous raised beaches are dominated by *Saxifraga oppositifolia, Salix arctica, Carex nardina, Dryas integrifolia* and lichens. Rock outcrops are dominated by lichens, and snowpatch sites show local dominance of *Cassiope tetragona.*

Results

Koerner (pers. comm.) reports that the upper 50 cm of snow showed no indication of meltwater percolation and probably represent the accumulation from the summer of 1972 to the date of collection. Below the 50 cm level there is evidence of meltwater derived from last summer's (1972) snow.

The results of pollen analysis of the 10-cm interval samples are summarized in Table 1 and Figure 1. A total of 600 pollen grains were identified. The upper two segments are dominated by *Pinus, Betula* and *Alnus*, all types of exotic origin. The 30 to 40, and 40 to 50 cm segments are dominated by local or regional pollen types (Cyperaceae, Gramineae, *Salix* and Ericaceae).

Discussion

Caution must be exercised in the interpretation of these data. The obvious sources of potential error are: 1) the assemblages contain a mixture of pollen of exclusively exotic origin (spruce, pine, alder, birch and ragweed) and pollen which might be derived from local (adjacent land surfaces of Devon Island) or more distant tundra regions; 2) increments of equal vertical extent might represent quite different time intervals because of variable snow accumulation rates; 3) percolation of meltwater might cause differential displacement of pollen downwards; 4) some pollen might be of secondary origin; 5) some pollen might have been destroyed by oxidation.

The evidence from the snow sections (Koerner, pers. comm., 1973) suggests that point 3) above can be disregarded. The other sources of variability remain pertinent.

If it is assumed that no vertical displacement of pollen has occurred, the substantial differences between the pollen spectra of the five samples suggest differences in either temporal or spatial provenance. The spectra from the upper samples (0 to 10, 10 to 20 cm) show high proportions of exotic pollen from plants which flower in early summer in the taiga region (e.g., pine, alder, birch). The lower samples (30 to 40, 40 to 50 cm) show high proportions of types which flower in mid-summer and probably have more local origins (e.g., willow, heath, grass and sedge). The 20 to 30 cm level shows a spectrum with intermediate proportions of spring and summer flowering types. Tentatively it might be concluded from the palynological data that the 30 to 50 cm layer was deposited in mid- to late-summer 1972 and that the 20 to 30 cm layer was deposited in winter 1973 (exotic alder, birch and willow). The assemblages from the 0 to 20 cm interval suggest spring 1973 deposition.

The composition spectrum (Table 1) shows a surprisingly high proportion of pollen of apparent local origin and relatively low frequencies of exotic pollen. A comparable spectrum from Cornwallis Island (Ritchie and Lichti-Federovich, 1967) shows higher proportions of exotic types, and the findings of Środoń (1960) and Hyvärinen (1970) also record

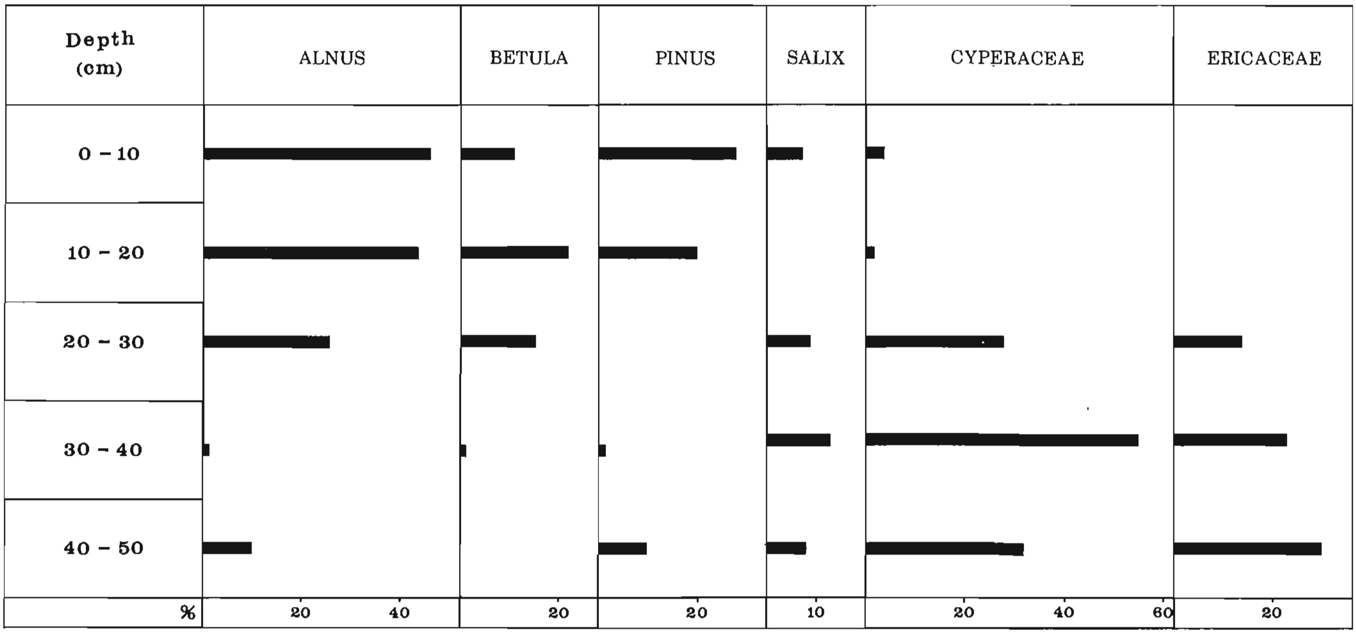

Figure 1. Bar diagram showing percent frequencies of the main pollen types.

TABLE 1

Pollen totals from snow samples from the Devon Island Ice Cap

	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	Total	% of S
Picea		1	1		1		3	0.49
Pinus	15	11		6	5	1	38	6.25
Ulmus				1			1	0.16
Betula	6	12	9	3			30	4.93
Alnus	25	24	15	4	5		73	12.00
Salix	4		5	52	4		65	10.69
Ericaceae			8	90	15		113	18.58
Gramineae	1		3	5			9	1.48
Cyperaceae	2	1	16	214	16		249	41.50
Amrosiae	1	3		2	2		8	1.31
Chenopodium					1		1	0.16
Artemisia		1					1	0.16
Polygonaceae				5			5	0.82
Rosaceae				1			1	0.16
Ranunculaceae				1			1	0.16
Lycopodium selago				2			2	0.32
Unidentified		1	1	5	1		8	1.31
Total	54	54	58	391	50	1	608	Pollen-spore sum

higher proportions of exotic pollen from High Arctic samples.

These results suggest that pollen analysis of the accumulation layers of ice caps has some potential value, provided that the several sources of variability and uncertainty are fully accounted for.

Future investigations require precise sampling techniques in order to measure more accurately seasonal fluctuations in pollen deposition, as well as the dilution effect of rapid snow deposition and the holding capacity of snow masses. Sampling at intervals of a few days is necessary to provide a basis for the correlation of pollen dispersal to local air circulation and long distance airmass movements.

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73. *NAJAS GUADALUPENSIS* (SPRENG.) MORONG. IN THE MISSINAIBI FORMATION, NORTHERN ONTARIO

Project 690064

Sigrid Lichti-Federovich
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A noteworthy paleofloristic record was made during megafossil analysis of peat samples collected from the Missinaibi Formation by R.G. Skinner, Geological Survey of Canada, in 1972. These beds of interglacial peat and silt (Skinner, 1973) occur at Moose River Crossing (50°19'N, 81°18'W) in northern Ontario within the James Bay lowlands. A total of 20 seeds of *Najas guadalupensis* (Spreng.) Morong. was recorded from peat samples. A complete report of the megafossil analysis and pollen stratigraphy of this material will be published separately.

Certain identification of seeds of *N. guadalupensis* is not difficult, since their dull, coarsely reticulate testae are quite distinct from all other *Najas* species, and particularly from the abundant *N. flexilis.*

The assemblages of microfossils and megafossils show remarkably little variation. Pollen analysis has confirmed Terasmae's (1958, 1960) earlier findings of a a fairly constant assemblage throughout the section, dominated by *Picea* (50-60%), associated with *Pinus* (20-32%), *Betula* (5-10%), *Larix* (1-5%) and *Alnus* (2-5%). Other plant megafossils associated with *Najas guadalupensis* are *Chara, Nitella, Typha, Hypericum, Carex, Potamogeton, Menyanthes, Viola, Nuphar, Nymphaea, Hippuris vulgaris* and *Najas flexilis.*

This record of *Najas guadalupensis* is notable because of the paleofloristic implications. The pollen and seed assemblages, with the exception of *Najas guadalupensis,* are similar to modern assemblages from conifer dominated boreal forest or taiga areas of northern Canada. However, *N. guadalupensis* is a southern species with its main North American distribution area in the Mississippi River basin and along the southeastern Coastal Plain (Clause, 1936; Fassett, 1966); it also occurs in South America. The northernmost record in Ontario is from Rideau Ferry (44°51'N, 76°08'W), Lanark County (W.J. Cody, pers. comm., 1973), which is situated within the Great Lakes - St. Lawrence mixed deciduous-coniferous forest region at a distance of 775 km from Moose River Crossing.

The occurrence of this species of southern affinity in an assemblage of plants of distinctly boreal-northern provenance is of interest. The species has not been recorded previously in pre-Wisconsin sediments of Canada, although it has been found by Grüger (1972) in sediments of Farmdalian and older age in south-central Illinois.

The most likely explanation for the apparent anomaly of its association with species of different floristic and ecological affinity is that it occurred at this site during some non-glacial late-Quaternary episode as a northern ecotype which has either not been recorded so far in modern communities or has not persisted to the present day. In his monographic treatment of the genus *Najas,* Clausen (1936) describes *N. guadalupensis* as "an aggregate species" presenting "a decidedly heterogeneous aspect"; this strengthens the above hypothesis accounting for these records.

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A PRELIMINARY LIST OF INSECT FOSSILS FROM THE BEAUFORT FORMATION, MEIGHEN ISLAND, DISTRICT OF FRANKLIN

Project 730027

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Introduction

The Beaufort Formation, consisting of unconsolidated sands, gravels and organic sediments, is exposed primarily along the western islands of the Queen Elizabeth group, from Meighen Island in the north to Banks Island in the south (Craig and Fyles, 1960; Fyles, 1965; Hills, 1969; Thorsteinsson, 1961; Thorsteinsson and Tozer, 1962). It has long been thought to encompass the late Tertiary and early Quaternary, but recent paleobotanical studies seem to indicate that at least the southern exposures are exclusively of middle to late Tertiary age (L. V. Hills, pers. comm., 1972, 1973).

During mid-July of 1973, with Polar Continental Shelf Project support, L. V. Hills and the author collected fossil plants and insects from Beaufort exposures in the southern part of Meighen Island (80°N), near to the locality described by Kuc (this publication, report no. 71). The sequence examined by Hills and the author consists of approximately 60 metres of fine to coarse fluvial sands with interbedded organic zones that are largely confined to former channel scars. Like Beaufort exposures to the south (Fyles, 1965; Hills, 1969), two depositional units are present, though there is no evidence that their mutual contact is angularly unconformable (Hills, 1969). On Meighen Island the Beaufort Formation is overlain by reworked till or a lag deposit of glacially striated cobbles, and is underlain by marine clay, whose presence beneath the Beaufort sands and gravels was first reported by J. G. Fyles (in Caley et al., 1962). The clay has yielded an assemblage of foraminifera which when studied should allow a statement as to the maximum age of the Beaufort Formation on Meighen Island. Peats within the Beaufort Formation include evidence of mammals (small mammal feces), indicating that bulk sampling and screening might be repaid by the discovery of identifiable fossils of chronologic significance. For the present, however, assessment of the age of the Beaufort sediments on Meighen Island must rely on paleobotanical data. Preliminary study of the plant fossils collected in 1973 by L. V. Hills and the author indicates that the sediments are probably no younger than Pliocene and may be as old as the Miocene (L. V. Hills, pers. comm., 1973).

Contemporary Meighen Island

An extremely impoverished flora (Savile, 1961) in combination with the ubiquitous occurrence of Beaufort Formation sands and gravels (Thorsteinsson, 1961) causes the landscape of Meighen Island to resemble a giant gravel pit. In fact, it is a good example of a high Arctic polar desert.

The insect fauna of the island is also impoverished. McAlpine (1965) records only two resident invertebrates; however we collected examples of at least two additional species, and the presence of the lemming *Dicrostonyx* (represented by one unoccupied nest) strongly suggests that some of the arthropods associated with it on neighbouring Ellef Ringnes Island (McAlpine, 1965) ultimately will be found on Meighen. Coleoptera, Hymenoptera, Homoptera (see Table 1) do not now occur on the island.

In addition to the evidence of *Dicrostonyx* and Arctic fox, the author and L. V. Hills observed caribou (with calves) and an Arctic hare while on the island.

Nearly all of the islands surrounding Meighen, even those extending farther north, have more diverse faunas and floras (McAlpine, 1965; Savile, 1961). In other words, Meighen Island is near the biotic pole of North America. As McAlpine (1965) has indicated, its present environment is marginal for existence of all life forms, especially invertebrates. Compare this environment with that which must have existed on the island during the late Tertiary (see below).

Fossils

A preliminary list of fossils of insects and related arthropods from the Beaufort Formation is presented in Table 1. Most of the fossils on the list are from Meighen Island, but a few come from exposures of the upper member of the Beaufort Formation at Ballast Brook on the northern side of Banks Island (Hills and Ogilvie, 1970). A thick lignitic forest bed in the lower unit of the Beaufort Formation at Ballast Brook (Hills, 1969) has yielded surprisingly few insect fossils (none reported in Table 1), and in general insect fossils from the upper unit are much rarer than in Beaufort sediments on Meighen Island. The reason for this distinction is not clear; however, it may be related to the fact that the peaty sediments on Meighen Island seem to be of a more autochthonous character than those on Banks Island.

Discussion

Unlike most Tertiary insect fossils (e.g., Rice, 1959; Darlington, 1969), those listed here consist of unaltered insect fragments rather than impressions, casts, or inclusions in amber. Most of the fossils represent heads, pronota and elytra of beetles (see Fig. 1, this publication, report no. 71). Rarely these were recovered in a semi-articulated state which greatly enhances the possibility of a specific determination. For many beetles, however, especially Carabidae, isolated pronota and elytra or fragments

TABLE 1

FOSSIL ARTHROPODA — BEAUFORT FORMATION, BANKS AND MEIGHEN ISLANDS

Taxon	Sample
INSECTA	
Homoptera	
Cicadellidae "leaf hoppers"	
Athysanella sp[1]	14[2]
Genus?[1]	14
Coleoptera	
Carabidae "ground-beetles"	
Trachypachus cf. *holmbergi* Mann	5[1]
Carabus sp.	5
Pelophila cf. *borealis* Payk.	5
Opisthius cf. *richardsoni* Kirby	9
Notiophilus cf. *directus* Casey	5
Diacheila cf. *polita* Fald.	11, 9, 5
Blethisa cf. *multipunctata* L.	5
Elaphrus sp.	9, 5
Asaphidion cf. *alaskanum* Wick.	9, 5
Bembidion (Plataphodes) sp.	9, 5, Bks
B. (Peryphanes) sp.	9
B. cf. *bimaculatum* Kirby	9
Tachys?	Bks
Pterostichus (Derus?) sp.	9
P. (Cryobius) spp.	9, 5, 11
P. cf. *punctatissimus* Rand.	9
P. cf. *agonus* Horn	9, 5
Asonum (Stictanchus) sp.	5
Agonum cf. *cincticolle* Say	5
Dytiscidae "predaceous diving beetles"	
Hydroporus sp.	9, 14
Agabus?	11
Ilybius?	5
Colymbetes sp.	9
Hydrophilidae "water scavenger beetles"	
Helophorus cf. *tubercalatus* Gyll.	5
Staphylinidae "rove beetles"	
Micropeplus sp.	Bks
Bledius sp.	5
Acidota sp.	14
Pycnoglypta cf. *lurida* Gyll.	14
Micralymma cf. *brevilingue* Schiodt.	5, 9
Omalinae, Genus?	5
Stenus sp.	5, 14
Tachinus sp.	5, 9
Tachyporinae, Genus?	Bks
Gymnusa sp.	5
Aleocharinae, Genus?	11
Silphidae "carrion beetles"	
Phosphuga cf. *atrata* L.	5
Byrrhidae "pill beetles"	
Simplocaria sp.	9
Morychus?	5
Byrrhus sp.	5
Elateridae "click beetles"	
Hypolithus cf. *sandborni* (Horn)[3]	5
Anthicidae "ant-like flower beetles"	
Genus?	
Curculionidae "weevils"	
Alophinae, Genus?	5
Lepyrus spp.	5
Grypidius cf. *equiseti* Fab.	9, 5
Notaris sp.	9, 5
Ceutorhynchus sp.	5
Diptera	
Coenomyiidae	
Xylophagus sp.	5
Chironomidae	
Genus?	9
Hymenoptera	
Apocrita — heads and thorasic fragments	all samples
ARACHNIDA	
Acari	
Oribatidae "oribatid mites"	
Cepheus cf. *corae* Jacot	14
Fossils of several other genera	14, 5

1. Identified or examined by K. G. A. Hamilton, Biosystematics, Canada Dept. Agriculture; Ottawa.
2. Numbers or letters refer to samples from various localities.
Numbers: Meighen Island, N. W. T.; "Bks": Banks Island, N. W. T. (upper Beaufort Formation).
3. Identified by E. C. Becker, Biosystematics, Canada Dept. of Agriculture, Ottawa.

thereof are sufficient by themselves for identification to the species level; hence the relatively large number of specific names in Table 1.

Evolution

All specific determinations in Table 1 are listed as tentative because of the small number of fossils that have been studied; nevertheless, it is clear even at this early stage of the project, that some fossils (e.g. those referred to *Trachypachus holmbergi, Opisthius richardsoni, Diacheila polita, Grypidius equiseti)* are within the range of variation of those extant species, this being further evidence for the extreme longevity of some beetle species (Coope, 1970). In contrast other fossils seem to be from species which are near but probably not conspecific with those to which they are tentatively referred. No doubt some of these represent species ancestral to those in the contemporary fauna. A similar mixture of extant and extinct(?) species was noted in the study of another northern Tertiary insect assemblage (Hopkins et al., 1971).

Paleoenvironments

Despite the preliminary nature of the list in Table 1, several conclusions on the nature of the former local and regional environment are possible. But the following statements refer only to Meighen Island since insect fossils from Banks Island are too rare to justify any paleoenvironmental conclusions.

In view of the fact that the organic sediments yielding the fossils are part of an alluvial sequence, it is to be expected that the living counterparts of taxa listed in Table 1 are now found near or in water. For example, dytiscid beetles, fossils of which were rather abundant, inhabit quiet to slowly moving water, while beetles of the genera *Blethisa, Pelophila, Gymnusa,* and the species *Helophorus tuberculatus* occur today within the zone of marginal and emergent vegetation surrounding ponds and lakes (Lindroth, 1961; Angus, 1973). This means that some of the ponds which existed on Meighen Island were semi-permanent, not simply temporarily blocked river channels.

Fossils of the weevil *Grypidius* cf. *equiseti* are abundant in some samples, which indicates that the food plant of *G. equiseti* - *Equisetum* (Cawthra, 1957) — was also locally abundant.

Presence of open scantily vegetated flood plain sites is indicated by fossils of *Opisthius, Asaphidion,* and possibly *Elaphrus.* Sites more removed from the stream system are represented by the fossils of *Trachypachus* cf. *holmbergi, Pterostichus* cf. *punctatissimus,* and *Agonum* cf. *cincticolle,* (Lindroth, 1961, 1963, 1966).

The regional implications of the Meighen assemblage are more interesting, because Table 1 includes taxa which are characteristic now of tundra as well as others which occur today only south of the treeline. For example *Micralymma brevilingue* is presently found only in Arctic treeless areas, while *Diacheila polita, Asaphidion alaskanum* and many species of the subgenus *Cryobius* (represented here by at least three fossil species) are primarily tundra animals. In contrast *Opisthius, Trachypachus,* and other genera on the list have their present northern limit within the boreal region, south of the treeline. Therefore it seems likely that Meighen Island was in a zone of forest-tundra during Beaufort time, a conclusion amply verified by the composition of the plant macrofossil assemblage (L.V. Hills, pers. comm., 1973) and the relatively small size of Beaufort Formation tree fragments on Meighen Island.

Existence of a forest-tundra environment on Meighen Island may mean that true tundra existed contemporaneously in regions only slightly farther north (northern Axel Heiberg Island, northern Ellesmere Island, and northern Greenland). In other words when the age of the Beaufort Formation of Meighen Island is established, we will likely know the minimum age of the lowland tundra biome. As indicated above, the present estimate is Miocene-Pliocene.

Zoogeography

The Meighen Island assemblage contains insect taxa which now have their northern limit more than 800 km to the south. Moreover, some of the insects listed in Table 1 (e.g., *Opisthius, Trachypachus, Agonum cincticolle)* are now restricted to far western or far eastern North America (Lindroth, 1961, 1966). Apparently during the late Tertiary these insects or their immediate progenitors had northern, but transcontinental distributions. Just how and why insects living on centrally located Meighen Island (long. 100°W) during Beaufort time came to be restricted today to more western or eastern sites are intriguing questions.

New insight on the history of the present North American insect fauna is provided by Meighen fossils, representing taxa that are either absent today in North America or which do not presently occur in the boreal region. The silphid beetle genus *Phosphuga* is not known from North America, though the group of carrion beetles in which it belongs is well represented (Arnett, 1963). The entire group of species and genera (tribe) to which one of the leafhopper fossils is related is presently absent from North America (K.G.A. Hamilton, pers. comm., 1973). The carabid beetle, *Notiophilus directus,* though present in North America seems to be restricted to the central portion of the western mountain ranges (Lindroth, 1961).

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FOSSIL INSECTS FROM THE EARLY PLEISTOCENE OLYOR SUITE (CHUKOCHYA RIVER: KOLYMIAN LOWLAND, U.S.S.R.)

Project 730027

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Terrain Sciences Division

Introduction

The study of Quaternary insect fossils has proved to be a valuable technique for defining past environmetal conditions and determining the origin of the distributional patterns of certain insect species (Coope, 1970; Matthews, in press; Ashworth and Brophy, 1972; Ashworth et al., 1972). The use of such information, supported by other paleoecological data, makes it possible to suggest that unglaciated Alaska possessed a unique steppe-tundra environment during the late Pleistocene. It would be interesting to compare such findings with those resulting from study of fossil insects from Siberia, but unfortunately, to date, no such studies have been performed.

This report, based on Siberian fossils submitted to the author by A.V. Sher (Paleontology Institute, Academy of Science, U.S.S.R.) is the first to deal with an assemblage of Quaternary insect fossils from Siberia. It is part of a jointly authored manuscript (Matthews and Sher, in preparation) intended for Russian language publication in a Soviet journal.

Sample Localities and Age

All fossils discussed below come from various sites at exposures of the Olyor Suite, a sequence of silts, sands and peats occurring on the right bank of the Chukochya River ($69^{\circ}05'$N) in the lower Kolymian Basin, northeast Siberia (Fig. 1 and Sher, 1970). According to the mammalian fossils from Olyor sediments the suite is of middle Pleistocene age (Mindel, Mindel-Riss) (Sher, 1970; Vangengeim and Sher, 1970). Further details on the stratigraphy, dating of the sediments,

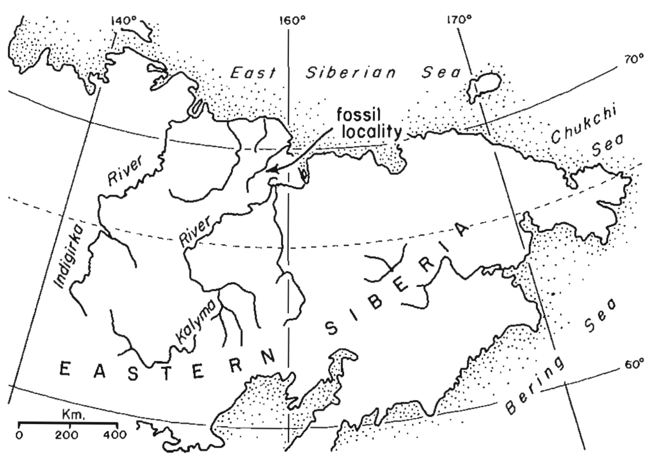


Figure 1. General location of the Olyor Suite exposures.

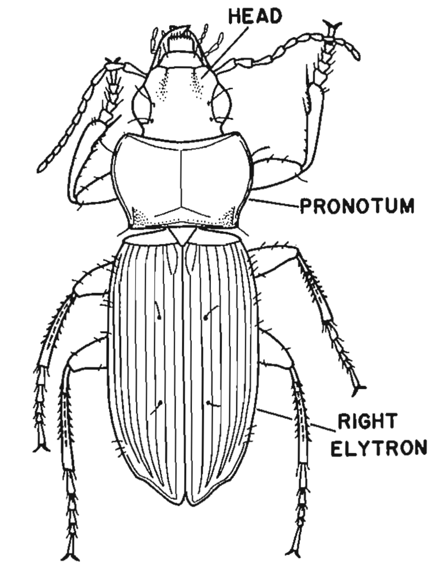


Figure 2. Dorsal view of generalized carabid beetle (Carabidae, Coleoptera), showing parts which most often occur as fossils.

and precise locations for samples listed in Table 1 are given in Sher (1970) as well as in Matthews and Sher (MS. in preparation).

Quaternary Insect Fossils

Most Quaternary insect assemblages are dominated by Coleoptera (beetles). Whole or fragmented beetle heads, elytra and pronota (Fig. 2) are abundant; but for the purpose of identification, fossil pronota usually possess the most critical morphologic characters, i.e., shape, size, type of posteriolateral fovae, etc. This is especially true for "ground-beetles" (Carabidae), a fact to be noted by those attempting to make field collections of insect fossils for later identification since pronota are smaller, less conspicuous, and much more likely to be overlooked than elytra or elytra fragments (see Fig. 2). In order to ensure a good representation of all diagnostic fossils, the best procedure is to collect bulk samples of sediments suspected of containing insects. These samples may be sieved at the site or later in the laboratory with 0.5 mm screens after which a technique developed by Coope (1961) is used to concentrate the insect fossils so that they may be easily isolated using a lower power microscope. It is best to keep all fossils recovered by this method in alcohol or glued to micropaleontology slides similar to the type used for Foraminifera.

Even under the best conditions of preservation, insect fossils such as those discussed here, consist only of fragments of the insect. In rare cases semi-articulated fossils do occur (none in the Olyor samples), but these usually lack fragments of the legs, antennae, genitalia or other critical characters commonly cited in the dichotomous keys used for identification of contemporary insects. While detailed taxonomic descriptions sometimes aid in identification of fossils, actual comparison of the fossils with contemporary museum specimens is often necessary. Thus a prerequisite of any study of Quaternary insect fossils is availability of reference specimens — in this case those from the Canadian National Collection (Ottawa), Strickland Museum (University of Alberta), Zoological Museum (Helsinki), and Matthews' personal Coleoptera collection.

Olyor Fossils

Table 1 is a list of fossil insects collected by A.V. Sher at several exposures of the Olyor sediments. Data on the distribution and habitat requirements of the listed species is also presented. Except for a few fossils retained by Matthews in Canada, all specimens studied in preparation of this report are now part of

TABLE 1

FOSSIL INSECTS FROM THE OLYOR SEQUENCE, CHUKOCHYA RIVER, KOLYMIAN LOWLAND (U.S.S.R.)

COLEOPTERA

Carabidae "ground-beetles"

Notiophilus sp., 4-24 (1)[1]

Bembidion dauricum Motsch., 4-24 (2), Ad2[2], (H[3])

B. cf. *dauricum* Motsch., 3-24 (2)

B. bimaculatum species group (Lindroth, 1963), 2-21 (2)

Bembidion sp., 2-21 (1), 4-24 (1)

Pterostichus (Derus) nearcticus Ltd., 4-24 (3), 3-24 (2), Adl, (N)

P. (Derus) sp., 2-21 (1)

P. (Cryobius) soperi Ball, 2-21 (2), Ad2, (N)

P. (Cryobius) cf. *kotzebuei* Ball, 4-24 (1), 3-24 (1)

P. (Cryobius) cf. *tareumiut* Ball, 2-21 (2)

P. (Cryobius) cf. *pinguedineus* Eschz., 2-21 (6), 4-24 (2)

P. (Cryobius) ventricosus Eschz., 4-24 (1), Bc2 (H)

P. (Cryobius) sp., 4-24 (2), 2-21 (2)

P. vermiculosus Men., 2-21 (1), Ac, (H)

P. sublaevis Sahlb., 2-21 (2), 4-24 (6), Ad2, (H)

P. haematopus Dej., 2-21 (1), Bc2, (H)

Amara alpina Payk., 3-24 (9), 2-21 (11), 4-24 (12), Ad2, (H)

A. bokori Csiki, 3-24 (1?), 2-21 (1), 4-24 (1), Ad, (H)

COLEOPTERA (cont'd)

Trichocellus punctatellus Reitt., 2-21 (2), (P)

Dytiscidae "predaceous diving beetles"

Genus? sp.?, 2-21 (1)

Staphylinidae "rove beetles"

Tachinus sp., 3-24 (3), 2-21 (1)

Leptodiridae "small carrion beetles"

Genus? sp.?, 3-24 (2)

Byrrhidae "pill beetles"

Morychus sp., 3-24 (++), 2-21 (++), 4-24 (++)

Chrysomelidae "leaf beetles"

Chrysolina sp., 3-24 (1)

Curculionidae "weevils"

Brachyrhininae, Genus? sp.?, 4-24 (3), 3-24 (1)

Cleonus cf. *plumbeus* (Lec.), 3-24 (2), 4-24 (1), (N)

Notaris sp., 2-21 (1)

LEPIDOPTERA

larval mandible?, 3-24 (1)

DIPTERA

puparial fragments, 3-24, 2-21

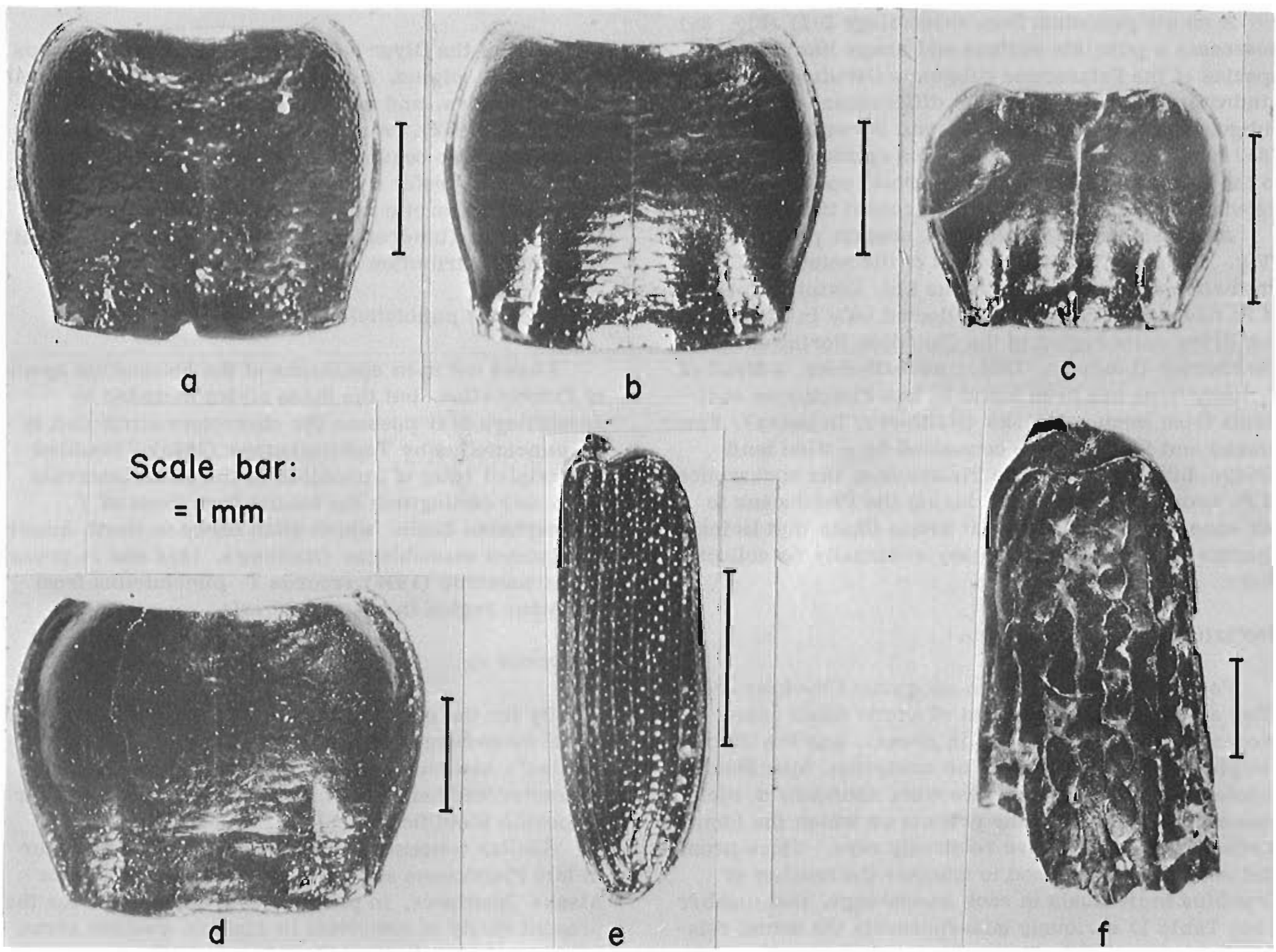
HYMENOPTERA

Apocrita, 3-24 (2)

1. Numbers, e.g. 4-24, 3-24, etc., refer to assemblage in which fossil occurs. Number in parentheses = minimum number of individual insects represented by fossils. ++ = very abundant.
2. Habitat requirements: A = obligate tundra, B = tundra and forest, c = damp to mesic sites, d = xeric sites, 1 = scantily vegetated, 2 = moderately vegetated.
3. Distribution: H = Holarctic, N =Nearctic, P = Palaearctic.

the collections of the Paleontology Institute of the U. S. S. R. Academy of Sciences in Moscow.

All species listed in Table 1 are extant. Accordingly, using knowledge of the present habitat requirements of the species, when known, and assuming that ecologic requirements of a species do not change significantly with time (Coope, 1970), one may define the type of environment in which the fossil insects lived. Reliable paleoecologic inferences are based on assemblages containing many identified species, but unfortunately this is not the case for the assemblages discussed here. However, each of the Olyor assemblages does contain specifically identified carabid fossils, and most carabids, or "ground-beetles", spend their life under the influence of macroclimatological conditions (Coope, 1970), meaning that their fossils indicate more about former regional environments than fossils of phytophagous insects or others whose habitat requirements are related to the presence of a group of plants or who occupy sites buffered from regional climatic influences. Therefore, despite the small size of the Olyor insect assemblages, they do allow some tentative paleoenvironmental conclusions (see *Discussion*).



(a) pronotum — *Pterostichus (Derus)* sp., assemblage 2-21. Note punctures on surface.

(b) pronotum — *Pterostichus (Derus) nearcticus* Ltd., assemblage 4-24.

(c) pronotum — *Pterostichus (Cryobius) soperi* Ball, assemblage 2-21.

(d) pronotum — *Pterostichus sublaevis* Sahlb., assemblage 4-24.

(e) Rt. elytron — *Trichocellus punctatellus* Reitt., assemblage 2-21. Note configuration of punctures in strial intervals.

(f) Rt. elytron (apical 2/3) — *Pterostichus vermiculosus* Men., assemblage 2-21.

Figure 3. Selected fossils from the Olyor assemblages. (Scale bar equals 1 mm)

Notes On Selected Species

Bembidion dauricum Motsch.:

Fossil elytra from Olyor sediments have isodiametric micro-sculpture, a definitive character possessed by no other member of the *grapei* species group in which *B. dauricum* is placed (Lindroth, 1963). *B. dauricum* has a nearly circumpolar distribution (including eastern Siberia) and is usually found at scantily vegetated, xeric tundra sites.

Pterostichus (Derus) spp.:

A single pronotum from assemblage 2-21 (Fig. 3a) possesses a punctate surface and shape like those in species of the Palaearctic subgenus *Derulus:* however, Lindroth (1966) considers the differences between the subgenera *Derulus* Tsch. 1896 and *Derus* Motsch. 1850 to be negligible. I follow his opinion by referring to the fossil in question as *P. (Derus)* sp. No specific determination is possible at the present time.

Assemblages 4-24 and 3-24 contain pronota (Fig. 3b) closely matching that of the holotype of *Pterostichus (Derus) nearcticus* Ltd. Livining specimens of *P. nearcticus* have been collected only in the Anderson River delta region of the Canadian Northwest Territories (Lindroth, 1966); nevertheless, a fossil of *P. nearcticus* has been found in late Pleistocene sediments from western Alaska (Matthews, in press). Since Alaska and Siberia were connected by a wide land bridge during parts of the Pleistocene, the occurrence of *P. nearcticus* in Siberia during the Pleistocene is not surprising, and in fact it seems likely that living specimens of *P. nearcticus* may eventually be collected there.

Pterostichus (Cryobius) spp.:

Fossils representing the subgenus *Cryobius* are often an important component of Arctic fossil assemblages (Matthews, 1968 and in press), and the Olyor samples discussed here are no exception. Specifically indeterminate *Cryobius* elytra were abundant in each assemblage; however, the pronota on which the identifications were based were relatively rare. Since pronota and not elytra were used to tabulate the number of *Cryobius* individuals in each assemblage, that number (see Table 1) seriously misrepresents the actual relative importance of the subgenus in the former fauna.

Some of the more common species of *Cryobius* can be recognized by pronotal characters alone, but a number of species cannot be reliably identified without reference to the median lobe of the male genitalia. Because fossils of the median lobe are absent from Olyor samples, most *Cryobius* fossils can be referred only to the subgeneric or species group level. Identification of Siberian fossils is further complicated by the fact that the *ochoticus* species group, including *P. (Cryobius) soperi, P. tareumiut,* and *P. kotzebuei,* probably contains several undescribed Palaearctic species (Ball, 1966). Thus pronota from the Olyor sequence which are similar to those in Alaskan specimens of *P. kotzebuei* and *P. tareumiut* may represent one or more undescribed Siberian species; hence the use of "cf." in reference to the fossils (Table 1).

The pronotum referred to *P. soperi* (Fig. 3c) is a good match with those in Alaskan specimens of that species. Although *P. soperi* has not been recorded from the Palaearctic, its occurrence at present in western Alaska indicates that it will probably be found to inhabit at least the northeast portion of Siberia. In Alaska *P. soperi* is found in tundra regions where vegetation cover is sparse.

Amara alpina Payk, *Amara bokori* Csiki:

Each of the Olyor assemblages contains numerous fossils of *A. alpina,* a circumpolar species which occurs only on tundra, and usually at mesic to xeric sites (Lindroth, 1968). A morphologically similar species, *A. bokori,* also occurs exclusively in tundra regions, but seems to prefer a sandier substrate than *A. alpina.* A single Palaearctic record from the lower Yenisei River valley (Lindroth, 1968) establishes the present Holarctic distribution of *A. bokori.*

Trichocellus punctatlellus Reitt.:

I have not seen specimens of the Palaearctic species of *Trichocellus,* but the three elytra included in assemblage 2-21 possess the characters attributed to *T. punctatellus* by Tschitscherine (1898). Doubled and tripled rows of punctures in the strial intervals (Fig. 3e) distinguish the fossils from those of *T. mannerheimi* Sahlb. which often occur in North American tundra assemblages (Matthews, 1968 and in press). Tschitscherine (1898) records *T. punctatellus* from the Amur region in eastern Siberia.

Morychus sp.:

By far the greatest number of fossils in each of the Olyor assemblages represents this genus of "pill beetles"; however, none of the fossils possess the characteristic hair like scales which are required for a specific identification.

Similar concentrations of *Morychus* fossils occur in late Pleistocene steppe-tundra assemblages from Alaska (Matthews, in press). One explanation for the present rarity of *Morychus* in Alaskan treeless areas, in contrast with its past abundance, is that the present regional tundra environment is significantly different from that of the late Pleistocene. But in Alaska as well as Siberia abundance of *Morychus* fossils may also be a reflection of edaphic local environmental conditions, e.g., scanty vegetation and bare soil areas.

Discussion

Several definite paleoenvironmental conclusions are possible. First, it is clear that each of the assemblages represents a sample of a tundra fauna. Second, the abundance of *Amara alpina* fossils suggests that the local environment was at least of a mesic to xeric character. Third, abundance of *Morychus* fossils may indicate sparsely vegetated regional or local conditions.

In general the above statements agree with results of plant macrofossil and pollen analyses of the Olyor sediments (Sher, 1970), except that Giterman (Sher, 1970) has concluded that the former environment was similar to that of the present (Sher, pers. comm., 1969). I doubt that any contemporary collection of beetles from an hypoarctic area such as that of the Chukochya region today would be dominated by *Morychus* as are the fossil assemblages, but at this time it is impossible to say if this distinction reflects differing local or regional conditions. It is interesting, however, that at Cape Deceit (Alaska), the nearest site to Olyor exposures where fossil insects have been studied (Matthews, in press), *Morychus* is nearly absent in sediments similar in age to those of the Olyor Suite, but very abundant in late Pleistocene sediments which were deposited in a steppe-tundra environment quite unlike the present hypoarctic tundra.

Hopefully this report of well preserved identifiable insect fossils from a Quaternary site in eastern Siberia will stimulate similar research efforts by Soviet scientists. In Alaska and northern Canada almost all sediments with any organic content contain insect fossils, and the same situation surely prevails in Siberia.

Acknowledgments

Thanks are extended to J.M. Campbell (Biosystematics, Dept. of Agriculture, Ottawa) for reviewing this manuscript and A.V. Sher (Paleontological Institute, Acad. of Sci., U.S.S.R.) for loan of the fossils. G.E. Ball (Strickland Museum, Alberta), J.M. Campbell (Dept. of Agriculture, Ottawa) and H. Silfverberg (Univ. of Helsinki) kindly loaned contemporary insect specimens.

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Project 690064

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Alberta

With the retreat of the Laurentide Ice Sheet from its maximum western extent in northern Alberta and British Columbia, a corridor was opened between the Laurentide and Cordilleran Ice Sheets which allowed migration of plants between the unglaciated areas in the Yukon and Northwest Territories and unglaciated areas, or areas deglaciated much earlier, to the south. The purpose of palynological field investigations in northern Alberta during 1973 was to obtain suitable samples for study of these plant migrations and subsequent vegetational and climatic changes in postglacial time as well as to ascertain when various events occurred.

Lakes are abundant in the area but very few were found to be suitable for coring because of their intermittent nature or shallowness, both of which hinder organic accumulation. However, three lakes were cored, two in the Peace River district and one adjacent to the Athabasca River valley.

One core was obtained from one of two lakes called the Dollar Lakes and is about 17 miles north of Valleyview, Alberta (55°19'N, 177°12'W). This lake is at an elevation of about 2,120 feet, and these two lakes occupy what appear to be kettle holes in an area of hummocky ground moraine. The site is below the maximum limit of the glacial lake that covered the area following deglaciation and the subdued character of the terrain may be due to wave action in the glacial lake. A total of 1,363 cm of sediment was recovered from below 9 metres of water. A sample has been submitted for radiocarbon dating and should provide a minimum date for isolation of the lake from the former glacial lake and the beginning of organic accumulation.

The second core was recovered from Sulphur Lake (56°43'N, 118°19'W) which is at an elevation of about 2,440 feet in the Clear Hills, 50 miles northwest of Peace River, Alberta. Sulphur Lake occupies a large bedrock depression possibly dammed by glacial material. Another very long core was recovered from below 8 metres of water with sediments totalling 1,215 cm. The basal organic sediment should provide a minimum date for deglaciation.

Mariana Lake (55°57'N, 112°01'W), adjacent to the Athabasca Highway about 55 miles north-northeast of Wandering River and 66 miles south-southwest of Fort McMurray, was the third Alberta lake sampled. The lake is at an elevation of about 2,300 feet and occupies an elongated depression in an area of hummocky glacial deposits, probably altered somewhat by wave action in the glacial lake that covered the area following deglaciation. The core showed 700 cm of organic sediment over slightly calcareous clay and was recovered from beneath 6 metres of water. The basal date should be a minimum for emergence of the basin from the glacial lake.

Since carbonate rocks are abundant in Alberta it is likely that carbonates will be present in any lake sediment profile leading to anomalously old radiocarbon dates due to the hard water effect. An estimate of the error involved can be obtained by radiocarbon dating some historically datable level near the top of the sediment profile. This will have to be done with each of these cores.

Quebec

Recent attempts at paleomagnetic analysis of freshwater lake sediment profiles (Mott and Foster, 1973) have produced promising preliminary results with some indications of a magnetic reversal in the 12,500 to 13,000 year B.P. range. Two lakes from eastern Quebec were cored to obtain samples in this age range that are oriented to a known azimuth. One lake, Petit Lac Terrien (46°35.2'N, 70°36.5'W), is located 3.5 miles southwest of Saint-Damien-de-Buckland in a narrow bedrock valley of Les Notre-Dame (monts). This lake was cored in 1964 and a radiocarbon date of 12,640±190 years B.P. (GSC-312) (Dyck et al., 1966) was obtained on organic clay near the base of the core. The new core, recovered from below 2 metres of water, shows a sedimentary sequence similar to that obtained previously with about 700 cm of organics and organic clay grading into a grey clay. The organic clay and grey clay at the base of the core will be particularly useful for paleomagnetic studies.

Lac Colin (46°43'N, 70°17.6'W), also in Les Notre-Dame (monts), about 8 miles northwest of St. Fabien-de-Panet, was also cored and 2 metres of grey clay were recovered from below 687 cm of organic sediment in 2 metres of water. Again it is the clay that will be most useful for paleomagnetic determinations but both cores will also be used for palynology and radiocarbon dating.

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77. ENVIRONMENTAL GEOLOGY PROTOTYPE STUDY; OTTAWA–HULL AREA

Project 700049

J. R. Bélanger and D. A. St-Onge
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This project is divided into two distinct parts, the first being directed toward the research of new methods for compiling, processing and presenting geological information in the framework of environmental geology. The second aspect of the project deals with the mapping of surficial geology of the Ottawa–Hull area.

An interpolation function for mapping continuous phenomena has been developed for the Urban Geology Automated Information System (UGAIS). Trail maps have been successfully produced using the interpolation function in conjunction with a General Purpose Contouring Program (GPCP). Various types of location maps indicating the nature of the source information also have been produced on a drum plotter. The entire system is now being adapted for the EAI flat bed plotter so that it is now possible to draw contour values directly on chronaflex base maps.

The urban geology data bank of the Ottawa–Hull region has been updated using information from numerous sources including various government and municipal agencies as well as private contractors' records. This also includes the incorporation of well records from the Ministry of the Environment of Ontario, which had to be edited in order to select only those records with geological parameters for inclusion in the data bank.

The program for producing an updated surficial geology map at the scale of 1: 125, 000 is nearing completion. All maps produced at the scale of 1: 50, 000 during 1972 have been reduced and the balance (less than one-third of the area) is currently being completed. This preliminary information has been made available to several agencies in the region who requested the information in order to plan their own projects.

Project 710081

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Field work during the 1973 season was planned to investigate and compare some areas of Champlain Sea marine clays in which large numbers of landslide scars indicate an unusually high landslide activity. It was recognized that some areas once very active now appear to be relatively stable whereas others are currently active and are responding to natural stimuli as well as to the stimulus of construction activity related to urban expansion.

During the 12-week field season June–August observations were made in three principal areas near Ottawa, Ontario: the Quyon River valley upstream from the village of Quyon, Quebec; the abandoned river terraces at and near the mouth of Gatineau River, north and east of Hull, Quebec; and the valley of the South Nation River, in the vicinity of Casselman and Plantagenet, Ontario. In the latter area the surficial deposits of Thurso Sheet 31 G/11 E (area south of Ottawa River) and of Russell Sheet 31 G/6 E were mapped for publication at the scale 1/50,000. In addition, special attention was given to a number of landslides that occurred in or near the study areas during the period April–June, 1973.

Landslide susceptibility in the various areas is obviously related in all cases to the capacity for holding water and the degree of saturation of the silt-clay deposits, commonly known as "Leda" clay or as "glaise bleue", to the presence of thick deposits of the material, and commonly to the development of steep slopes within these deposits. Observations made in the field during the past field season strengthen the writer's hypothesis that several other factors contribute greatly to slide susceptibility, particularly as these factors affect the hydrology of the slide mechanism and the relative bearing capacity of the soil materials. The following are related working hypotheses or suggestions intended to aid further research:

1. Stratigraphic position

We may assume that the Ottawa valley and its tributary valleys received thick deposits of marine clay during the early stages of the Champlain Sea and that more recent erosion along the valleys has removed large volumes of that original deposit. Hence, there are remnant pockets of clay at high levels, and thick clay units in terraces at various levels down to the present stream levels. Distribution of landslides in the Ottawa region (Hanley, 1972, unpubl. report) indicates not only a low incidence of slides in deposits at and below 200 feet a.s.l., but also shows a gradation in size and type of landslide according to the relative position within the original deposit, in other words to its stratigraphic position within the unit. In general terms the lower terraces, being cut in the lower and older part of the clay sequence, are underlain by clays with a relatively high degree of precompression or preconsolidation, relatively high unconfined compressive strength, and subject principally to small rotational gravity slides in which liquefaction of the clay occurs mainly along the failure surfaces (e.g. Touraine, Quebec, failures along Gatineau River banks). On progessively higher terraces and in isolated pockets of clay at high level where saturation conditions obtain, there is an apparent progressively greater degree of liquefaction of the sediment during landslides and more common retrogressive expansion of the slide area. This may be due, in part, to the apparent upward decrease through the stratigraphic unit of the degree of preconsolidation of the clay.

2. Drainage

Local conditions of drainage related to the geologic history and present hydrology of a particular site may affect drainage of the clay either adversely or beneficially:

a) A sand and/or gravel unit on the surface of the clay generally constitutes a perched aquifer (often with associated springs) which tends to maintain a high degree of saturation in the underlying clay. This factor apparently affected conditions in the destructive landslides at Chelsea, Que. and Templeton, Que., in the spring of 1973. In contrast, exposures of clay with little or no sand cover, such as parts of broad abandoned river channels for example, are relatively impervious, have a high run-off rate and a generally lower degree of saturation of underlying materials. Silt and clay in the uncovered situation is much less susceptible to landslides than clay of nearly identical composition in the covered situation.

b) Visual inspection of sediments from different parts of the marine basin, particularly considering their position relative to the inlet sources of material, suggests difference in granulometry that may affect the rate and degree of drainage. It appears that coarse, near-source sediments are better drained and more stable than finer grained distal sediments of the same local basin. This is subject to further investigation by projected laboratory study of selected samples.

c) A sand or gravel unit underlying a marine clay deposit may contribute in one of two ways to the stability of the clay body. If the sand or gravel unit bears water under artesian pressure, such pressure acting upward into the overlying clay may increase pore-water pressures in the clay and reduce its stability. Such conditions may be common along the north flank of Champlain Sea because outwash deposits from the retreating ice margin were progressively buried by bottom sediments of Champlain Sea; some of these buried outwash deposits may be continuous with deposits of the same origin that lie above the local level of marine submergence and thus may have exposed recharge areas to provide for artesian head beneath the clay. The writer speculates that artesian pressures beneath the clay blanket in Quyon River valley may have contributed to an early extensive development of landslides there. The present hydrology of the Quyon valley area may be studied for the purpose of examining this hypothesis.

3. Vibration in relation to landslides

Since it has been observed during the season's field work that there are some places in which vibration shock is obviously transmitted through slide-susceptible marine clays, it is suggested that a field of research is open to earth scientists of the Ottawa area. Field instrumentation for the measurement of transmitted shock could provide some of the parameters necessary for a quantitative understanding of the effect of earth shocks such as earthquake, explosion, and traffic vibration on the physical properties of the marine clays in place. Laboratory study of the limits of frequency and amplitude of vibration necessary to cause failure of the material either by liquefaction or by extension of existing fracture systems under a range of load and moisture conditions, would be most valuable knowledge to apply to the prediction and prevention of landslides.

ENVIRONMENTAL GEOLOGY — MOUNTAIN COAL MINING ALBERTA AND BRITISH COLUMBIA

Project 720083

John E. Harrison
Terrain Sciences Division

Study of the geological, geomorphological and hydrological factors affecting mountain coal exploration, exploitation and subsequent land reclamation was continued during the 1973 field season. The initial field program (Harrison, 1973) covered an area of approximately 2, 600 square miles and embraced almost all the areas of mining activity in the Crowsnest Pass region, whereas the present field program was restricted to the area covered by the Crowsnest West (82G/10W) and Tornado Mountains West (82G/15W) map-sheets (see Fig. 1). In addition to mapping the surface materials, including waste dumps, and investigating the Quaternary history, numerous tests were conducted in the field and samples gathered for laboratory analysis to determine the physical and engineering properties of these materials.

The glacial and postglacial history of the region has resulted in a variety of surficial deposits, the distribution and properties of which are and will be extremely important in transport and engineering of facilities associated with coal mining. With the exception of the summits of the Paleozoic ranges, the entire area has been glaciated. Till deposition on the upland areas is thin and discontinuous, with most till found plastered on the sides of the major valleys and in the lower areas of the uplands. A distinctive dark grey till, commonly found filling bedrock gullies above 5, 000 feet and restricted to the east side of the Elk Valley and lower Michel Valley, has been the cause of numerous road failures. Preliminary results indicate a plasticity index of less than 5%.

During the early stages of deglaciation, south-flowing ice occupied the Elk Valley and pushed a tongue up the Michel Valley to the vicinity of Loop. Ice originating in the Flathead Range flowed north down the Michel Valley to meet the Elk Valley ice at Loop. It is not known whether ice crossed the Crowsnest Pass into Alberta.

As ice began to retreat a proglacial lake was formed between the pass and the ice. Between Loop and the pass this lake was filled with sand, gravel, and silt; this material now forms flat benches some 200 feet above the present stream and roadway.

The retreating Michel Valley ice built a series of moraines across the valley at Loop which are now covered by lake silts and sands up to 100 feet thick. A number of slides have occurred in these sediments. The flat top of the lake sediments forms the prominent benches seen between Loop and Michel. This ice retreat also resulted in a lake in the middle reaches of the Michel Valley into which tributary streams built small deltas.

Retreat of the Elk Valley ice down the lower Michel Valley was accompanied by the building of kame terraces between the ice and the hillside. These gravels, deposited against the steep walls of the valley, form a veneer along the valley walls from Michel to where the valley widens, east of Sparwood.

Drainage of the proglacial lake to the south did not follow immediately upon retreat of ice out of the Elk Valley. A dam, perhaps formed by ice remaining in the trench in the vicinity of Elko, resulted in a large proglacial lake stretching from at least Fernie to north of Elkford. Silts and clays deposited in this lake, commonly with a layer of postglacial river gravels covering them, have caused a great deal of difficulty in road and rail construction.

A number of deltas were built by tributary streams into the lake including larger deposits at Brûlé, Boiven and Crossing Greeks and the Fording River.

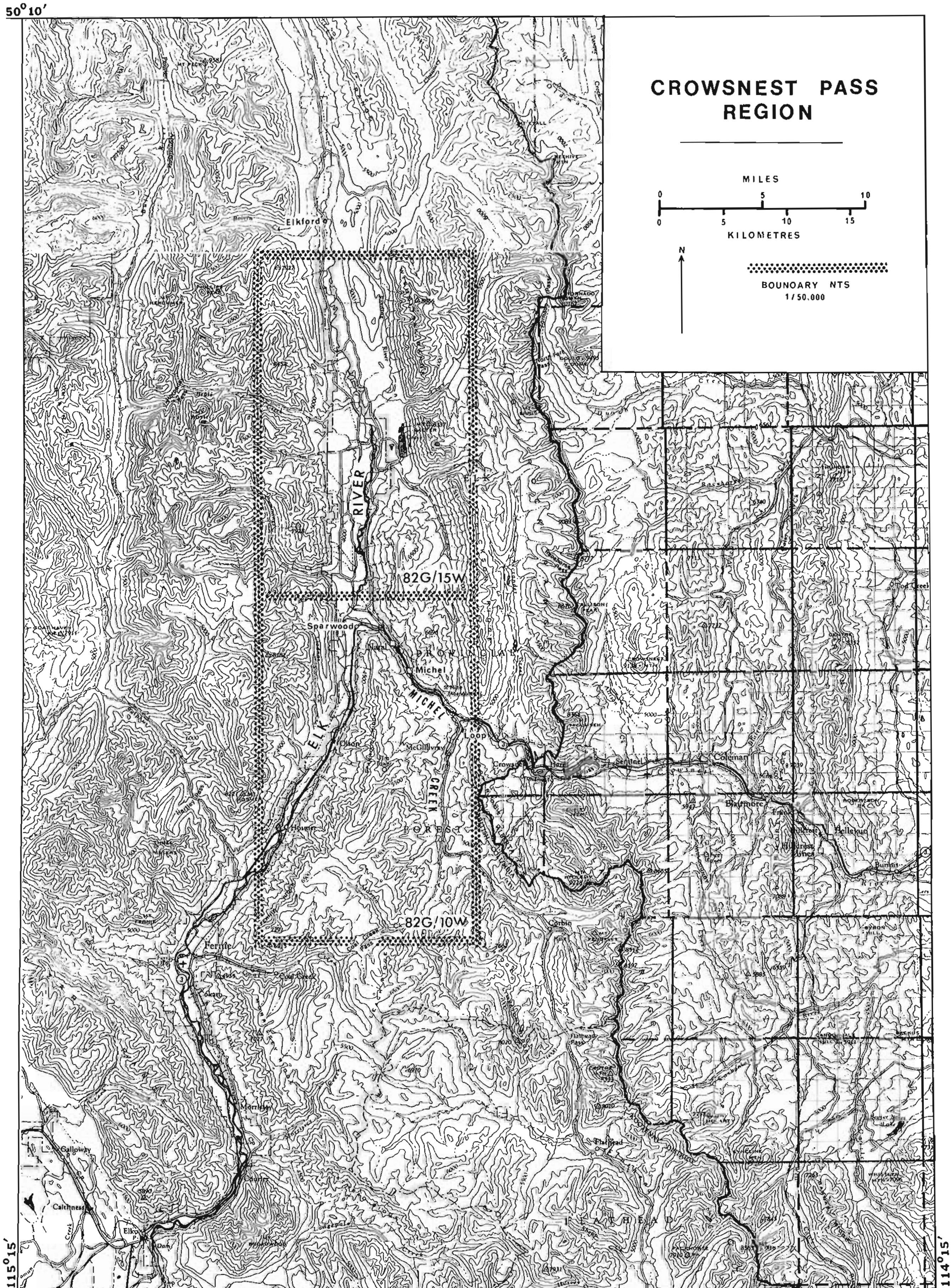
Grave Lake lies in an ice block depression formed by a stagnant ice mass lying at the foot of Mount Salter and Sheep Mountain. To the west, kettles are developed in a thick till cover mantled in places by thin lake deposits.

As the ice front retreated north up the Fording Valley a large moraine was built in the preglacial valley, forcing the river to cut a new channel. The segment of the Fording Valley occupied by Grace Creek probably has up to 400 feet of glacial fill. The river was forced to detour to the west side of a small mountain lying between the Wisukitsak Range and the Greenhill Range, and now flows through a gorge in this area. Lake sediments deposited on the north side of this moraine are subject to slope failure and have caused numerous problems in rail construction and maintenance.

Following the retreat of the ice from the region and the drainage of the proglacial lake, the major rivers reestablished themselves and began to form the flood plains and gravel terraces which make up much of the valley bottom topography. Detailed analysis of the deposits mentioned in the above summary are now being carried out.

The mapping of the glacial and postglacial deposits was conducted to aid planning of exploration and coal exploitation activities, whereas the investigation of the physical and engineering properites of coal spoil and plant tailings is more directly related to present mining and reclamation activities. Six areas of concern were investigated: surface temperature, deep seated stability, surface movement on slopes, infiltration rate, weathering characteristics and dust on tailings ponds.

Temperature measurements on fine-grained (less than 28 mesh), black coal spoil and tailings show variations with altitude, aspect and slope. Highest temperatures are recorded at lower elevations on south aspects sloping 26 degrees. The maximum recorded



CROWSNEST PASS REGION
MILES
0
5
10
0
5
10
15
KILOMETRES
N
BOUNDARY NTS 1/50,000
50°10′
115°15′
49°15′
114°15′
82G/15W
82G/10W
Elkford
Sparwood
Natal
Michel
Loop
ELK
RIVER
MICHEL
CREEK
Olson
McGillivray
Hosmer
Fernie
Coal Creek
Corbin
Coleman
Sentinel
Blairmore
Frank
Hillcrest
Bellevue
Burmis
Morrissey
Galloway
Elko
Flathead

TABLE 1

Infiltration Data - Crowsnest Pass Area

Location	No. of readings	Average (in./hr.)
Tailings ponds	12	2.3
Pit roadway	4	.63
Coarse spoil	8	1.87
Till, weathered rock	2	.26

temperature in the top 2 cm of spoil exceeded 70°C. This temperature is sufficient to damage the plant at the air-soil interface. Samples of small trees collected on spoil piles show varying degrees of damage including burns and scar tissue. Cooler temperatures were recorded with increased elevation, decreased slope (below 26 degrees), and away from the south and southwest aspect. Preliminary analysis of the data suggests that revegetation programs on south- and southwest-facing spoil slopes must be designed to minimize high, summer soil temperatures. This might be accomplished by establishing a grass cover prior to tree planting, using more heat resistant tree species such as poplar and aspen, creating micro-relief, and in extreme cases by irrigating.

The investigation of deep seated stability was approached from a case study point of view. Having established that most failures are preceded by a creep phase (Harrison, 1973), investigation concentrated on data gathering to provide input for a computer model of failure using the Price-Morgenstern Slope Stability Computer Program. Important field observations include: (1) in the late stages of creep prior to failure, rocks can be heard breaking at depth; (2) a high rate of dumping contributes to instability; (3) arcuate dumps are more likely to fail than straight ones, probably because the ratio of the volume of material to the total surface of the failure is smaller in arcuate dumps; (4) the failure plane is nearly vertical in the upper 30 to 60 feet, with the lower portion often approaching 25 degrees; (5) layering in dumps results in weak surfaces along which failures can develop; (6) while failures encountered in the early stages of dumping can often be attributed to failure of the foundation material, they have been observed where the failure plane lies entirely within the spoil.

Surface movement was measured by constructing sediment traps on the slopes. The degree of movement is expressed in terms of grams per 24-hour-day of material that would pass across an imaginary line one metre long lying across the strike of the slope. For coal spoils of sand and pebble sized material, rates range from about 30g/day/metre for a slope of 28 degrees to 160g/day/metre for a slope of 35 degrees. On an extremely active slope of 37 degrees, values as high as 1,600g/day/metre were recorded. Movement of material was recorded over an average of 60 days, and was found to be irregular. Movement occurred as slopes dried and material was subjected to wind disturbance and also occurred as small mudflows during intense summer storms. Flexible tubes planted perpendicular to the slope indicated that transport of material occurred in the upper 5 cm. Surface movement on spoil slopes is a function of slope angle and material; most movement seems to occur as discrete events. These measurements coupled with observations from various abandoned spoil piles indicate that surface movement of individual particles is sufficiently rapid on slopes greater than 25 degrees to seriously jeopardize revegetation efforts.

A concentric ring infiltrometer was used to measure infiltration rates for various spoil and tailing materials. These data will be analyzed in relationship to moisture content, in place density and grain size as soon as all the data is available. Table 1 is a summary of the infiltration data only.

Field observations indicated that shales, some siltstones and carbonaceous shales encountered in the spoil, weathered much faster than more resistant sandstones. Samples and representative sections of core are now undergoing tests to determine the strength characteristics and weathering properties of the spoil.

A waste product of the coal cleaning plant is a slurry of water and reject which is pumped into a lagoon; this waste is usually smaller than 28 mesh. The waste material forms a cone under the waste pipe with a slope of 1 to 2 degrees. As the cone builds, only about one quadrant at a time is wet. Strong winds lift material from the dried areas creating a dust problem. A number of observations pertaining to this problem were made: (1) The material near the apex of the cone has an average ash content of 85% while at the cone margin ash contents average less than 20%. (2) Much of the fine dust is picked up by the wind at the margin of the cone. (3) Numerous leaks in the pipe resulted in smaller, steeper cones which stayed damp and reduced dust. These observations suggest that as lagoon size increases, dust problems will become critical unless a different design of either the lagoon or the delivery system is adopted.

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ENVIRONMENTAL GEOLOGY — HAMILTON URBAN AREA, ONTARIO

Project 730029

F. Morin
Terrain Sciences Division

The principal objectives in the environmental geology project for the Hamilton urban area during the 1973 field season were to identify, contact and interview the largest number of potential users of geoscientific information working within the study area and to ascertain:

1. The nature of the information required
2. The best system of representation to be used so that the geoscientific information, compiled in the existing data bank for the area, can most easily be used by the people.

Accordingly, the information gathered can then be used to plan future work within this project.

The nature, density and quality of the geoscientific information available and compiled in the data bank for the area has to be evaluated in order to determine the level of additional information needed to meet the requirements expressed by the users interviewed. The first part is now completed. Computer outputs from the data bank are being used along with reinterpreted surficial geology and agricultural maps to plan field work that is required to supplement existing usable information to meet the needs.

Very briefly the results of the interviews carried out are presented below.

In general

Many of the people interviewed made a number of similar requests:

1. Maps showing soil types according to some engineering classification.
2. Maps and sections illustrating the thickness of overburden and/or bedrock topography for the area.
3. Maps showing the locations of existing boreholes with an indication of the sort of analysis carried out on the samples retrieved.
4. Maps portraying some information on groundwater characteristics.
5. Maps showing the location of old landfill areas.
6. Listings of all available information within the data bank.

In particular

Four different groups of users and potential users have been interviewed:

Planners - feel that all documents which can be produced from the data bank can be useful in their work. These include interpreted maps on which all available geoscientific considerations are evaluated and weighed for a particular need.

Beside the more general requests listed above, people of this group have often mentioned their need for:

1. Maps showing slopes,
2. Maps showing hazard lands,
3. Maps showing groundwater quality and quantity.

Engineers - Since people of this group are concerned with very specific projects in small areas, the type of documents resulting from this project can be of little use to them beyond the stage of general terrain evaluation.

Besides the general requests mentioned above, they stress the usefulness of the data bank as a reference library for boreholes that have been drilled and compiled. Hence, engineers are greatly concerned with the cost and difficulties to be encountered in having access to the information within the data bank.

Soil Consultants - As well as the general request mentioned above, consultants are also interested in the data bank as a reference library for boreholes drilled and compiled.

Among their requests special emphasis is placed on maps showing location of existing borehole records along with some indications as to where the original report can be found. This request not only extends to the Hamilton urban area, but to all the Canadian urban areas where the Geological Survey of Canada has compiled a data bank.

Others - This group contains several types of users and potential users of geoscientific information (agronomists, health officers, environmental scientists, etc.). Besides the more general requests mentioned above, people of this group need information associated with groundwater (permeability, aquifer recharge area, groundwater quality).

In addition, two organizations offered to keep and update the data bank compiled by the Geological Survey for the Hamilton urban area as well as manage the retrieval system that will be developed for it. These organizations are the Corporation of the City of Hamilton and McMaster University, Engineering Department.

Finally two direct requests were made to the author for a printout of all available information already in the data bank. These were made by the Corporation of the City of Burlington, for the area under its responsibility, and the Hamilton–Wentworth planning area board.

81. URBAN GEOLOGY OF VICTORIA, BRITISH COLUMBIA

Project 730029

D.A. St-Onge
Terrain Sciences Division

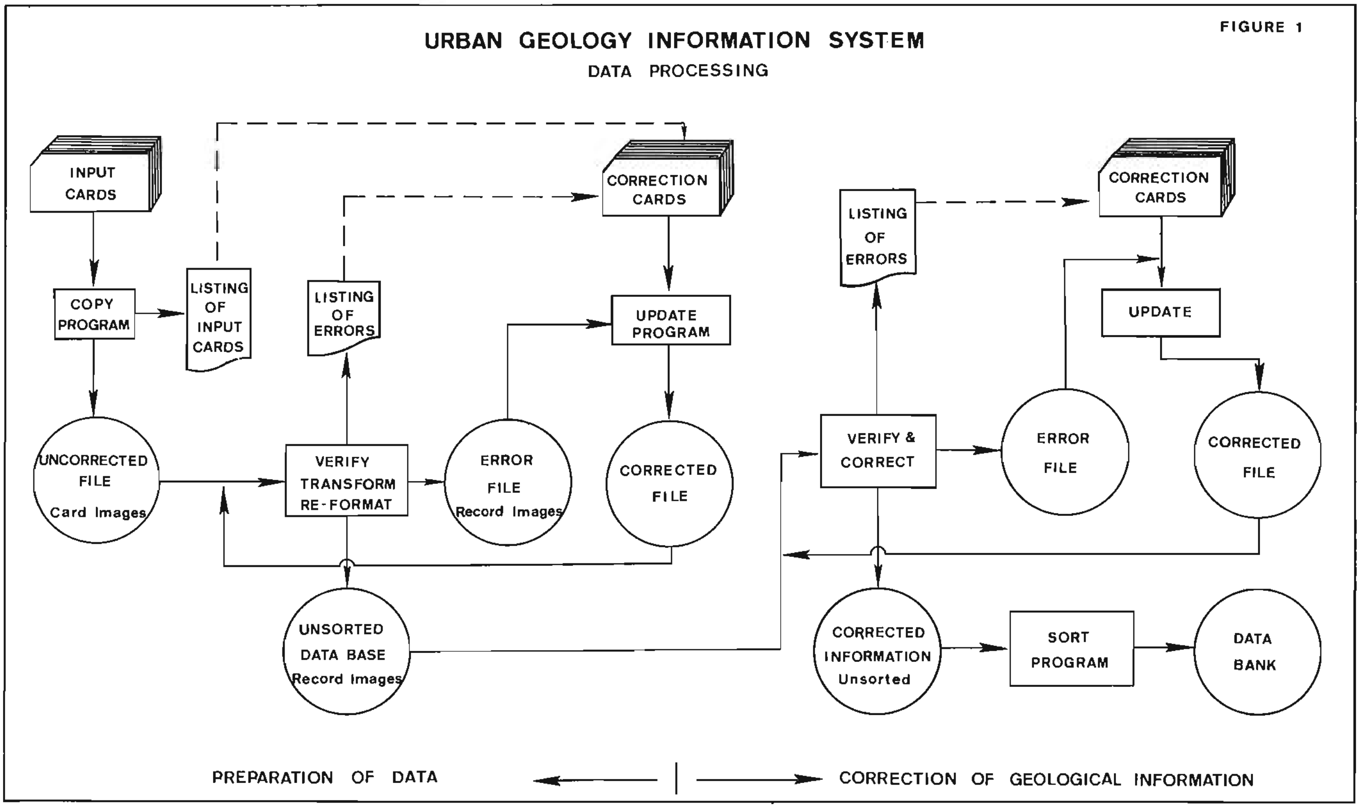
This project was designed to gather information within an urban centre in order to determine the feasibility of creating a data bank of engineering geology data that would be useful to city engineers.

The 1973 season, the first phase of the project, was essentially concerned with gathering information in the City Engineer's office in Victoria.

The result of this work is several hundred data points which have been collected from service excavations such as sewers, gas mains, electrical and telephone lines and so on. We thus have a high density of information points on near-surface materials within the central core of Victoria. Currently this information is being edited and transferred to punch cards. The next step will be to adapt programs from Project 700049 so that updated detailed engineering geology maps can be produced on a routine basis.

Project 730028

D. A. St-Onge and J. R. Bélanger
Terrain Sciences Division



This project is designed to follow-up on the Winter Works Projects of 1971-72 and also of 1972-73 as required for the editing of large volumes of data collected during those projects.

Figure 1, Data Processing Flow Chart, indicate the sequence followed between the collection of the raw data to the final compilation in the data bank on magnetic tapes.

Figure 2, Urban Geology Automated Information System (UGAIS) dateline chart, gives some idea of the magnitude of data that had to be itemized, edited and reduced to magnetic tape.

During the past year for reasons of economy and computer efficiency, the language used in data processing was changed from Fortran to Cobol.

Various trial maps have been attempted under this project to better define the quality of the contouring programs developed within the section. These are presently being evaluated by specialists in the cities concerned.

Visits to city engineers and others has made it possible to establish on a preliminary basis, the needs and requirements of various potential users for this type of automated information.

It is intended to continue this aspect of the work in order to determine the ultimate method of access to this information by all potential users.

Figure 2

DATA PROCESSING — U.G.A.I.S. — TRAITEMENT DES DONNÉES

REGION	NUMBER OF RECORDS / NOMBRE DE FICHES	DATE-LINE: PUNCHED / PERFORÉ	ON TAPE / SUR RUBAN	VERIFY – 1 / 1ère VÉRIFICATION	CORRECT – 1 / 1ère CORRECTION	TRANSFORMATION CARD OF RECORD / CARTE À FICHE: DÉBUT / START	COMPLÉTÉ / COMPLETED	VERIFY – 2 / 2ème VERIFICATION: DÉBUT / START	COMPLÉTÉ / COMPLETED	CORRECT – 2 / 2ème CORRECTION: DÉBUT / START	COMPLÉTÉ / COMPLETED	ÉCHÉANCE — RE-CODIFICATION: DÉBUT / START	COMPLÉTÉ / COMPLETED	MERG-SORT / FUSION-TRI: DÉBUT / START	COMPLÉTÉ / COMPLETED	NUMBER OF RECORDS / NOMBRE DE FICHES
CALGARY	3,988	30/5/72	8/1/73	16/2/73	18/2/73	24/4/73	24/4/73	30/4/73	25/5/73	15/5/73	25/5/73			25/5/73	26/5/73	
CHICOUTIMI	1,529	30/5/73														
EDMONTON	1,400	30/5/72	8/1/73	16/2/73	16/2/73	30/4/73	30/4/73	16/5/73	21/6/73	25/5/73	21/6/73			21/6/73	21/6/73	
FREDERICTON	1,205	30/5/72	10/1/73	12/2/73	12/2/73	27/7/73	27/7/73	1/8/73	14/9/73	11/8/73	14/9/73			17/9/73	17/9/73	
HALIFAX	4,850	30/5/72	10/1/73	12/2/73	12/2/73	27/7/73	27/7/73	1/8/73	13/9/73	17/8/73	13/9/73			14/9/73	14/9/73	
HAMILTON	5,639	30/5/72	9/1/73	6/5/73	6/5/73	18/5/73	19/5/73	7/6/73	11/7/73	7/6/73	11/7/73			12/7/73	12/7/73	
KIT. WAT.	1,641	30/5/72	22/11/72	28/11/72	17/4/73	17/4/73	11/5/73	25/4/73	22/5/73	14/5/73	22/5/73	8/6/73		22/5/73	23/5/73.	
LONDON	2,775	30/5/72	4/1/73	9/1/73	9/1/73	31/7/73	31/7/73	11/8/73								
MAURICIE	1,286	30/5/72	14/2/73	27/2/73	27/2/73	28/6/73	28/6/73	24/7/73	5/9/73	24/7/73	5/9/73			5/9/73	6/9/73	
MONCTON	1,763	30/5/72	10/1/73	12/2/73	12/2/73	27/7/73	27/7/73	14/8/73	14/9/73	30/8/73	14/9/73			17/9/73	17/9/73	
MONTREAL — ÎLE DE MONTRÉAL	25,540	30/5/72	10/8/72	1/11/72	14/2/73	12/6/73	14/6/73	21/6/73	14/8/73	10/7/73	14/8/73			6/9/73	13/9/73	
MONTREAL — ÎLE JÉSUS	1,560	30/5/72	12/12/72	2/1/73	27/2/73	26/6/73	26/6/73	18/7/73	7/9/73	23/7/73	7/9/73			7/9/73	12/9/73	
MONTREAL — RIVE SUD	1,750	30/5/72	14/2/73	27/2/73	27/2/73	27/6/73	27/6/73	23/7/73	12/9/73	23/7/73	12/9/73			12/9/73	12/9/73	
NIAGARA	6,045	30/5/72	9/1/73	6/5/73	6/5/73	11/6/73	11/6/73	15/6/73	20/9/73	18/7/73	20/9/73			24/9/73	24/9/73	
OSHAWA	3,868	30/5/72	9/1/73	6/5/73	6/5/73	8/6/73	8/6/73	11/6/73	6/7/73	22/6/73	6/7/73			9/7/73	10/7/73	
OTTAWA	1,094	30/5/72	18 4 73	27 9 73	26 9 73	8/5/73	8/5/73									
REGINA	2,600	30/5/72	20/8/72	3/11/72	3/11/73	27/4/73	27/4/73	28/4/73	18/5/73	14/5/73	18/5/73			18/5/73	23/5/73	
SAINT JOHN	3,339	30/5/72	10/1/73	12/2/73	12/2/73	23/7/73	24/7/73	11/8/73	19/9/73	17/9/73	19/9/73			20/9/73	20/9/73	
ST. JOHN'S	1,895	30/5/72	10/1/73	12/2/73	12/2/73	27/7/73	27/7/73	14/8/73	13/9/73	6/9/73	13/9/73			14/9/73	14/9/73	
SAULT STE-MARIE	1,380	30/5/72	8/1/73	2/2/73	2/2/73	31/7/73	31/7/73	13/9/73								
SHERBROOKE	965	30/5/73														
SUDBURY	2,533	30/5/72	8/1/73	2/2/73	2/2/73	31/7/73	31/7/73	14/8/73		22/8/73						
THUNDER BAY	550	30/5/72	8/1/73	2/2/73	2/2/73	31/7/73	31/7/73	12/9/73								
TORONTO	24,130	30/5/72	19/8/72 30/1/73	7/1/73 20/2/73	7/1/73 20/2/73	18/7/73	19/7/73	19/7/73	26/9/73	22/7/73	26/9/73			27/9/73	28/9/73	
VANCOUVER	4,400	30/5/72	25/1/73	2/2/73	2/2/73	26/4/73	26/4/73	18/5/73	19/7/73	28/5/73	20/7/73			23/7/73	24/7/73	
VICTORIA	3,100	30/5/72	25/1/73	12/2/73	12/2/73	11/5/73	11/5/73	14/5/73	25/5/73	18/5/73	25/5/73			25/5/73	25/5/73	
WINDSOR	1,850	30/5/72	9/1/73	6/5/73	6/5/73	5/6/73	5/6/73	8/6/73	4/7/73	11/6/73	4/7/73			4/7/73	4/7/73	
WINNIPEG	5,700	30/5/72	8/1/73	16/2/73	16/2/73	25/4/73	25/4/73	8/5/73	21/6/73	15/5/73	21/6/73			21/6/73	21/6/73	

PHYSICAL AND CHEMICAL PROPERTIES OF UNCONSOLIDATED SEDIMENTS IN PERMANENTLY FROZEN TERRAIN, DISTRICT OF KEEWATIN

Projects 700014, 700013

W.W. Shilts
Terrain Sciences Division

In 1973 a program of mapping and laboratory study was begun in order to define physical and chemical properties of the various sediment types that are associated with two distinct types of patterned ground, mud boils and frost cracks. One or the other of these varieties patterned ground occurs on virtually all unconsolidated deposits found south of Chesterfield Inlet, in the eastern District of Keewatin. Samples collected for project 700014 in 1970 and 1971 were analyzed in Ottawa; a field laboratory was operated in Rankin Inlet in 1973 to analyze selected physical properties of samples collected during the 1973 field season. The purpose of these studies is to ascertain relationships between surface patterns and properties of underlying unconsolidated sediment in order that reconnaissance mapping for terrain inventory may be improved. This report presents preliminary results for the ongoing program; however, most of the data presented relate to the properties of sediments forming mud boils.

Mud boils and frost cracks or tundra polygons rarely occur together (Fig. 1) and almost always indicate the textural and engineering properties of the unconsolidated sediment in which they are developed. Mud boils indicate poorly-sorted sediment with low liquid limit (<20%) and significant amounts of silt and clay, whereas frost cracks usually indicate either water-sorted sediments with high liquid limits, insignificant fine-grained component, and low pH or thick organic soil cover (in low, flat occurrences). Mud boils are common in areas underlain by till, marine silty clay, and colluvium containing significant fines; frost cracks are characteristic patterns on eskers, gravelly ribbed or De Geer moraine, marine or lake beaches or deltas, sandy shallow-water bottom sediments, and alluvium or alluvial plains along modern streams or adjacent to eskers.

Mud boils are referred to in the literature, by various names, such as frost boils, soil medallions, non-sorted circles, tundra craters, etc. Mud boil, a term with some current informal usage, has been chosen because neither permafrost nor frost are absolutely necessary to form mud boils and a muddy sediment is necessary. It should be emphasized, however, that seasonal frost and permafrost

Figure 1. Mud boils developed on a drumlin mantled by marine silty clay. Note frost polygons in surrounding sandy marine and/or fluvial sediment. Each of the two surface patterns is confined to a specific sediment type.

TABLE 1

SAMPLE TYPE	LIQUID LIMIT Mean/# of Samples	LIQUID LIMIT Range	PLASTICITY INDEX Mean/# of Samples	PLASTICITY INDEX Range	MOISTURE CONTENT Mean/# of Samples	MOISTURE CONTENT Range	MOISTURE CONTENT / LIQUID LIMIT Mean/# of Samples	MOISTURE CONTENT / LIQUID LIMIT Range	EXCESS WATER Mean/# of Samples	EXCESS WATER Range	pH Mean/# of Samples	pH Range
MINERAL SOILS FROM MUDBOILS (SAMPLES FROM THAWED ZONE) A	12.2/15	9.7-14.3	0	0-0.8	7.0/16	3.0-10.6	0.60/15	0.36-0.82	NA	NA	6.1/15	5.2-8.1
B	14.2/33	12.1-19.0	3.2/33	0-8.0	10.1/33	6.8-16.8	0.71/33	0.48-0.99	NA	NA	6.6/33	5.3-7.4
C	20.1/14	16.2/29.7	1.0/14	0-4.9	16.7/14	7.3-39.1	0.80/14	0.35-1.35	NA	NA	5.8/14	4.7-7.7
MODERN LAKES (SAMPLES FROM THAWED ZONE) D	29.1/9	18.1-64.3	0	0-8.8	39.6/10	14.0-87.1	1.24/9	0.75-1.77	NA	NA	4.9/6	3.9-5.7
E	16.5/6	12.4-20.2	0	0	14.1/6	11.9-16.2	0.87/6	0.72-1.05	NA	NA	5.5/6	4.6-6.0
ORGANIC AND MINERAL SOILS IN TERRAIN WITH FROST CRACKS (FROZEN SAMPLES TOP OF FROST TABLE) F	25.5/19	16.6-35.2	0	0	44.9/35	13.7-132.1	1.42/19	0.58-3.38	48.4/31	0-300	5.0/26	4.5-6.0
G	160.5/5	105.4-269.9	NA	NA	390.4/15	185-801	1.89/5	0.89-3.36	8.2/6	0-26	4.6/8	4.5-5.0
H	NA	NA	NA	NA	900/7	442-1210	NA	NA	0/7	0	4.8/4	4.5-5.0

Selected physical and chemical properties of unconsolidated sediments from eastern District of Keewatin:

A. till carapace,
B. till,
C. marine silty clay,
D. shallow water lake-bottom sediment,
E. nearshore lake sediment or modified glacial sediment in subaqueous mud boil,
F. frozen marine and/or alluvial silty sand,
G. frozen grass-sedge peat,
H. frozen Sphagnum peat.

facilitate the formation of mud boils to the point that mud boils and associated patterns are an important feature of the landscape where these conditions exist in combination with muddy sediment.

Jahn (1948) and Shilts (1973) have proposed similar mechanisms for formation of mud boils. Both suggest that mud in a plastic or liquid state is confined between a rigid surface soil layer and the frost table. Shilts (1973) proposed that the liquid mud phase must be under hydrostatic pressure on any slope and that it is injected in diapiric fashion to the surface through points of weakness in the rigid layer or carapace. Thus, the system is analagous to an artesian groundwater system with liquid mud replacing water. As mud is extruded to the surface, surface runoff carries away clay and fine silt, and the sandy, pebbly residue left behind adds to the thickness of the carapace.

Atterberg Limits and Moisture Contents

Table 1 summarizes data from the Rankin Inlet laboratory and Figure 2 indicates Atterberg limits on sediments collected from mud boils in 1970, 1971, and 1973. From both displays it is apparent that liquid limits for Keewatin "muds" are very low with respect to other arctic or subarctic "muds" and that plasticity indices are low (<4%) or unmeasurable. This means that at very low moisture contents, Keewatin "muds" pass from a solid state possessing considerable shear strength to a liquid state shear strength, either directly or after passing through a very minor plastic phase. Thus, a very slight increase in moisture content or an increase in pore-water pressure may cause a seemingly solid soil to liquify or founder, or conversely, very slight decrease of these stresses may cause an

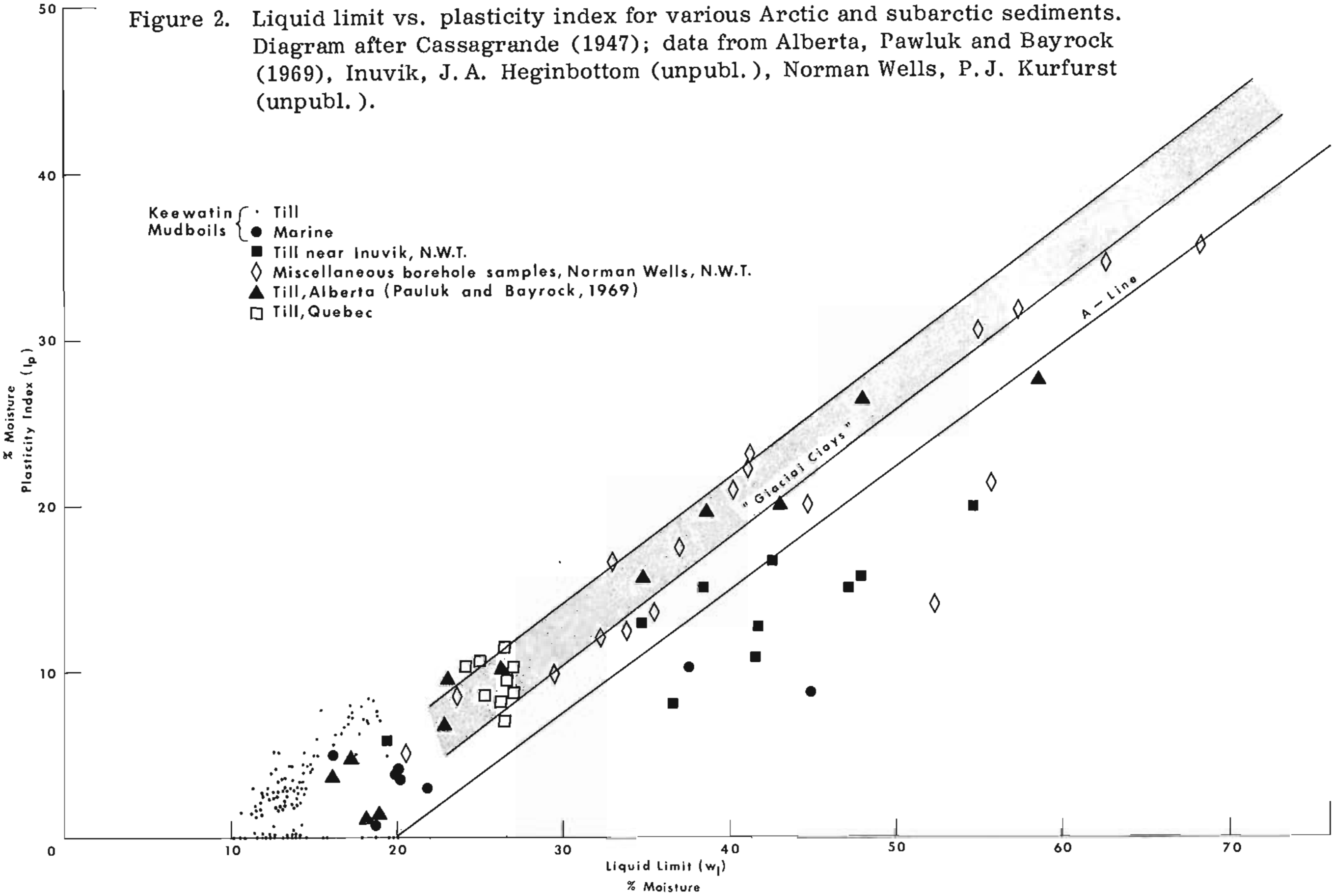


Figure 2. Liquid limit vs. plasticity index for various Arctic and subarctic sediments. Diagram after Cassagrande (1947); data from Alberta, Pawluk and Bayrock (1969), Inuvik, J. A. Heginbottom (unpubl.), Norman Wells, P. J. Kurfurst (unpubl.).

apparently liquid, soft mud to become solid.

A dramatic example that illustrated these properties occurred on August 7, 1973 when a field assistant (C. I. D. A. student Aaron Villakazie) became trapped in a subaqueous mud boil (Type E, Table 1) on an island in Kaminak Lake (Figs. 7, 8). His foot sank in mud which, because of increased pore-water pressure caused by his weight, was above liquid limit (12.4% with a natural moisture content 11.9%) at and below the sole of his boot, but below liquid limit, or solid, above the toe of his boot. The liquid and plastic limits of the sediment are equal so that it could not behave plastically, only as a solid or liquid. Thus, in two hours and despite the efforts of seven men, he sank almost to the frost table and was extricated only after the rigid sediment around his leg was excavated hydraulically by a portable, high-discharge pump.

Texture

Figures 3, 4, 5, and 6 illustrate the relationship of texture to Atterberg limits for sediment from mud boils. Carapace samples on Figure 3 are clearly distinguished from their parent material (till) by their poverty of fine particles. This gives rise to liquid limits of 10-12% and a plasticity index near 0% for carapace materials. At its mean natural moisture content of only 60% of the liquid limit, however, the carapace is rigid and only under conditions of very high rainfall or loading does the carapace absorb enough water to pass the liquid limit.

The finer texture of unmodified till and marine sediment (Fig. 3) allows for higher natural moisture contents, higher liquid limits, and greater plasticity indices. Moisture content averages 70 - 80% of the liquid limit, suggesting that these sediments would become mobile before carapace-type sediment would (i.e., at lower amounts of added moisture).

Figure 4 suggests that sediments forming mud boils have liquid limits and plasticity indices that both increase with decreasing mean grain size. The plasticity index increases with poorer sorting (Fig. 5) but the liquid limit is somewhat independent of sorting; marine sediments, particularly, show high liquid limits and good sorting. The plasticity index increases with increasing clay (-2μ) content (Fig. 6) but the liquid limit varies widely at low clay contents (<10%). At clay contents >10%, liquid limits increase with increase in clay percentage.

It may be concluded from these data that textural parameters have a strong influence on the plasticity index but that only mean grain size consistently affects the liquid limit.

Moisture Contents and Excess Water

Moisture contents and excess water calculations shown in Table 1 are probably somewhat misleading,

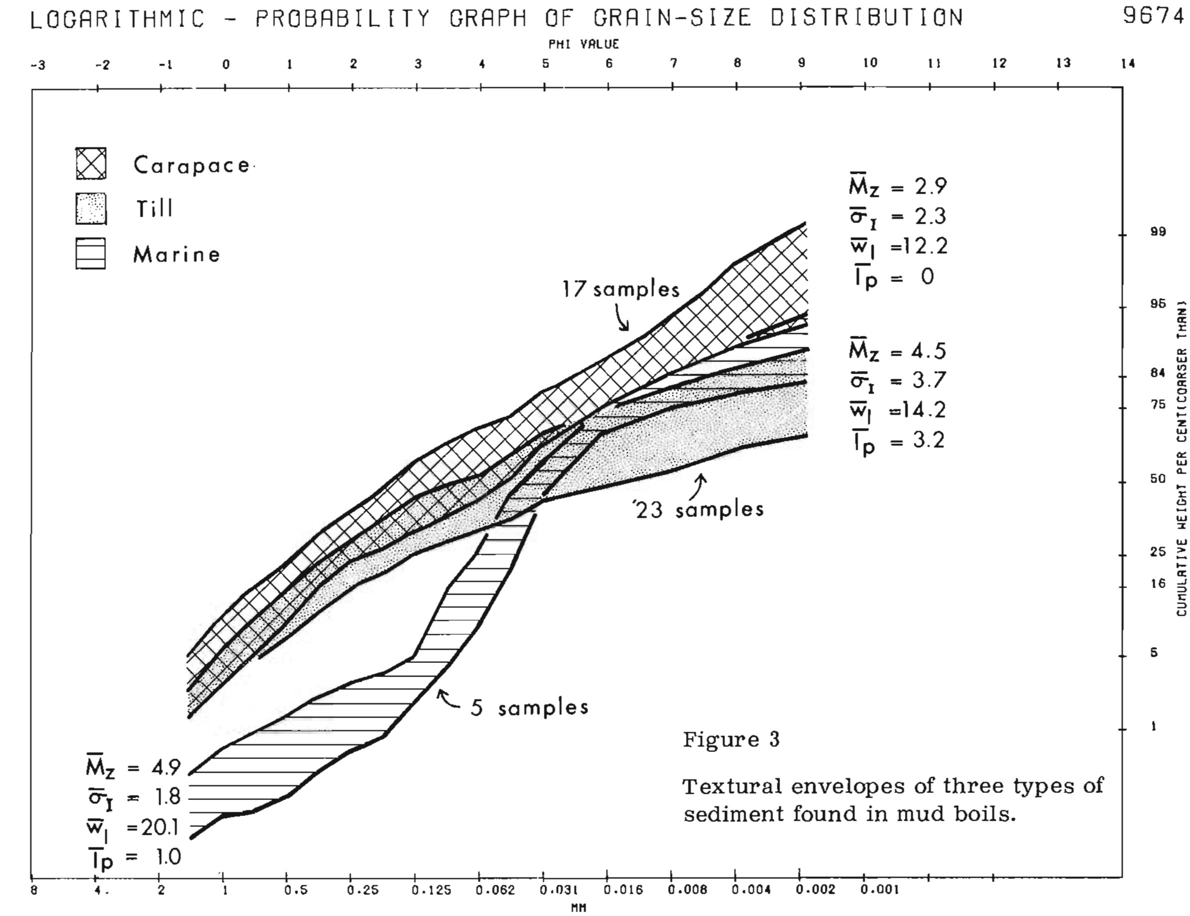


Figure 3

Textural envelopes of three types of sediment found in mud boils.

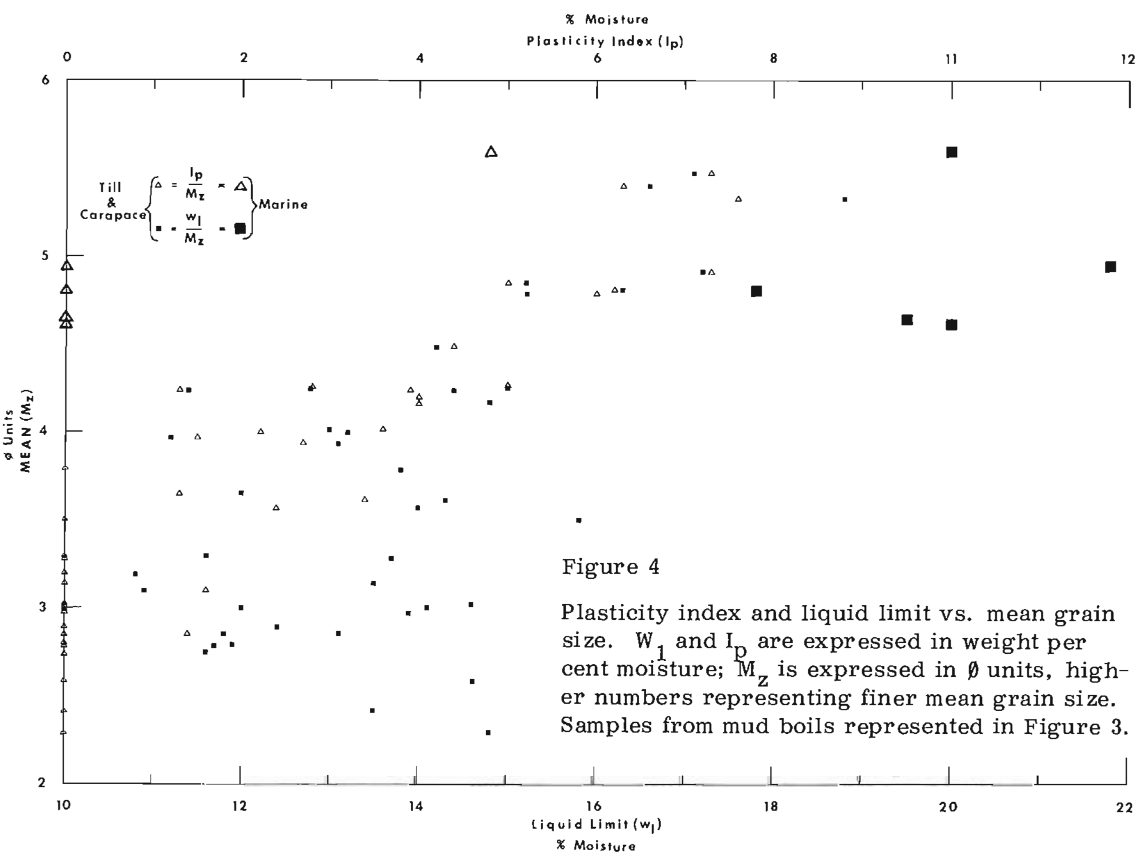


Figure 4

Plasticity index and liquid limit vs. mean grain size. W_1 and I_p are expressed in weight per cent moisture; M_z is expressed in ∅ units, higher numbers representing finer mean grain size. Samples from mud boils represented in Figure 3.

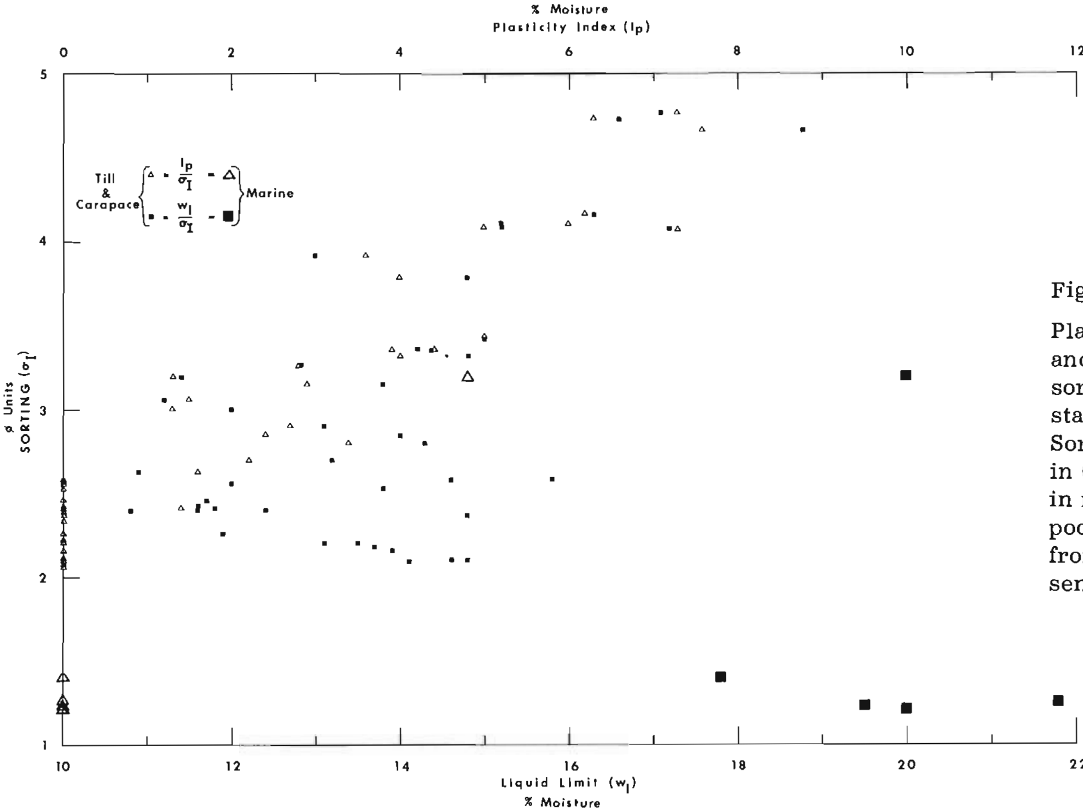


Figure 5

Plasticity index and liquid limit vs. sorting (graphic standard deviation). Sorting expressed in Ø units. Increase in number indicates poorer sorting. Samples from mud boils represented in Figure 3.

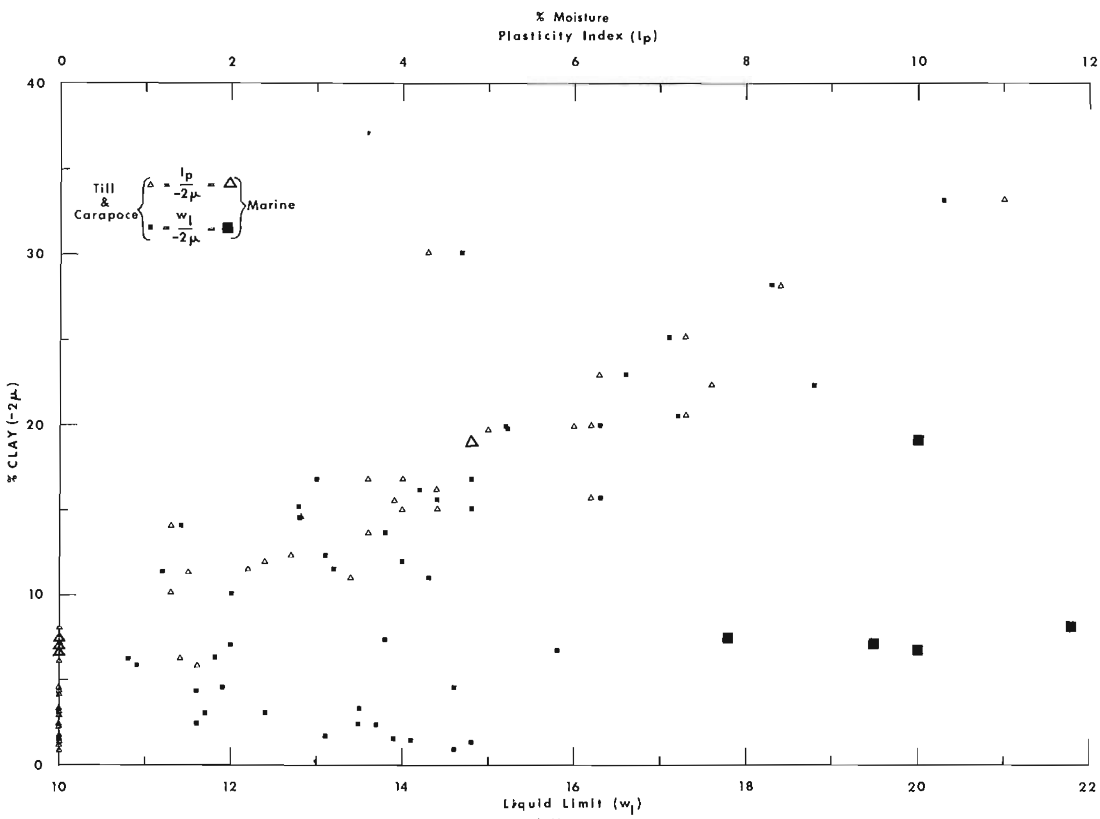


Figure 6.

Plasticity index and liquid limit vs. percentage clay. Samples from mud boils represented in Figure 3.

but provide rough estimates for comparison with data from other areas. Samples were collected before August 15, 1973. From early May to that date, less than 1 in. (2.5 cm) of rain fell on the areas sampled (as opposed to 10 in. (>25 cm) in June-August 1970, and ∿4 in. (∿10 cm) in June-August 1971), and air temperatures and cloud-free periods were well above normal for this period. Thus, samples collected from the active zone were noticeably drier than in other years.

A second source of bias occurs in computation of excess water, which is an indirect measurement of excess ice. This value was derived from the ratio (free water volume/total volume), x 100 of a melted sample collected from below the frost table. Since most samples were within 6 in. (15 cm) of the frost surface, ice-lensing, which is always prominent near the frozen/unfrozen interface, was prominent in most samples; these figures cannot be extrapolated to conditions at depth.

It is interesting to note (Table 1) that frozen *Sphagnum* mosses with very high visible ice contents produce little or no excess water when melted because of the very high absorptive capacity of *Sphagnum*. Peats derived from grasses or sedges, on the other hand, may produce significant amounts of excess water on melting.

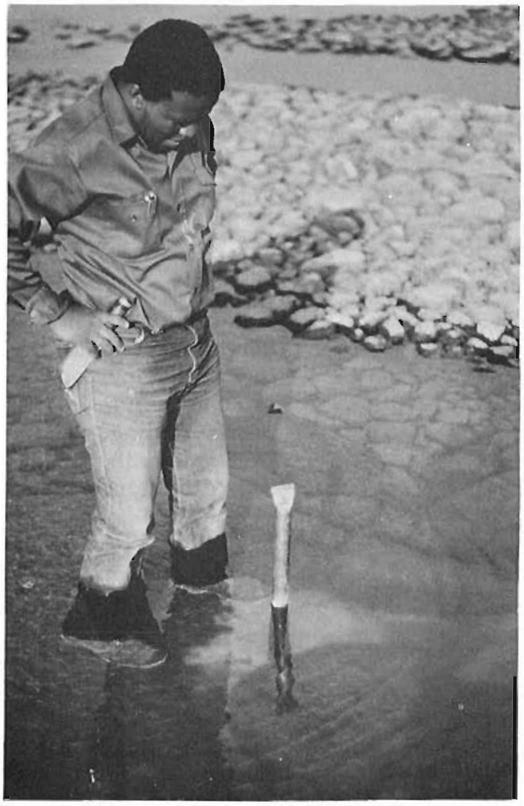


Figure 7. Probing depth to permafrost at edge of island in Kaminak Lake (probe rests on permanently frozen till, 1.5 m below water surface).

Conclusions

Preliminary data on Atterberg limits and natural moisture contents of unconsolidated sediments from Keewatin support the artesian concept of mud boil formation. Because of the low liquid limits and small plasticity indices of sediments forming mud boils, slight increases in pore-water pressure due to loading, small amounts of precipitation, cryostatic pressures created during fall freeze-up, or moisture increases during spring-summer thaw could all be causes of temporary liquefaction of the active zone with resulting hydrostatically driven diapirism or mud boiling. This seasonal activity would destroy other features, such as incipient frost polygons, so that these features are incompatible with sediment that form mud boils. Organic growth would also be disrupted seasonally so that no persistent organic cover could be established.

Figure 8. Attempting to dig student out after left foot sank in bare sediment of mud boil probed in Figure 7. Sinking took place over a span of two hours (see text for Details).

In dry sands and gravels of ridged or hummocky stratified drift, organic cover is slight because the moisture content of the well-drained active zone is low, the liquid limit of the sediment is very high; because of these factors, the thawed zone is stable enough to perpetuate seasonal growth of vertical ice wedges that are expressed at the surface as frost cracks. Only locally, where moisture from spring thaw builds up temporarily behind snow banks, is the liquid limit likely to be exceeded and slumping or flowing take place.

Frost cracks or polygons also occur where sediments derived from marine reworking or alluvial or lacustrine deposition have partially filled depressions that existed on the glaciated surface after retreat of the ice. These pockets of sediment have flat surfaces and occur in strips along major rivers and eskers, in post-glacial lake basins, and in numerous, smaller, random pockets at all altitudes up to marine limit (560±20 feet a.s.l. higher on the hill between Rankin and Chesterfield Inlets). Three factors may cause mud boils to be absent and frost cracks to predominate in these areas: 1) the flatness of most basins would not allow for significant hydrostatic head to develop; 2) the sedimentary fill is commonly sandy or gravelly so that liquid limits are too high to cause flow at normal moisture contents; 3) where the sedimentary fill is very wet, organic growth is lush, and a thick, insulating cover of peat develops on the sediment. In such areas the maximum depth of thaw is slight (15-30 cm) so that the active zone is never thick enough to develop the artesian system necessary for mud boil formation, no matter what the properties of the underlying mineral sediment might be.

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Project 710086

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This year's field work was a continuation of work begun by W.F. Bawden in 1971 (Bawden, 1971). In contrast with the reconnaissance and inventory of slope instabilities in southwestern British Columbia carried out in 1971, this year's work consisted of a detailed engineering geology study of the Drynoch landslide.

The Drynoch slide, according to the Highway Research Board classification (Varnes, 1958), is a slow earth-flow, and is located approximately 8 km south of Spence's Bridge, B.C. The slide extends approximately 4.5 km east from the Thompson River and varies in width from 100 m to 400 m. The difference in elevation from the Thompson River to the head scarp is 700 m. Brawner (1959) estimated the volume of material involved in the slide to be 15,000,000 cu m. Both the Trans-Canada Highway and the Canadian Pacific Railway traverse the lower portion of the slide.

Initial movement of the slide material, as determined by radiocarbon dates, began between 6,600 and 3,175 years B.P. (Fulton, unpubl. MS). Movement has continued to the present. In recorded history it has moved at rates varying between ½ m to 4 m per year. (B.C. Department of Highways, pers. comm.). Obviously this movement has created problems for both the Department of Highways and the C.P.R.

The slide material consists of a mixture of gravel, sand, silt and clay. The clay portion has a high percentage of montmorillonite (Bawden, 1972). Material in the slide comprises both glacial drift and locally derived bedrock. Boulders up to 1 m in diameter found in the slide are derived from local Cretaceous volcanics and sandstone. Poorly consolidated Tertiary sediments are also found in the vicinity of Drynoch. The origin and significance of these materials in the history of the slide is not yet fully understood.

Between 1957 and 1963 the B.C. Department of Highways carried out a major engineering study and construction program on the Drynoch slide during the realignment and upgrading of the Trans-Canada Highway. Since then little has been done at Drynoch except for routine maintenance by the Highways Department. The present investigation is timely because continued movement of the slide has reduced the effectiveness of remedial highway construction.

A portion of the field work consisted of mapping the surface of the slide and surrounding area for: (i) distribution of the various rock and soil types, (ii) surface drainage, (iii) surface expression of groundwater, (iv) tension and shear cracks, and (v) other surface expressions of movement.

Under the supervision of the author, three 5-inch diameter boreholes were drilled by and in conjunction with B.C. Department of Highways. Four more boreholes are to be drilled this fall. The purpose of the drilling is to: (i) obtain stratigraphic information on the slide material, (ii) determine depth to bedrock, (iii) recover disturbed and undisturbed soil samples for testing, and (iv) install piezometers to determine water pressure and pressure gradients in the slide material.

In conjunction with the field work, existing engineering and geological data will be compiled and a laboratory testing program will be carried out to produce a full engineering geology study of the Drynoch slide. This will include: (i) determination of the origin of the material, and (ii) understanding the history and processes involved in the major slide.

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85. SURFICIAL GEOLOGY AND GEOMORPHOLOGY OF MELVILLE ISLAND, DISTRICT OF FRANKLIN

Projects 710041 and 710042

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Terrain Sciences Division

Field work continued under these projects east of 112°W as part of a pilot project for an integrated landscape survey to be undertaken for the Environmental-Social Program - Northern Pipelines. Participation by and collaboration with officers of both the Forestry Management Institute (S.A. Edlund and I. Resch) and the Canadian Wildlife Service-Eastern Region (L.S. Prevett and D.C. Thomas), Department of the Environment was found to be mutually beneficial in the development of an integrated landscape classification and mapping system at a working scale of 1:125,000

Initially the landscape was divided into three orders of units, the highest being the geological formation boundaries slightly modified from those of Tozer and Thorsteinsson, 1964. This unit is equivalent to the "land district" in the Biophysical Land Classification (Lacate, 1969). The intermediate level units were primarily based on surface sediment texture (geological facies). Closely interrelated aspects of vegetation, soil moisture and topography were determinants of the boundaries of the lower order landscape units. Significant changes of surface properties and vegetation were frequently related to discontinuous veneers of material (mainly till and postglacial marine material).

Wildlife habitat and a statistical evaluation of plant communities, including biomass production complemented the vegetation mapping.

Evaluation of the variability and character of ice in the surface materials was continued using the modified SIPRE core barrel with a 9 hp GE power head. This power unit proved superior to the less powerful Haynes used previously. Twenty-six additional one-metre cores were obtained this year. Winkie diamond drill was used during August to obtain cores deeper than one metre. The weight of the drill and the quantity of water needed for circulation made it necessary to sling the equipment and materials to each drill site by helicopter. Heat generated and water circulation in the operation caused partial melting of any ice in the core, some core disaggregation and subsequent poor recovery. The circulating water developed into a slurry which caused rapid wear of pump components necessitating frequent replacement. This and other maintenance led to significant down time for the drilling operation. This draw-back combined with average flying weather for August (frequent fog) yielded approximately one drill core per day (22), making the data expensive. A replacement pump with an impeller instead of a progressing cavity significantly improved short term performance but was probably not tested long enough or in a sufficient variety of materials to conclude that it is completely satisfactory, but it definitely merits further testing.

The Winkie drilling also allowed installation of two thermistor strings to somewhat less than 5 metres, one at Sherard Bay and one at Drake Point. Both locations on Sabine Peninsula are expected to be reasonably accessible for periodic reading.

When all aspects of the data are evaluated an overall sensitivity rating will be assigned to each unit allowing initial qualitative assessment of which areas would be preferable for routing pipelines or other developmental work.

In-field co-operation and assistance of Panarctic Oils Ltd. is gratefully acknowledged.

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TERRAIN STUDIES OF CAPE BRETON ISLAND, NOVA SCOTIA AND OF THE NORTHERN PENINSULA, NEWFOUNDLAND

Projects 690065, 700056, 720028

D.R. Grant
Terrain Sciences Division

Investigations in response to requests from external organizations were made in six areas:

1. Canso Strait area of Nova Scotia, where further detailed studies to supplement earlier reconnaissance mapping (Grant, 1971a) were carried out to provide background information on the distribution and composition of surface materials and bedrock relief for the Canso Strait Environmental Marine Geology Project, of the Atlantic Geoscience Centre, Dartmouth, N.S.

2. Cap Rouge on the Cabot Trail, Cape Breton Island, Nova Scotia, where rock failure involving the highway was examined to supplement an earlier airphoto interpretation of the causative factors, for the Department of Public Works.

3. Margaree Valley Nova Scotia, where surface materials, stratigraphy, geomorphology, and glacial features (Grant, 1971b) were mapped in connection with a detailed geochemical survey of the Margaree watershed by the Nova Scotia Department of Mines

4. Springdale and Sheffield Lake map-areas of Newfoundland, where surficial geology maps based on airphoto interpretation were field-checked prior to open file release in connection with drift-prospecting research by D.W. Alley, Memorial University, St. John's, sponsored by the Department of Energy, Mines and Resources.

5. Gros Morne National Park Newfoundland, where similar surficial geology maps requested in connection with park planning, development, and interpretation were field checked and updated from new highway exposures, and where a special study, financed by the National Parks Branch, was made of a large postglacial landslide (Grant, 1973), together with L.M. Cumming, Geological Survey and Greg Wickware, National Parks

6. L'Anse au Meadow Newfoundland, where additional information on former land-sea relations (Grant, 1972) and paleoenvironments (in collaboration with M. Kuc, Geological Survey) was sought from current excavations of a Viking settlement (ca 1000 A.D.) proposed as a National Historic Site.

Canso Strait, Nova Scotia

As sea level in the Port Hawkesbury map-area during postglacial time has risen at least 100 feet to its present level, most of the marine geology study area can be regarded as the fringes of the present landmass that have only recently acquired a superficial marine aspect, namely a cover of sea water. Using seismic profiling, bedrock distributions can be extended offshore and should show the same geomorphic expression as various lithologies do on land. Except on steep slopes, till cover is thought to have largely survived marine transgression, considering that presently eroding till cliffs continue seaward as boulder-armoured till ramps, and should therefore have comparable composition and distribution to tills on land. Further, the bulk composition of postglacial and recent marine sediment should relate to the source tills in the immediate hinterland. Proglacial marine sediment, deposited near the former wasting ice margin, might be encountered at depths greater than 100 feet and could show weathering effects since those sediments may have been briefly emergent during postglacial rebound.

Rocks in the area include mainly folded, well-bedded clastics, ranging from conglomerate to shale, with minor protrusions of crystalline basement, and more distant areas of limestone and gypsum. Most of the area is blanketed with a clayey, red till that thins over hills and uplands of resistant rock, and thickens over buried valleys and bedrock lows which are usually underlain by friable shales and evaporites. The till cover is organized into a regular series of ridges up to 200 feet high trending southeastward on both sides of the Strait from Guysborough to Isle Madame. Superimposed on these ridges are fluted patterns or smaller drumlinoid masses trending south-southeastward. Elsewhere, the latter trend takes the form of discrete drumlins on the quartzite ridges west of Mulgrave, and till tails streaming northward from the cuestas east of Port Hastings. The till forms have been previously attributed to a three-phase ice-flow sequence produced by a shifting ice cap (Grant, 1971b).

Further work will include: (1) comparing drift thickness and geomorphology of subaerial and submarine areas, in part to bear upon the controversy about the effect of marine trangression, (2) treating the heavy metal content of tills and stream sediments as "background" with respect to pollution of marine sediment with metals derived from industrial effluents, and (3) interpreting seismic profiles to construct a map of submask bedrock geology.

Cap Rouge, Nova Scotia

The "Cabot Trail" is the only road link skirting northwestern Cape Breton Island. Five miles north of Cheticamp, where the highway begins its traverse along the escarpment of the Cape Breton plateau 400 feet above the sea, a minor rock settlement recently fractured and lowered the pavement. During the past summer Public Works drilled to probe subsurface conditions, and established a grid of surveyed monuments to monitor future movement. Terrain Sciences Division

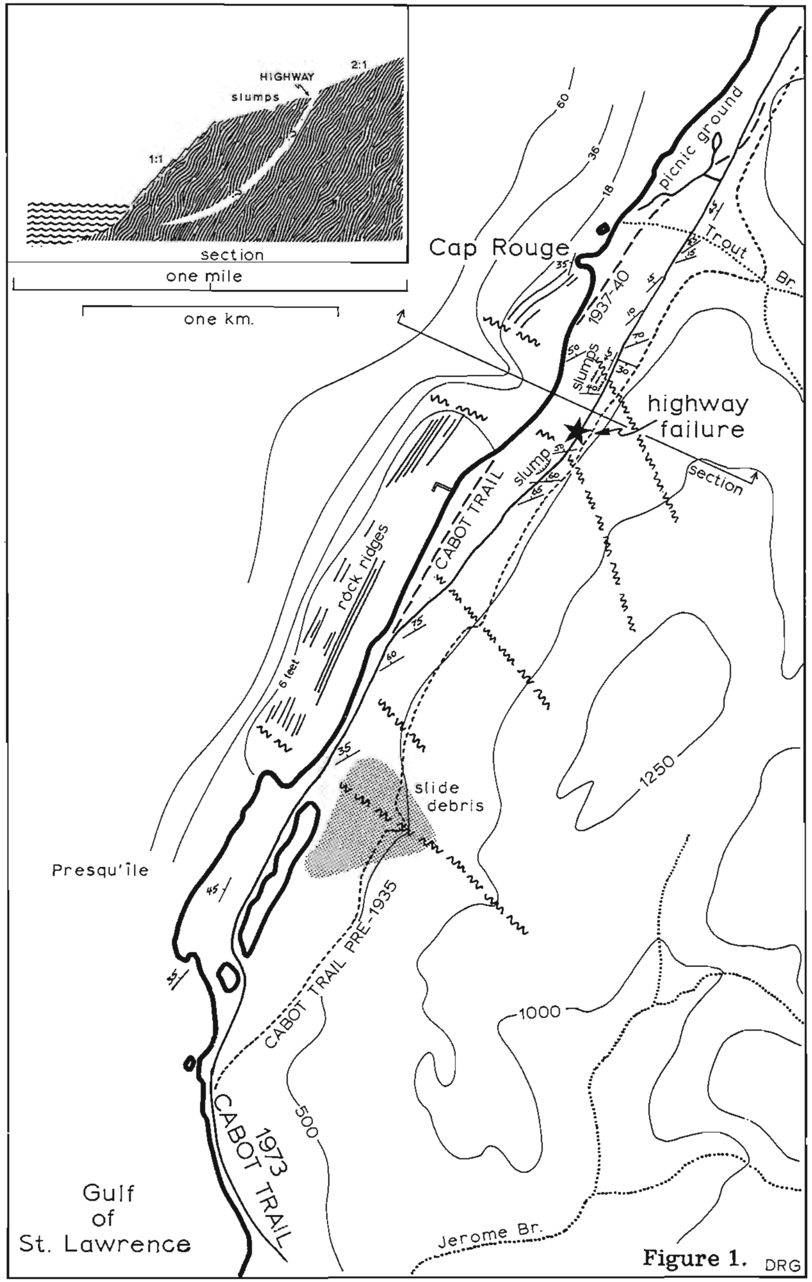

Figure 1.

Geological setting of recent slope failure along Cabot Trail, near Cap Rouge, Cape Breton Island, Nova Scotia.

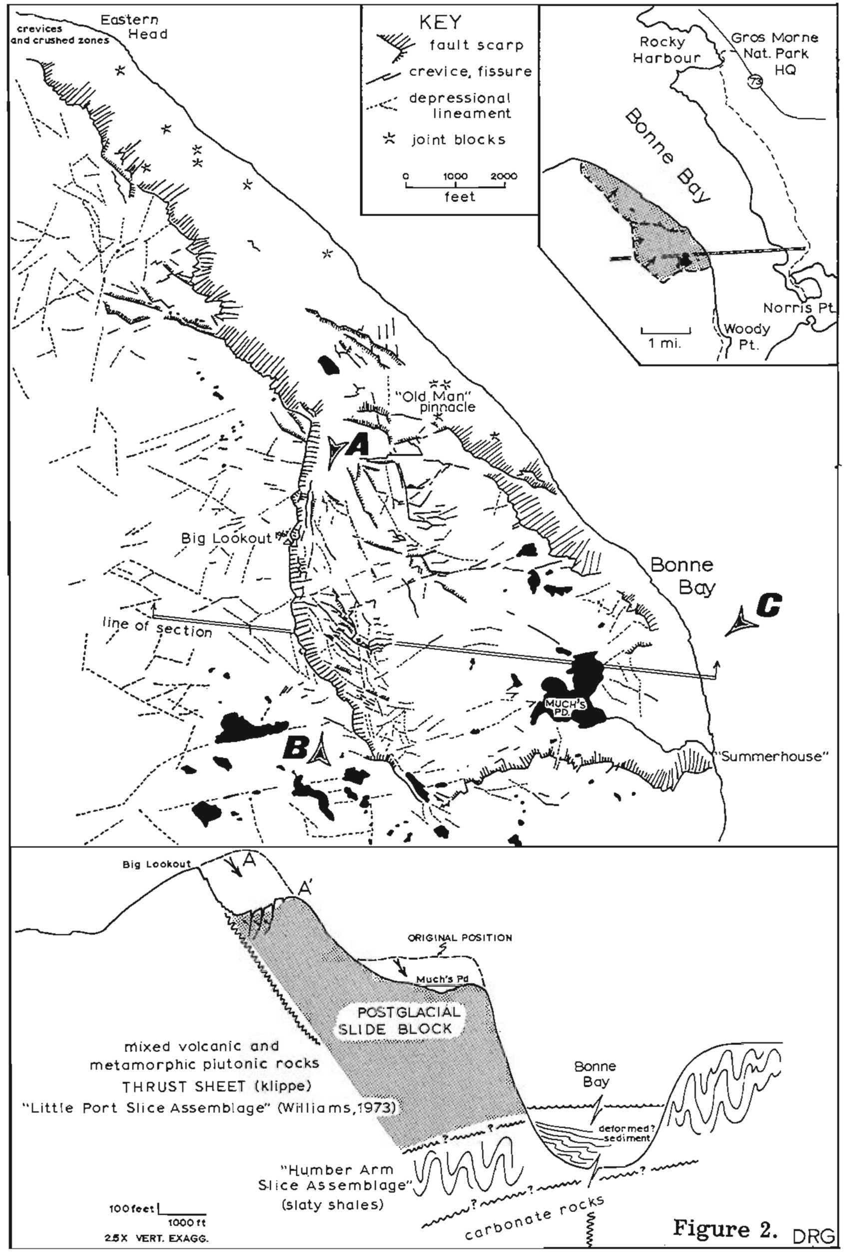

Figure 2.

Map and schematic cross-section of postglacial landslide, Bonne Bay, Gros Morne National Park, Newfoundland. Letters (A, B, C) denote camera positions of photographs reproduced as Figures 3, 4, 5. Bedrock geology adapted from Williams (1973).

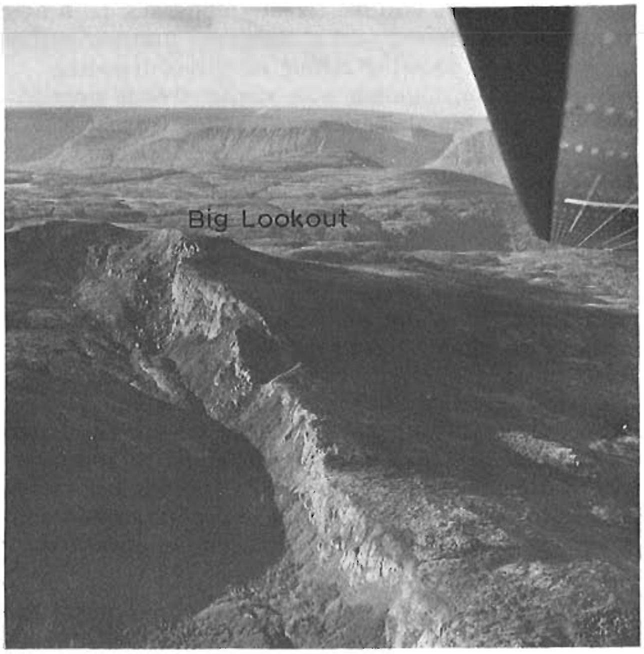

Figure 3.

Aerial view of fault scarp 200 to 300 feet high crossing a hill on the Long Range plateau. (GSC photo 202303 by L. M. Cumming.)

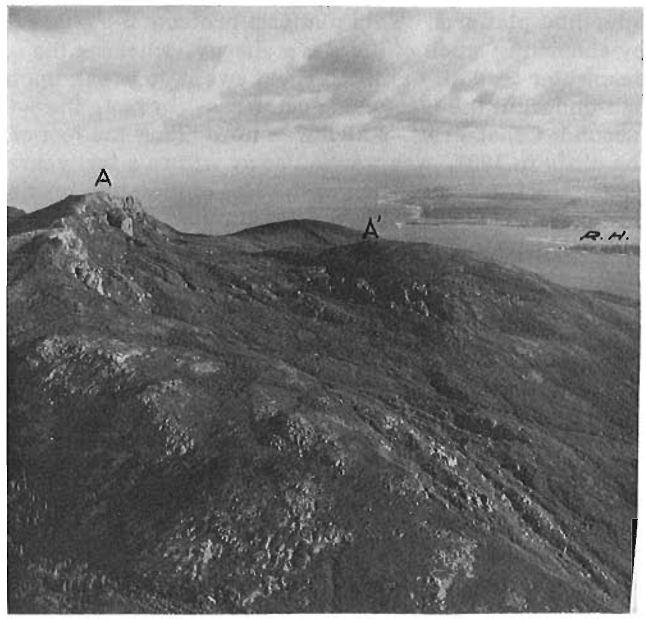

Figure 4.

Aerial view showing displaced summit (A-A'; see also Fig. 2) which is deeply fissured on trailing edge. Rocky Harbour (R. H.) in upper right. (GSC photo 202303-A by L. M. Cumming.)

Figure 5.

Aerial view of fault scarp (broken line) crossing tableland beyond Much's Pond (outlined). Bonne Bay in left foreground. (GSC photo 202303-B by L. M. Cumming.)

provided a brief on-site investigation of structural geology and geomorphic process (Fig. 1).

The escarpment is composed of fractured Precambrian phyllites inclined seawards, dissected by zones of incoherent crushed rock trending both parallel the shore and obliquely up the slope where they have been etched out as narrow ravines. A fault slice of Carboniferous sandstone outcrops under Trout Brook picnic ground and continues south as an intertidal platform. 1935 airphotos (N.A.P.L. A5076-74) show a level strip of clearings opposite the wharf, interpreted as the top of an older slide block, now followed by the present highway. Clearing of the slope opposite Presqu'île, seen on 1947 airphotos (A11762-78), showed a large area of chaotic topography interpreted as slide debris. At least two other smaller slump slices, now overgrown, interrupt the slope below the highway disturbance.

The zone of rock failures is localized opposite a deepwater lead in excess of 50 feet that penetrates within a few hundred feet of shore, through the otherwise intertidal platform. This platform protects the shore by absorbing much of the wave energy, whereas the deepwater lead allows the largest swells to break upon and undercut the fractured rock mass. In fact, the 'second' Cabot Trail, which was built along the foot of the cliffs in 1937, was washed away within a few years. Thus, the intense erosion at the foot of the slide prone section is expected to promote continuous, spasmodic rock adjustments farther upslope, necessitating occasional road repair.

Margaree Valley, Nova Scotia

About 200 square miles were mapped using the road network throughout the drainage basin of the Margaree River and its tributaries, as well as the slopes and plateaus of the surrounding Cape Breton Highlands. The upland areas between 500 and 1,500 feet are composed of Precambrian crystalline rocks on which a locally deep weathered mantle has developed. Patches of till, usually displaying a southeast-trending drumlinization, occur sporadically on the plateau, whereas the lower slopes below 500 feet are deeply till covered. Below 250 feet the valley floors feature broad overlapping outwash fans composed largely of far-travelled igneous gravel not always related to the modern stream presently dissecting it. The outwash has been extensively reworked into a series of river terraces. Although as much as 200 feet of alluvium has been penetrated in borings for groundwater in the upper Margaree valley, the unconsolidated materials filling the bedrock valley probably average less than 25 feet. Karst topography is widespread and developing rapidly through the gravel cover overlying soluble rocks such as limestones, gypsum, and calcareous clastics. However, "The Plains", along the upper Northeast Margaree, although widely pockmarked with small sinkholes, is actually produced by a smooth 10-foot-thick veneer of till over a bedrock flat in which the modern river is entrenched 30 feet.

Glacial movements, insofar as they affect the distribution of materials on which geochemical anomalies may develop, are still imperfectly understood. A new road over the plateau east of Margaree Harbour exposes many outcrops showing strong southeast-trending stossing which, together with similar trends mapped elsewhere on the plateau, suggest that the area was overridden by ice from the Gulf of St. Lawrence. Moreover, these facets are truncated by an opposite and later set of ice-flow features trending westward to the Gulf, as if from an ice cap remaining active inland. This is corroborated by northward stossing on outcrops along Lake O'Law Brook, by a spillway sloping northward down the Southwest Margaree River valley and by outwash plains sloping northward from Nile and Tompkins brooks.

Although most heavy metal concentrations in stream sediment should be locally derived, the few till plains on the plateau contain much transported Carboniferous material that may locally influence geochemical values. The metal values in the gravels of the Margaree Valley are expected to be lower, erratic, and of uncertain origin.

Springdale and Sheffield Lake Map-areas Newfoundland

The surficial geology is pertinent to the continuing search for the bedrock sources of the several hundred ore-grade erratic boulders discovered 25 years ago that contain base-metal sulphides, chromite and asbestos. The Springdale map-area lies within the Newfoundland Central Lowlands physiographic region, a monotonous upland averaging 750 feet elevation. This is crossed by the major valleys of Indian, West, and South brooks which converge on Halls Bay to the northeast. Sheffield Lake map-area lies on the edge of the Newfoundland Highlands region, here characterized by broad rounded hills to 1,500 feet, and crossed by Birchy Lake valley, a former extension of Indian Brook now isolated by drift dams. Throughout the region, the uplands are obscured by boggy tracts of hummocky and ribbed moraine, whereas the hills are skirted by till veneer, grading upward under colluvial debris, and surmounted by rocky crags ("tolts") rising from talus aprons.

During the main phase of the last glaciation, ice flow in the Sheffield Lake area is shown, by areas of drumlinoid till, crag-and-tail hills and scattered stoss-and-lee summits, to have been northward across the topographic fabric, over Burlington Peninsula to White Bay; over the Springdale area it paralleled the structural-geomorphic grain northeastward to Halls Bay. The pattern of ice flow during glacier retreat was different, as inferred from the trend of ribbed moraine and eskers, the disposition of outwash fans and the slope direction of the many sidehill meltwater channels. These features show there was a major separation of ice-flow domains along the Birchy Lake — Indian Brook valley, so that an ice shed became isolated over Burlington Peninsula and caused outwash to be poured southward while the main inland ice sheet retreated southward with a highly lobate margin up the valleys to the central upland. Ice had cleared the head of Halls Bay prior to 12,000±220 years B.P. (GSC-1733), the age of shells in the bottomset beds of a glaciomarine delta at South Brook. Remnant ice masses became landlocked in Sheffield Lake basin and near the Birchy Lake — Indian Brook diffluence and wasted by concentric stagnation. From this, the source of mineralized erratics south of Indian Pond should be sought less than a few miles away to the southwest toward the east end of Sheffield Lake.

Gros Morne National Park, Newfoundland

Terrain conditions have been outlined in an earlier report (Grant, 1973) that also drew attention to a large postglacial rock movement along the edge of the Long Range plateau facing Bonne Bay fiord. There, a coherent rock mass, measuring 3½ miles along the cliff by one mile wide by at least 1,500 feet thick, slipped about 200 to 500 feet. Recent, closer study by aerial and ground traverse, although somewhat hampered by poor weather and difficult access, yielded no definitive information as to the mode and timing of the slide, nor could its future behavious be inferred.

In Figure 2 the complex of scarps, fissures and preexisting joints is shown together with a schematic cross-section relating the slide to the regional structural geology. Although the main zone of movement is obscured by talus and vegetation on the plateau, open fissures and rubbly brecciation are present where it intersects the coast at Eastern Head and "Summerhouse". The main feature of the slide is the prominent scarp slicing across Big Lookout, a 600-foot summit or monadnock on the plateau (Fig. 3). The downthrown or trailing edge is broken by numerous open fissures up to 100 feet across, parallel to the slide scarp (Fig. 4). These were presumably dragged open by friction against the fault plane as blocks separated from the moving mass. The scale of movement is clearly shown by the wholesale lowering of the plateau surface in the vicinity of Much's Pond (Fig. 5). The alignment of the scarp was apparently influenced by the regional northeast — northwest joint system (Fig. 2). The main factor contributing to the weakness of the glacially over-steepened fiord wall is the superposition of a thrust sheet (klippe) composed of dense ultrabasic rocks over older thrust slices composed of relatively weak shales and carbonate rocks. This is borne out by the occurrence of other smaller slides of identical morphology on the opposite edge of the ultrabasic klippe near Gregory River and along the coast north of Trout River, 10-15 miles southwest.

Rock mechanics expert, Karl Terzaghi (1962, pp. 255, 256) made several pertinent comments regarding postglacial failure of ice-sculptured slopes:

> Rock slides.... are attributable solely to the development of joints.... after removal of lateral support once provided by glacial ice.... the real surface of sliding follows the joints wherever possible. The critical height of slopes on unweathered rock is determined by.... joints and faults, not by the strength of the rock. The foremost requirement for evaluating the degree of stability.... consists in a thorough joint survey. (However).... the cohesion of jointed rock cannot be determined by any of the presently available methods for rock investigations.

Short of instrumenting the slide block with telemetering microseismometers to monitor strain noise signalling imminent collapse, little else can be done to assess the hazard, if any. Information of the event age would be useful, possibly by sampling the bogs and ponds along the fault trace or by seismic profiling of the presumably deformed postglacial clays on the floor of Bonne Bay. In all likelihood, however, this feature will come to be regarded as less of a threat and more as a highlight of the park interpretation program.

L'Anse au Meadow Viking settlement, Newfoundland

A settlement dating 1,000 years old, ascribed to Viking occupation, consists of eight building foundations situated on a raised beach about 10 feet above present high tide level. Assuming the occupants settled near the shoreline of their time, the implied age of the beach is consistent with the radiocarbon dating of shells from beaches of comparable elevation elsewhere in that part of the Northern Peninsula.

Current excavations for a detailed archeological study have cut through the four lowest raised beaches and the sediments later deposited on them. The plane-bedded openwork gravel of the settled beach is overlapped by an accumulation of driftwood laid in against the beach face by the last highest storm before the berm was finally abandoned. Lower down and nearer the present coast, the beach ridges are overlapped by lenticular bodies of muddy gravel with organic intercalations. These are interpreted as fluvial and marsh sediments laid down by the stream that meandered against the beach plain as sea level fell and caused the small bay around which the houses were built to shallow and become a stream. Finally, on the meander plain in which the present stream is now entrenched, a 3-foot bed of sedge peat has accumulated containing suspended rounded beach cobbles and driftwood, presumably dropped by winter ice floes thrust inland by storm tides.

Dating of a whalebone from the occupied beach level and of the highest driftwood below the occupied beach should provide an independent means of bracketing the period of occupation.

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SURFICIAL GEOLOGY, GEOMORPHOLOGY AND TERRAIN DISTURBANCE, CENTRAL ELLESMERE ISLAND, DISTRICT OF FRANKLIN (Parts of 49D, E, G, H, 340B)

Projects 720081, 720082

D.A. Hodgson
Terrain Sciences Division

Investigations were continued on the Fosheim Peninsula (Hodgson, 1973 a, b) and extended to include parts of eastern Axel Heiberg Island, and the lowlands east of Cañon Fiord. To meet project objectives, work was conducted as follows:

a) Air and ground traverses to map surface materials, including an assessment of their 'sensitivity' to disturbance.
b) Detailed site investigations of selected disturbed and undisturbed areas.
c) Shallow drilling and coring to support the above activities.
d) Observations on the Pleistocene history of Ellesmere and Axel Heiberg Islands.

Mapping

Maps portraying texture and genesis of surface materials, active and inactive geomorphic processes, and ground ice content are in preparation. Contrary to an opinion expressed previously (Hodgson, 1973b) bedrock lithologic contacts do not necessarily outline differences in the texture of surface materials - though uplands (>300 m) roughly correspond with more resistant, and lowlands with less resistant rocks. Poorly lithified rocks break down to produce a regolith up to 5 m deep, and despite sharp tonal differences on air photos, representing contacts of formations or even beds, the impression on the ground is frequently one of a uniform expanse of material in the silt to fine sand range. Even resistant Paleozoic limestones weather to provide large areas of lime mud.

Substantial areas of Pleistocene deposits are present. The main deposits are (a) a silty stony till flanking parts of the west side of the Sawtooth Range and the south shore of Greely Fiord; (b) remnants of a gravel-veneered peneplain, possibly pre-Pleistocene in age, mainly overlying the Eureka Sound Formation; (c) postglacial and interglacial fills of fluvial and estuarine silt, sand and organic material in lower elevation valleys; (d) a discontinuous veneer of postglacial marine deposits, ranging from gravel beaches to clay, below the marine limit (160 m in western Fosheim Peninsula, less than 100 m in the east).

West of the Sawtooth Range, in a predominantly lowland setting with a very low annual precipitation (~65mm), variations in soil moisture and thickness of the active layer appear to have a greater influence on the 'sensitivity' of the ground surface than does the texture of surficial materials. All materials are most sensitive during the period of snowmelt as this coincides with the initial lowering of the frost table. At this time the thin active layer is saturated, and materials ranging from clay size to fine gravels are equally unstable, both on flats and slopes. On average, this period of maximum sensitivity extends from late May through June; but will continue longer in the zone downslope from snowdrifts. It is for this short period only that solifluction - the most widespread geomorphic process - is active. As the season advances, the active layer quickly becomes stabilized at ca. 45 cm ± 15 depth, while the dry climate permits upper layers to dry out to the extent that a crust forms on fine-grained materials. The heaviest 24-hour rainfall recorded at Eureka in the past summer was ca. 8 mm, and following this, moisture did not penetrate more than 5 cm into bare silt - though the upper 2 cm were saturated. By early September, the active layer rapidly thins as freezing takes place simultaneously from the frost table upwards and the ground surface downwards.

East of the Sawtooth Range, there is much resistant bedrock, felsenmeer and talus, however there are also large areas of finer grained overburden. The region appears to receive more precipitation (both snow and rain) than the Eureka area, and soil moisture values consequently remain high through the summer.

Cone index readings from a proving ring penetrometer will be used to compare the shear strengths of materials with different textures, as well as seasonal changes in the strengths of the same materials.

Site investigations

Surface observations and coring in the Eureka area were concentrated at three locations: (1) Old Eureka airstrip, abandoned 23 years ago, and on which changes in vegetation and the surface expression of ice wedges have subsequently occurred; (2) the vicinity of the Gemini drilling site (occupied early in the winter of 72-73), where high ground ice content led to the failure and emptying of a sump excavated on a slope. (3) An area south of Slidre Fiord where many of the areas Mesozoic formations outcrop. Low level vertical colour photographs of each of these areas were taken by K.C. Arnold, Department of the Environment.

Measurements of the thickness of the active layer, beneath and adjacent to roughly graded winter roads, were repeated at the same points as in 1972. Results showed no significant increase in the depth of the frost table where roads cross either bare or vegetated areas. Occasional gullying has resulted from the concentration of snowmelt runoff in the slightly depressed (i.e., compressed) road bed, but this is generally in bare areas where gullying is a natural process. As runoff is at a maximum when the active layer is thin, gullies are not deep, though obviously a small incremental deepening could occur each spring. Little rutting is evident on winter roads, despite multiple passes by wheeled and tracked vehicles. Far more damage results from the single pass of a vehicle during the thaw period.

Thus, in much of the drier western Fosheim and eastern Axel Heiberg areas, overland vehicle movements outside the saturated active layer period cause minor disturbance. The main effects, such as compression of soils (and also vegetation where present), turning over the lichen covered stones etc., do not appear to activate erosional processes, although they may be blemishes on the landscape. There are however areas which retain high moisture content throughout the summer, due to perennial snowpatches or groundwater movements, and which are susceptible to disturbance. The widely scattered distribution of such areas poses problems in regulating land use activities.

One of the major engineering problems at this latitude is that the active layer does not thicken sufficiently for adequate drainage of meltwater. This is as much a problem with filled sites which contain any fines (e.g., Eureka airstrip) as with undisturbed materials.

Coring

A modified Winkie drill, assembled by J. Veillette, and a powered SIPRE type corer, were used to drill a total of 130 holes to depths between 1 and 8 m. Lithology, including visible ice, was described, and samples were retained for field determination of moisture (and thus ice) content, and for laboratory determination of grain size. Average ice contents of 10 to 50 per cent were common in the upper 2 to 5 m of all materials drilled (which excluded gravels and indurated rock), and massive ice lenses were often encountered.

The most significant finding was the large volume of ice in ice wedges. Ice-wedge polygons are ubiquitous features in unconsolidated clay to fine sand size materials and are visable over 75 per cent of the western Fosheim Peninsula. Polygons are 15 to 30 m in diameter, as outlined by depressions (or less commonly, raised borders) which vary in width from cracks 10 cm across, to thermokarst troughs 5 m broad. Irrespective of the surface expression, the main ice wedge was usually encountered at a depth of 60 to 80 cm, with a width at the top of 3 to 4 m, and a further 5 to 8 m of wedge ice below. Thus in the top few metres of permafrost, wedge ice represents 10 to 20 per cent of the surficial material.

Glacial history

Further field work to delimit and date a late-glacial readvance in central Ellesmere Island was conducted from a camp at Irene Bay (see also Hodgson, 1973c). Shell samples near the marine limit were collected along the south shore of Greely Fiord, and at the west end of Nansen Sound.

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QUATERNARY GEOLOGY INVENTORY
LOWER NELSON RIVER BASIN (63 I, J, G, 64 G, H)

Project 710092

R.W. Klassen and J.A. Netterville
Terrain Sciences Division, Calgary

Mapping of surficial deposits and terrain classification was expanded from the initial project area (Klassen and Netterville, 1973a) to include 4½ additional map-sheets. Photogeologic maps of 63 I, J, N/2G, 64 G, and H were prepared prior to field work and field checked during late May and June. Field work also included a week's study of the short term effects of road construction underway across permanently frozen terrain within the Nelson House (63 O) and Sipiwesk (63 P) areas.

The map-units delimited in these areas are essentially the same as units identified in earlier work (Klasser and Netterville, 1973b). The extensive lacustrine plain adjacent to the Grass River (63 O, P) widens southward to include most of the Wekusko Lake (63 J) area where it is mantled by thick bog and fen. Permafrost occurs in the bogs but is more restricted and thinner than it is in the areas to the north. Most of the terrain in the Cross Lake (63 I) and Big Sand Lake (64 G) areas consists of low hills or knolls of Precambrian bedrock separated by lacustrine clay basins. The clays of the northern areas are thinner and are not as extensive as they are in the south. Also, the flanks of hills and tops of knolls are commonly veneered by water-eroded till or patches of sand and gravel. Drift is thickest in the Northern Indian Lake (63 H) area where it underlies extensive till plains and scattered morainic hills. In the northwestern part the plains are drumlinized and water-eroded, whereas in the southeastern part a clay veneer mantles the till. Ice-contact hills, knolls and ridges composed mostly of sand occur in prominent, north-south trending belts in the western part of the Big Sand Lake (63 G) area and the central part of the Northern Indian Lake (63 H) area.

The short-term effects of road construction across permanently frozen terrain were evident along the steepest slopes of clay-mantled bedrock hills. Thawing of the low ice-content clays combined with the effects of gullying has caused downslope movement of clay sheets by a series of small step-like flows with 1- to 2-foot scarps. The cuts studied were exposed for less than a year and the road bed will probably be disturbed in a short time by undercutting and by the indirect results of clay-blocked culverts. Elsewhere, segments of the clay-fill road bed less than 3 years old, built across frozen bogs on lacustrine clay basins, appeared stable and settling due to thawing was only evident where the peat cover had been disturbed and along the sharp boundary between frozen bog and unfrozen fen.

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89.

GEOLOGICAL, GEOPHYSICAL AND HYDROGRAPHIC STUDIES IN LANCASTER SOUND AND MAXWELL BAY, DISTRICT OF FRANKLIN

Projects 730031, 730078

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D.I. Ross, Atlantic Geoscience Centre, Dartmouth, N.S.

During August and September 1973 the Geological Survey participated in a Canadian Hydrographic Service cruise of CSS Baffin to obtain regional geological information from the Lancaster Sound area. This multidisciplinary cruise completed the detailed bathymetric mapping in Lancaster Sound between longitudes 86°15'W and 90°00'W as shown in Figure 1 along survey lines spaced 1.25 km under Decca Hi-Fix control. The hydrographic and geological work in Maxwell Bay was controlled visually by sextant measurement of horizontal angles. Gravity and magnetic field measurements were obtained along most sounding lines in Lancaster Sound but not in Maxwell Bay.

Sediment grab samples were obtained at most of the 115 bottom stations (Fig. 1) using a double Shipek sampler. Samples from inner Maxwell Bay were collected with a Ponar grab sample. In addition, gravity cores and/or camera observations were obtained at a few stations. Continuous seismic profiles, totalling 500 line miles, were obtained using Huntec single channel equipment with a sparker source in Maxwell Bay and with an air gun source of 10 cu. in. or 40 cu. in. in Lancaster Sound. The seismic and bottom station survey was designed to provide reconnaissance information concerning the nature of the seafloor, thickness of sediment, occurrence of bedrock outcrop and surficial structure.

The islands bordering the survey area, Devon Island, Prince Leopold Island, Somerset Island and Brodeur Peninsula of Baffin Island, are composed principally of flat-lying to gently dipping carbonate strata of Paleozoic age (Fortier et al., 1963). The rock strata are truncated at the islands' coasts to form cliffs, commonly over 300 m high, with talus slopes. The cliffs of Devon Island are broken by fiord-like inlets, for example Maxwell Bay, in which some of the island's rivers discharge to the sea.

Although the floor of Lancaster Sound is irregular in detail, it slopes regionally to the east from 250 to 300 m water depths to 400 to 500 m depths across the survey area. A trough, filled with 100 to 140 m of sediment, traverses the area just north of the medial axis of the sound. A second trough, with less than 90 m of sediment, trends northeastward into the area from Prince Regent Inlet and runs eastward down the sound just south of the medial axis. The bedrock surface rises between these two 'lows' to form a slightly elevated axial region within the sound where rock may outcrop locally through the relatively thin sediment cover.

The predominant sediment in offshore regions is a firm, sticky, clayey silt mud with varying admixtures of sand and gravel. Beneath a thin (1 to 2 cm) brown oxidized zone the mud is characteristically olive grey in colour and commonly contains black streaks of reduced sulphides. At depth the mud becomes stiff and light grey in colour. Gravel, commonly composed of subangular cobbles and stained in places with a ferromanganese oxide, blankets the seafloor adjacent to the coasts and on the medial rise.

A carbonate rock terrane is believed to underlie much of the survey area because the bedrock surface commonly formed an acoustic basement. However, softer (and younger?) sediments appear to underlie the northerly trough east of Maxwell Bay where the seismic records clearly revealed strata dipping into an east-west trending synclinal structure.

Reference

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

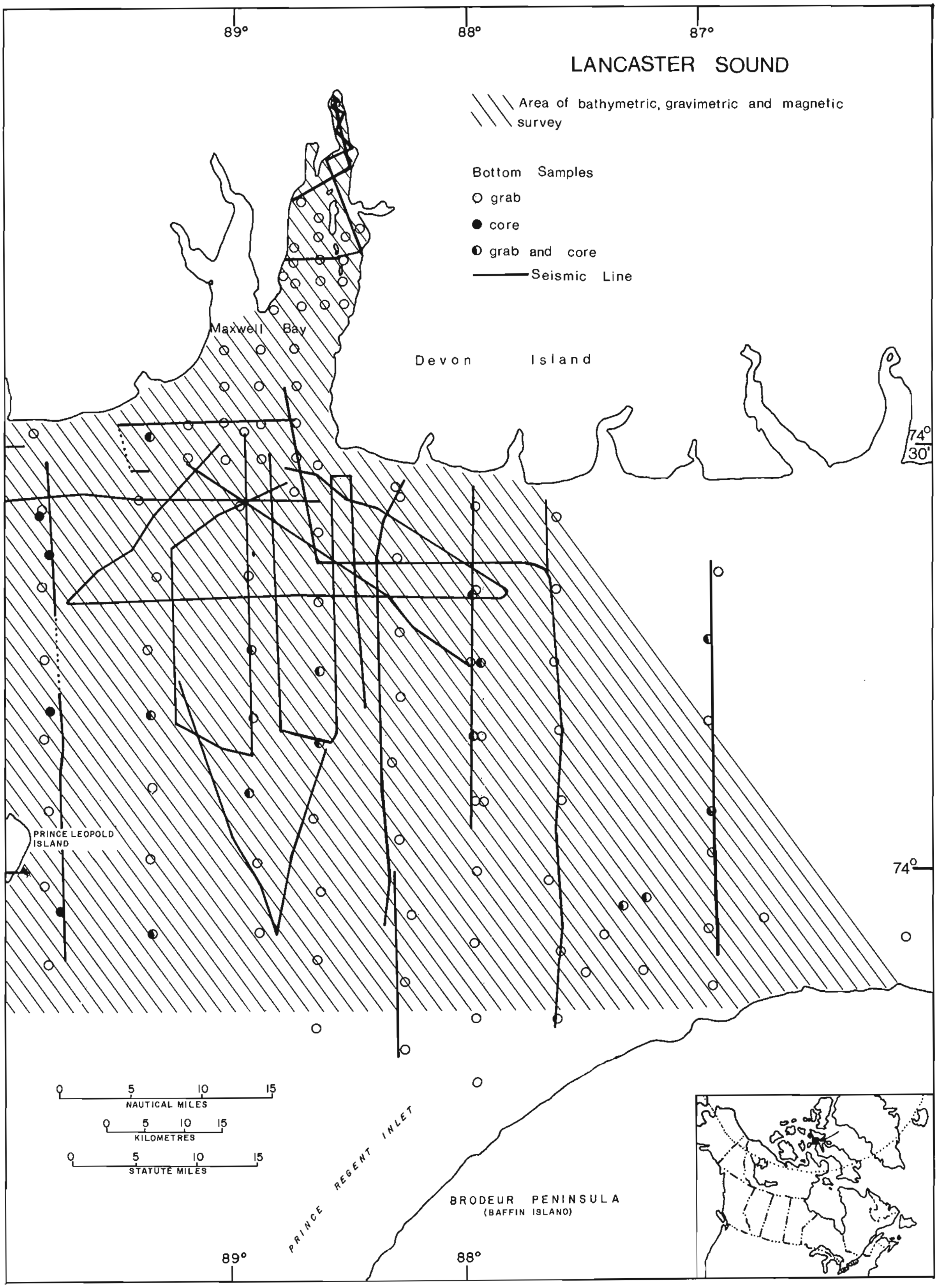

Figure 1. Location and types of work done by the 1973 multidisciplinary cruise of CSS Baffin in Lancaster Sound. The gravimetric and magnetic data were obtained in Lancaster Sound only.

TERRAIN MAPPING IN THE CHURCHILL-CHESTERFIELD INLET CORRIDOR DISTRICT OF KEEWATIN

Project 730013

W.W. Shilts and A.N. Boydell
Terrain Sciences Division

This project was carried out in the region south of Chesterfield Inlet, east of 96° longitude and north of 60° latitude, an area of approximately 40,000 square miles. The objectives of the project are to provide 1) an air-photo interpretative map of surficial materials on a general scale of 1:125,000. Field work in 1973 was designed to provide 1) ground observations of sufficient frequency to allow material types and properties to be assigned to map-units delineated on the photo maps; 2) ground observations in the vicinity of settlements to provide samples of terrain types in problem areas and to improve interpretation of terrain units that will be delineated on large scale settlement maps. The most intensive ground checking was done by Boydell by 50 helicopter traverses along aerial photograph flight lines north of 62°15' latitude. Less intensive ground checking was done by Shilts using helicopter traverses over the terrain from 60° to 62°15'N. Over 500 samples of various sediment types were collected specifically for engineering tests and an additional 3,000 geochemical samples, collected for project 700014, will also be available for engineering tests. About 90 per cent of all samples were collected within a 50-mile radius of Kaminak Lake. Within that area most of the important terrain types (zones 4, 5, 6 and 7) are represented (Fig. 1); zone 3 has been extensively sampled only during the settlement study of Eskimo Point. A mobile laboratory was operated at the Arctic Research and Training Centre (Rankin Inlet) to provide immediately available data on Atterberg Limits, pH, moisture content, and excess ice content of various types of unconsolidated sediments (see report, this volume).

Terrain Units

For convenience of description, the map-area has been divided into 8 zones that represent 8 distinct terrain conditions (Fig. 1). These zones are generalized, and terrain characteristic of any one zone may be a minor element of another zone, or one zone may grade into another. Boundaries of various zones have largely been generalized from the excellent series of ERTS images created during three orbits in June, July and August of 1973. Band MSS-7 is particularly useful for delineating large-scale terrain units, once sufficient ground observations have been made to characterize the unit.

A strong northwest-southeast to east-west grain has been imparted to most of the terrain by glacier flow from the Keewatin ice divide (see Lee, 1959). In zones 1 and 2, ice flow appears to have been north to south, producing many east-west trending morainal features, and in zone 8 topographic trends correspond to bedrock structure. Ribbed and DeGeer moraine give a strong, secondary northeast-southwest grain to much of the surface in zone 6 and in minor portions of zones 4, 5 and 7. Beach ridges produce a pronounced northeast-southwest grain in zone 3 where raised beaches are common and are generally parallel the modern marine strand.

The following paragraphs describe each of the terrain zones more fully with comments, where appropriate, about general terrain conditions that might affect access or have relation to possible terrain disturbance.

Zone 1 — The terrain in this zone is generally hummocky till with numerous, oriented lakes and organic terrain overlying permafrost at <90 cm depth in the depressions between hills. The generally east-northeast — west-wouthwest trending ridges are probably ribbed moraine and/or crevasse fillings associated with a lobe of ice that flowed southerly, or at 70 to 90 degrees from the general ice-flow trend north of this zone (eastward). Geillini River, which bisects this zone, is severely disrupted by thermokarst features, indicating that significant amounts of ground ice, probably in the form of vertical wedges, underlie its wide alluvial plain. South of Geillini River, the moraine ridges and crevasse fillings are densely covered by boulders averaging 1 m or more in diameter. Marine reworking is relatively minor in this zone, compared to the terraced terrain farther north. It is the writers' opinion that any attempt at terrain utilization in this zone would encounter difficulties, and that north-south access at this latitude would be best accomplished through zone 3.

Zone 2 — This zone is mostly fluted till plain similar in most aspects to zone 4, except that the oriented elements are aligned north-northwest — south-southeast, an angle of 60 to 70 degrees to the alignment of elements in zone 4. Zones 1 and 2 reflect deposition from a glacial lobe that extended southward from the generally westward-retreating ice mass to the north. Similar discordant flow is recorded at this latitude west of the map-area by Lee (1959) who attributes southerly flow location at the southern end of the Keewatin ice divide.

Zone 3 — The coastal zone may be described as a sandy silt to gravelly sand plain with numerous low, sandy, subparallel raised beaches. The greatest thickness of marine sediment was observed in a 4-mile-long series of bluffs along the north bank of Tha-anne River where over 15 m of grey, sandy, marine silt is exposed. Where major rivers cross the coastal zone their alluvium is typically bouldery and their deltas are extensive bouldery fans that extend out over sandy, pebbly tidal flats.

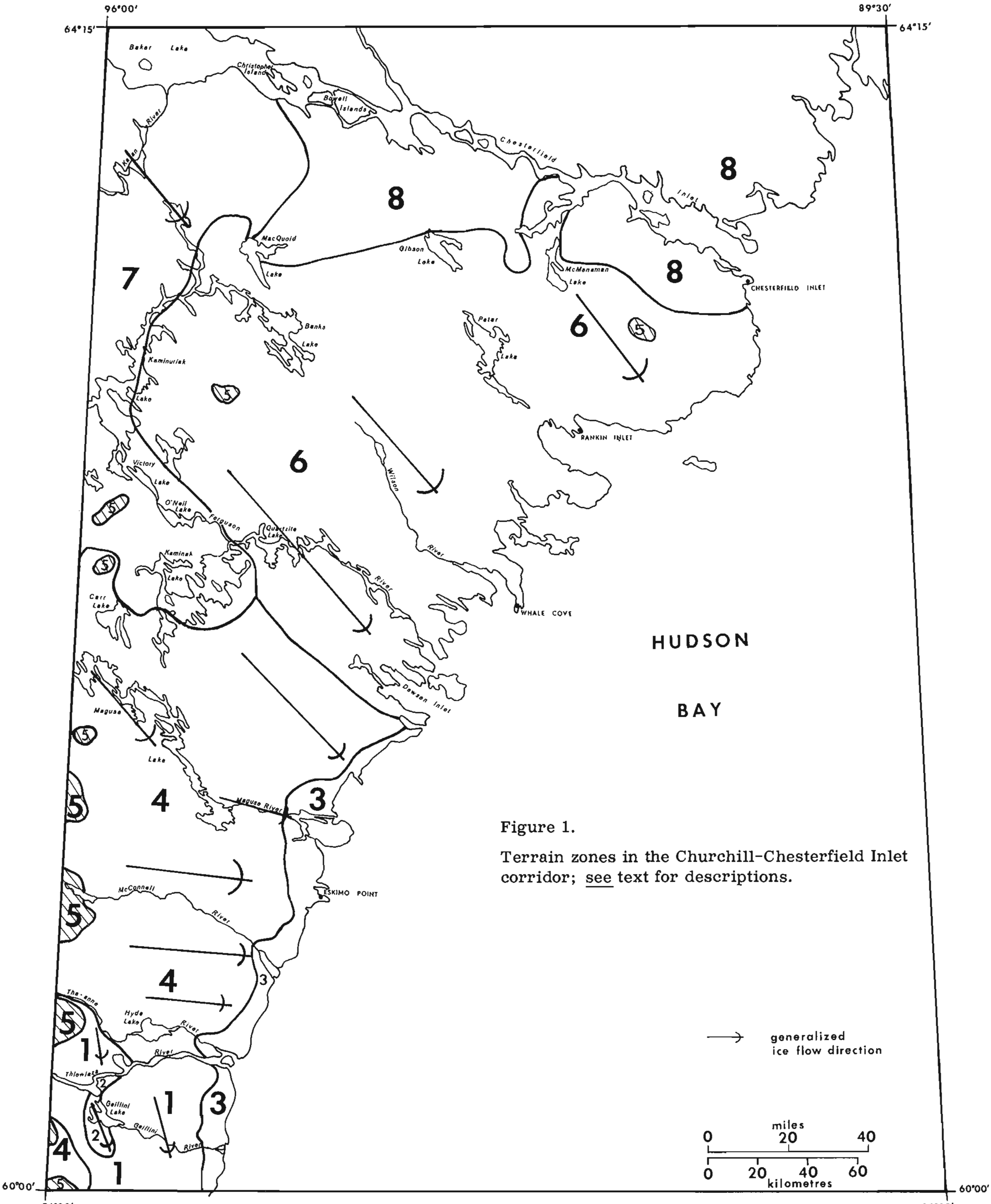

Figure 1.

Terrain zones in the Churchill-Chesterfield Inlet corridor; see text for descriptions.

Except for eskers and ice-contact deltas in the vicinity of Maguse River and Eskimo Point, the coastal zone is nearly devoid of glacial features. It is covered by scattered boulders and is fringed on the seaward side by boulder-strewn, pebbly mud tidal flats from 2 to 6 miles wide. It passes abruptly into zones 1, 2 and 4 at or near the 100-foot contour; this boundary is marked in several places by 20- to 50-foot-high escarpments that comprise the foreslopes of extensively reworked marine ice-contact deltas. (Many marine features in the map-area were deposited from glacier ice fronting the Tyrrell Sea (Lee, 1959) during marine inundation at maximum post-glacial isostatic depression. They have been subjected to a second cycle of marine, nearshore sedimentation-erosion as they were raised above sea level during isostatic rebound.)

The coastal plain is dotted with tens of thousands of small, unoriented, shallow lakes, many of which dry up in the summer. Most of the lakes freeze to the bottom in winter and they have a high organism and iron content in the summer, making their water only marginally fit for human requirements. In areas other than lakes, beaches, or rivers, the coastal zone is largely covered by various types of mosses, grasses and sedges that form a peristent insulating cover under which permafrost is only 15 to 90 cm deep at maximum thaw. The vegetation often takes the form of low, grassy ribs, subparallel to the present coast and confined to shallow depressions that are former or ephemeral lakes. The vegetation patterns in these areas, which comprise a significant proportion of the coastal zone, are reminiscent of "string" bogs. The portion of zone 3 extending for about 15 miles north of the north distributary of Maguse River delta is largely a sandy, gravelly plain nearly devoid of beaches or vegetation.

The coastal zone generally represents an environment that is inimical to permanent human habitation because of 1) very poor water supply; 2) lack of access to shipping; 3) shallow permafrost table; 4) insect population; and 5) foggy climate.

Zone 4 — Zone 4 is heavily covered by drift and can be characterized as a fluted or drumlinized till plain. Bedrock outcrops are prominent only in the northwestern portion, and are scattered or rare elsewhere. Prominent esker systems, starting at Carr Lake and west of Turquetil Lake, follow the Turquetil Lake-Maguse Lake, Maguse River drainage. Several eskers exist north and northeast of this system; eskers are rare in the rest of zone 4.

Zone 4 was completely submerged at the maximum extent of the Tyrrell Sea. As the land rebounded after glacial recession, all features in zone 4 were subjected temporarily to wave action in the nearshore environment. Thus, drumlins, eskers, and hills are commonly terraced or surrounded by beaches. Drumlins tend to be reworked into a bouldery lag deposit on their south or southwest-facing sides, a generalization that apparently may be applied to the entire map-area. This situation is probably related to prevailing wind directions in post-glacial time.

Till is the most prominent sediment in zone 4. It is sandy and pink to red north of Maguse Lake-Maguse River, becoming progressively more grey or tan to the south. Marine silty sand is an important but sporadically occurring sediment. It is probably most common at altitudes below 200 feet. Boulders are not an important surface component in this zone but do form a heavy cover in some small areas. Areas underlain by till and silty marine sediment have surfaces characterized by numerous 1- to 3-m-diameter mud boils and 30- to 50-m-wide solifluction stripes. Sediment containing more than 20 or 30 per cent silt and clay characteristically forms similar surface features in all parts of the map-area.

Grassy or sphagnum peat forms a 20- to 100-cm-thick cover over sand or sandy gravel in depressions between drumlins, on the flat plains adjacent to eskers, and along alluvial plains. As in all zones, the surfaces of these areas are cut by well-developed frost cracks and frost polygons and the depth of frost is roughly proportional to the thickness and type of organic cover. Black-brown sedge or grassy peats have maximum thaw depths of 25-40 cm, light brown spagnum "peats" thaw to 15-25 cm and, sand or gravel overlain by 15 cm or more of A_o horizon thaw to depths of 30 to 90 cm, depending on A_o thickness.

Lakes with long axes oriented in the direction of glacial flow and depths generally exceeding the maximum thickness of winter ice are numerous in this zone.

Zone 5 — Zone 5 includes areas that were not submerged in the Tyrrell Sea. Within the map-area they are isolated islands but the 96th meridian approximates marine limit, except in the vicinity of Baker Lake. Between Kaminak and Yathkyed lakes, the only area above marine limit examined, the terrain consists of monotonous till plains with weakly northwest-southeast-oriented hills and very little stratified sediment. Small areas of organic soil over sandy-gravelly alluvium occur in depressions but this type of terrain is not so common as below marine limit.

Marine limit is commonly marked by a 1- to 2-metre-high solifluction scarp where seasonally thawed, saturated till has flowed down over well-drained raised beach or nearshore sediments, dried out, and ceased flowing.

The surface of till plains above marine limit is easily differentiated from till plains below marine limit both on aerial photographs and from aircraft. Viewed from the air the summer vegetation appears uniformly dark green as opposed the dark and light-green mottling common below marine limit. The lighter hues below marine limit are caused by sedges, grasses, and mosses that grow in wet depressions that were filled with sand or sandy gravel during isostatic emergence from the sea. The darker hues are derived from dwarf trees and bushes that grow preferentially in moist areas around mud boils or between solifluction lobes.

Zone 6 — Zone 6 is a zone of marine terracing and reworking that has been subject to marine modification similar to that noted for Zone 4. Zone 6, however, is characterized by a distinctly different set of glacial features from zone 4; 1) Drumlinized till plains are rare; 2) Ribbed moraine is common in most depressions; 3) DeGeer moraine is present near the coast from Rankin Inlet to Dawson Inlet; 4) Eskers are numerous throughout the zone, and beaded eskers are particularly common; 5) Extensive portions of zone 6 are covered by dense mantles of large boulders. These boulders are in glacial trains that form northwest-southeast trending bands 100's of feet to miles wide and 100's of feet to 10's of miles long; 6) Bedrock outcrop, is much more common in zone 6, particularly near the coast and near Banks and Quartzite lakes.

Zone 6 is generally difficult terrain to work in. The most difficult regions are the boulder fields that are associated with ribbed moraine. In extreme cases, boulder fields consist of angular to rounded boulders, 1 m or more in diameter, piled one upon another with no matrix and little vegetation. Boulders may be directly on bedrock or on unknown thicknesses of till or stratified sediment.

Abundant beaches and eskers provide conveniently located aggregate sources for most of zone 6. It must be remembered, however, that these deposits thaw to a maximum depth of only 1 to 2 m in summer and, if saturated, would have a frozen gravel core.

Major eskers would be the logical loci of northwest-southeast transportation corridors in this zone but southerly or southwesterly trending access would be somewhat impeded by the northwest-southeast grain of glacial features.

Zone 7 — Zone 7 is outlined on the basis of the type of till that occurs within the zone. Proximity to "red beds" of the Dubawnt Group (Wright, 1967) causes the till to be red to maroon and to contain a significant amount of finely divided specular hematite and clay-sized particles. Its texture makes the till readily susceptible to the formation of mud boils. The characteristic appearance of the zone is that of a gently rolling, mud boil-covered till plain. Major areas of frost-cracked marine or alluvial sediments occur near the northwest portion of Kaminak Lake. Outcrop is common in the Kaminak Lake-Carr Lake region, near Mackenzie Lake, and northwest of Kaminuriak Lake.

The zone is largely below marine limit so that beaches are common, but they are not as frequent as in zones 4 and 6. Eskers and other forms or stratified drift are rare and marine sediments are only prominent in isolated bedrock depressions and below 200 feet a. s. l. in the Kaminak Lake basin.

Zone 7 appears to be relatively easily accessible terrain, but aggregate supplies are limited in their aerial distribution and the red till is unstable when disturbed during the thaw season. Mud boils in this zone are commonly covered by efflorescences of salts during dry periods in the summer and caribou herds may be preferentially attracted to the Kaminuriak Lake area by the easily available salt. Many mud boils in the Victory Lake-O'Neil Lake area were observed (in 1971 and 1973) to be completely covered by randomly oriented hoofprints, as would occur if an animal(s) was licking the muddy portion of the mud boil.

Zone 8 — Zone 8 is a zone of thin drift. Bedrock grain forms the major surface lineations and the only common unconsolidated deposits are marine silty clay, sandy silt, and beaches. The beaches contain abundant marine shells below 300 feet a. s. l. Felsenmeer (areas of frost shattered bedrock) is common in this zone.

It should be noted that the zones described above have been defined tentatively and that conditions within zones may be very different, locally, from those described for the zone in this preliminary evaluation.

Tundra Fires

Tundra fires were numerous during the particularly dry summer of 1973. From the abundance of fires in the Baker Lake-Kaminak Lake areas, it is estimated that most of the map-area has been burned over at least once since the retreat of the glacier. The fires must have considerable influence on slope stability, particularly where they have burned away the deep vegetation surrounding mud boils. The removal of this organic support could cause increased slope activity in mud boils.

While most fires seem to have started by lightning, human activity was the cause of some. The extreme ease with which a summer fire may be started in this area of tundra desert was apparent to us in the summer of 1973, and fire with subsequent terrain disturbance should be regarded as a major hazard associated with human utilization of the area.

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TERRAIN STUDIES IN THE JAMES BAY HYDROELECTRIC PROJECT AREA

Project 730033

R. G. Skinner
Terrain Sciences Division

In July 1973 terrain investigations were initiated in the region to be affected by the James Bay Hydroelectric Project (Fig. 1). The activities in 1973 were primarily of reconnaissance nature comprising 3 programs:

1) An assessment of sedimentology of the La Grande River downstream from LG-1 including study of the types and rates of erosion of beds and banks, the nature and distribution of sediment, the nature and rate of sediment movement with particular emphasis on the immediate vicinity of Fort George.

2) The sedimentology of Goose Bay, a small bay and marsh and convenient goose hunting area, 5 miles north of the mouth of La Grande River and Fort George.

3) Mapping of surficial geology at scale 1: 50, 000 along the La Grande River to LG-2's future reservoir and south to Eastmain River crossing along the new highway route.

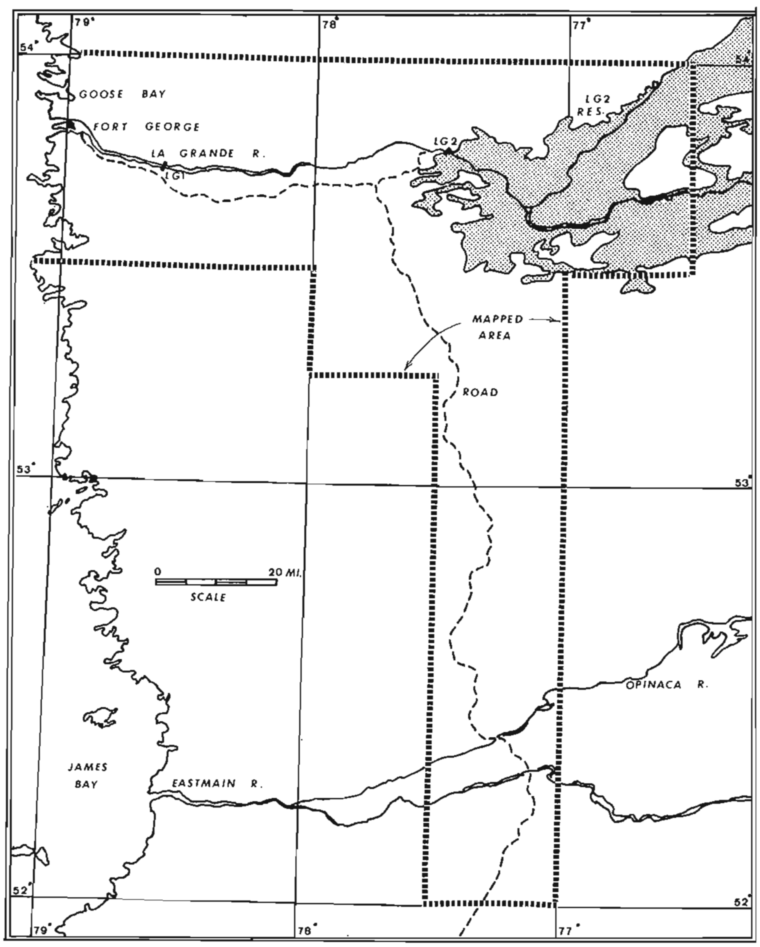

Figure 1. Location map, east side of James Bay, Quebec.

Sedimentology of lower La Grande River. The La Grande River valley down from Lg-1 (Mile 17) is asymmetrical; the steeper, higher, south valley wall is composed of coarse, cross-stratified terrace sands overlying marine sand, silt and clay at the base; the north bank is low, vegetated, commonly boulder-veneered or composed of bedrock. The asymmetry reflects the southward longshore drift in James Bay which has prevailed during off-lap of the sea over the past few thousand years, and has resulted in a net transport of sand to south of the river. Above LG-1, where the valley is narrower, both banks are high, steep and capped with terrace sands. Large (1/4 to 1/2 mile wide) scars from ancient clay slides occur between longitudes 78°00' and 78°30' along the river.

Erosion below LG-1 is in the form of landslides, retrogressive flow slides, and wave cutting. Wave action is an important erosive agent during the free flow period, creating plumes of suspended sediment along the edges of the river. Wave action eventually leads to undermining and failure of banks.

Coarse sediment is dropped in the channels around Fort George Island. The mean grain size of 40 samples from bars in the river mouth is medium to coarse sand. Longshore drift tends to move the coarse sediment southward; the fine sediment load, which is greatest during spring, is carried farther out to sea.

The nature and rate of sediment movement in the mouth of La Grande River are complex. In small channels between islands, where flow decreases, fine sediment is trapped. In some areas in the main part of the river, downstream movement of sand at certain points on the tidal curve is later countered by longshore drift which tends to move the same sand back upstream. In other areas, sand apparently moves downstream only when a critical water depth is attained, say towards the end of ebb tide. This discontinuous and ratchet-like sediment movement leads to bar-formation and shoaling around the river mouth. Bed forms on the lower flanks and between bars indicate formation due to downstream current, whereas dunes on the upper, outer seaward rim of bars suggest formation due to upstream longshore drift. A current-generated sand dune in the main channel out from St. Joseph Mission was monitored for 22 days (45 tidal cycles) during a steadily decreasing discharge (91, 000 cfs to 60, 000 cfs). The rate of downstream movement varied over this period from 0 to 2 inches per day with a total movement of 30 inches (Figs. 2 and 3).

Banks are actively eroding around Fort George and erosion seems accelerated where the

Figure 2. Sand dune on river bar out from Fort George, Quebec, July 17, 1973, 0730 hours when steel rods emplaced.

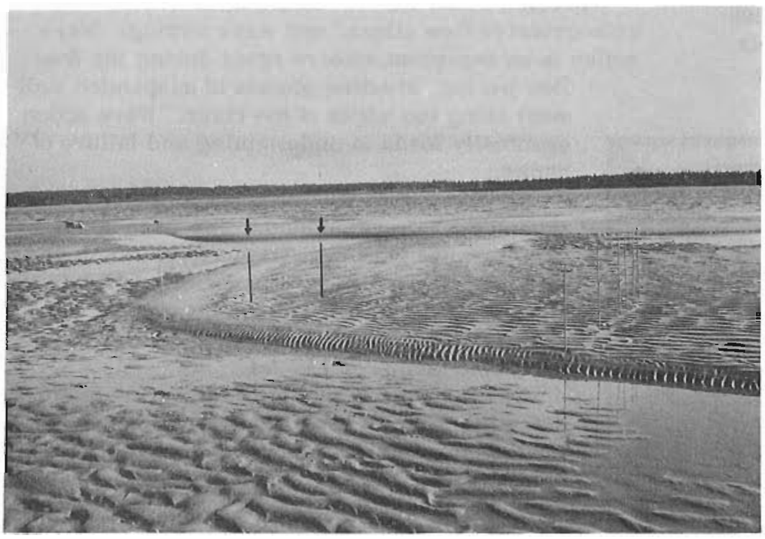

Figure 3. Same dune as in Figure 2 at low tide, August 8, 1973, 0800 hours. Toe of slip face of dune moved about 30 inches.

top of the bank has been cleared of trees. The concave bank along the airstrip on the southeast side of the island eroded 90 to 110 feet between 1954 and 1969. The erosion here is attributed mostly to the current which impinges against the bank. In the same period forty to sixty feet of erosion has taken place along the 'potato patch', a cleared area between the old Revillon Frères trading post and St. Joseph's Mission. Other eroding banks have retreated comparable distances. In most cases wave action is an important factor contributing to bank retreat. Around the river mouth the water table intersects the sandy banks between the high and low tide marks; consequently at low tide, springs drain and weaken the bank. Where steel palisades were installed at Fort George, the build-up of water pressure in the sand eventually led to their failure. Bank erosion on Fort George and adjacent alluvial islands is a natural phenomenon which will continue regardless of hydroelectric development.

Sedimentology of Goose Bay. This phase of the project was in response to wildlife specialists' concern with the relationship between sediment and the marsh vegetation on which migrating geese feed. On August 3 the unvegetated tidal flat was traversed and sampled at low tide. Samples were restricted to the upper 2 or 3 inches in the bottom of ice pan depressions on the tidal flat. Thus, this year's sediment accumulation (since melting of the ice pan) was collected. Although analyses were not available at time of writing, a first impression gained during field work is that the Guillaume River and not the La Grande River supplies the bulk of sediment to Goose Bay. In view of this, changes in hydrology of the La Grande that will accompany hydroelectric development are not expected to seriously disrupt the patterns of sedimentation and vegetation and, therefore, geese habitats in Goose Bay.

Surficial Geology Mapping. J.S. Vincent undertook surficial geology and terrain mapping at scale 1: 50, 000 along the La Grande River and south along the highway route. N.T.S. (1: 50, 000) map-sheets 33 C/3, 6, 11, 14; 33 E/9, 10, 11, 14, 15, 16; 33 F/3, 5, 6, 10, 11, 12, 13, 14 and 15 were traversed along at least 6 lines each. Supplemented by airphoto interpretation, the objectives of this program are to provide basic impact and terrain data along principal development corridors and to gather information on the stratigraphy and postglacial history of the region. Resulting maps will present surficial geology as well as indicate distribution of the following: terrain unsuitable for transportation, sources of aggregate, permafrost features, and hazardous areas.

Permafrost in the form of palsas was discovered 2.5 miles south of Fort George. It is suspected that the cool summer maritime climate along the coast and the presence of frost susceptible marine soils blanketed with peat encourage the development of permafrost.

92. DRIFT PROSPECTING IN THE ENNADAI–RANKIN INLET GREENSTONE BELT, DISTRICT OF KEEWATIN

Project 700014

W.W. Shilts
Terrain Sciences Division

Sampling of till from mudboils (Shilts, 1973) on one-mile centres was continued, providing, with samples collected in 1970 and 1971 (Shilts, 1972), a complete grid along a strip approximately 80 miles long by 25 miles wide (Fig. 1) an area of about 2,000 square miles. Approximate cost of such a project in this or similar areas is tabulated in Appendix II. Costs cited in Appendix II were actually exceeded in this project because of the developmental nature of the work and because subsidiary studies were carried out. For a negligible increase in the budget, target areas could be sampled by foot, boat, or all-terrain vehicle traverse, on the detailed level. Principal costs are for aircraft support and neither these nor other field costs would increase significantly if close sampling were to be added to the program.

In 1973, several sample plans and spacings were followed around targets discovered during the 1970-71 seasons or around showings that have received serious attention by mining companies. At three sites in the northwest corner of Kaminak Lake, several hun-alization and over a granite porphyry. In addition to till, samples were collected of stream sediments, marine sediments, and marine or alluvial silty sand underlying frost-cracked peaty terrain. This suite of samples should provide comparisons both among various types of tundra sediment and among a variety of types of mineralization associated with different rock types.

Till (mudboil) sampling on ¼ mile centres was carried out in the Spi Lake—Carr Lake area to evaluate the glacial dispersal of known mineralized material and to further define areas of anomalous values outlined by reconnaissance sampling. One target, C25I, mentioned by Ridler and Shilts (1973) and by Shilts (1973, p. 24, 25), was on an island at the southeast end of Spi Lake, about 2 miles southeast of the main showing. Thirty samples were collected on this island and several rounded boulders of massive sphalerite and galena with minor chalcopyrite in chloritized fine-grained rock were found around a gossan-stained mudboil at one site. Analyses of these rocks are included in Appendix I, and a discussion of their significance may be found in Ridler (this publ.).

Lake Sediments

R. Klassen, financed by a research agreement between Queen's University and the Geological Survey and under the direction of I. Nichol, E. Hornbrook, and the author, initiated a program to evaluate chemical and physical factors that control geochemical properties of the several sediment facies in eastern Arctic lakes. Five lakes near various types of mineralization and in background areas were studied and an extensive suite of grab and core samples was collected from each. In addition, temperature Eh, pH, and salinity profiles were measured at numerous stations and certain stations were monitored during the summer. Extensive sampling of rocks, glacial sediments, and postglacial marine and fluvial sediments was carried out around each lake so that the various lake-sediment facies may be compared to their parent materials.

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1973: Drift prospecting; geochemistry of eskers and till in permanently frozen terrain, District of Keewatin, Northwest Territories; Geol. Surv. Can., Paper 72-45, 34 p.

Ridler, R.H. and Shilts, W.W.
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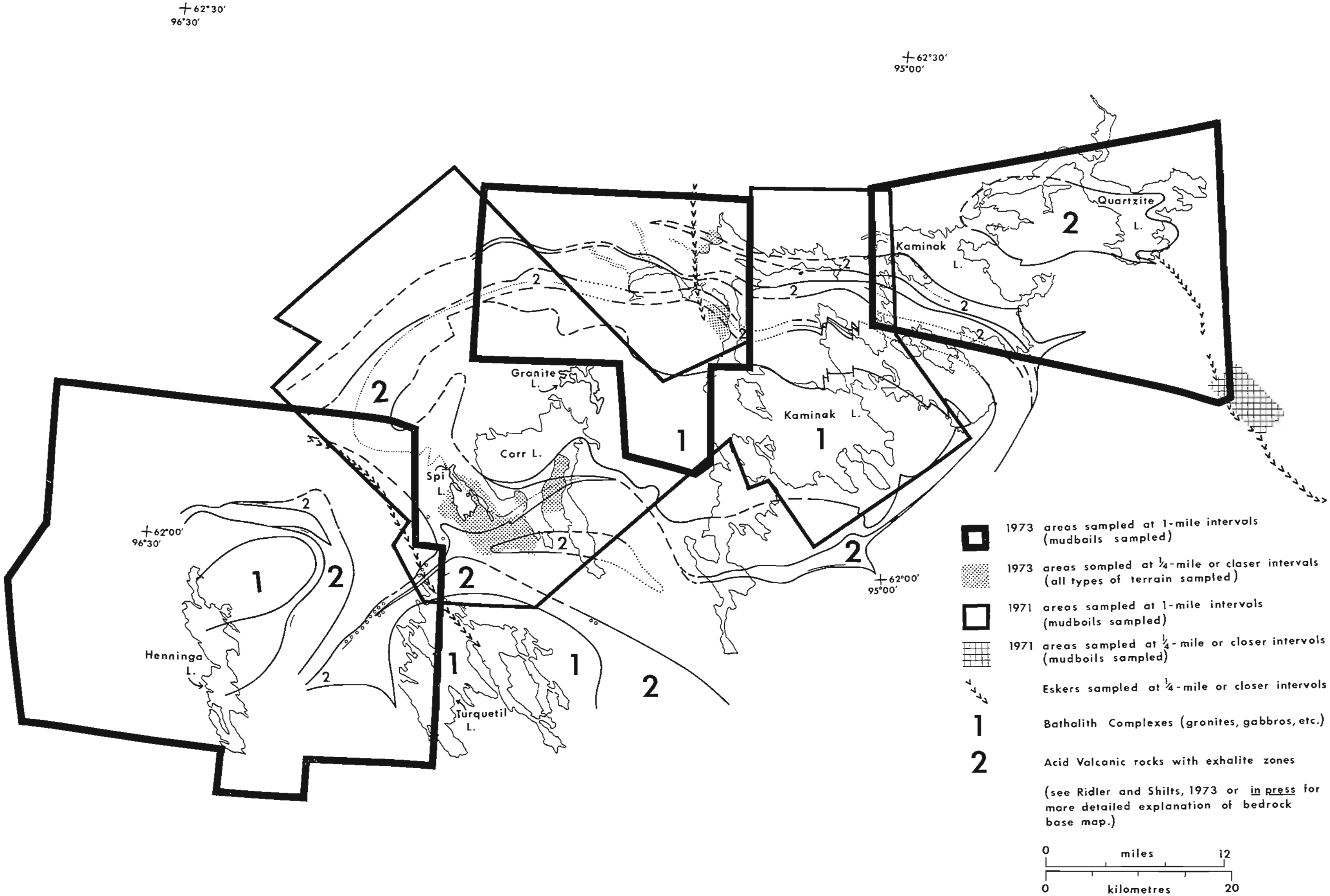

Figure 1. Drift sampling grids in Ennadai–Rankin greenstone belt, 1971–1973. Base map derived from Ridler and Shilts (1973).

Appendix II

Costs of reconnaissance sampling of 2,000 square miles. These costs are based on centre of operations 300 miles from railhead and 2-month field season utilizing Bell 206A, B, or equivalent; costs of camp equipment and office gear not included; costs approximate and are thought to represent cost to private sector.

Aircraft Charter:	Bell 206B or equivalent: 180 hrs. at 200.00/hr.		$36,000.00
	or		or
	Bell 47G4-A or equivalent: 300 hrs. at 110.00/hr. (would probably necessitate longer field season)		33,000.00
Casual Charter:	Gasoline positioning (DC-3 or equivalent) (cost drops significantly if larger a/c can be used)		12,000.00
	Positioning gear and personnel (depending on a/c available)	$2,700.00 -	3,600.00
	Supply flights, etc.		2,000.00
	Depositioning samples to railhead		4,000.00
	Depositioning camp and personnel		2,500.00
	Air travel personnel to railhead (based on Ottawa to Churchill or equivalent)		2,500.00
		Total aircraft costs	$62,600.00
Other:	Gasoline (Jet B or JP-4) based on 25 gal./hr. for 200 hrs. at .45/gal. at railhead		2,250.00
	Barrel deposit (110 bbl at $12.00/barrel)		1,320.00
	Food		3,500.00
	Lodging _en route_ to and from field		750.00
	Shipment of gear and samples from railhead (based on Churchill—Ottawa or equivalent)		1,000.00
		Total	$8,820.00
Salaries:	Cook		2,500.00
	Geologist in charge		3,000.00
	4 samplers		6,000.00
		Total	$11,500.00
		Total field expenses	82,920.00

Analytical Expenses (estimate based on suggestions in Ridler and Shilts, 1973; Shilts, 1973)	$8,000 - $10,000 Sample Prep.
	8,000 - 10,000 Chemical
Total analytical	$16,000 - $20,000

Grand Total $103,000.00

93. GEOMORPHOLOGICAL PROCESSES AND TERRAIN SENSITIVITY, BANKS ISLAND, DISTRICT OF FRANKLIN

Project 640004

H.M. French[1]
Terrain Sciences Division

Natural and man-induced thermokarst processes were investigated on eastern Banks Island during the summer of 1973 between Thomsen River and Johnson Point and on southwest Banks Island at Sachs Harbour. This work is a continuation of studies commenced in 1972 (French, 1973). In addition, limited drilling in late June provided information on ground-ice conditions in the study area. In late August, a short visit was made to the site of the 1972 Deminex exploratory drillhole at the Big River, in south-central Banks Island.

significantly greater in 1973 (Table I). In addition, a number of new ground-ice slumps became active in late July - early August, a time which appears to be an optimum for ground-ice slumping.

Six boreholes were drilled in and around two areas of active thermokarst activity, one being an active ground-ice slump, and the second being an area of dissection and thermal erosion along ice wedges. Both areas were previously reported upon (French, 1973). In the first area, one borehole was drilled in undisturbed terrain behind the headwall of the slump, and a second within the slump hollow. Both boreholes revealed lenses of ground ice; thawed samples gave excess ice values of between 10 and 35 per cent. Vx ice (Pihlainen and Johnston, 1963) was the most common type present. Detailed examination of the ice face exposed in the headwall of the slump suggests that ice content may vary greatly over small distances. For example, Table II illustrates the variation in sediment content, as a percentage of the total sample, across part of the ice face. In the other area, frozen core

TABLE I

SLUMP FEATURE 1.								
1973	- Period of measurement	22/6-27/6	28/6-7/7	8/7-13/7	14/7-25/7	26/7-31/7	1/8-5/8	6/8-12/8
	- Retreat, feet/day	0.25	0.34	0.25	0.26	0.81	0.69	0.85
1972	- Period of measurement		30/6-10/7	11/7-23/7	24/7-3/8	4/8-13/8		
	- Retreat, feet/day		0.39	0.37	0.27	0.26		
SLUMP FEATURE 2.								
1973	- Period of measurement	22/6-11/7	12/7-24/7	25/7-1/8	2/8-8/8	9/8-13/8		
	- Retreat, feet/day	0.18	0.17	0.47	0.58	0.42		
1972	- Period of measurement		15/7-28/7	29/7-12/8				
	- Retreat, feet/day		0.41	0.31				

Thomsen River area, Eastern Banks Island

Observations carried out from June 14 - August 15 indicate that ground-ice slumping is the most dominant and widespread thermokarst process in this area. Relatively warm weather and an early summer resulted in higher levels of thermokarst activity than in 1972. Rates of headwall retreat at two sites monitored in 1972 were

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TABLE II

	Sediment Content (as % of total sample weight)		
	Position A	Position B	Position C
Samples:			
Top of ice face, depth 30 cm	88.1	15.0	11.1
Middle of ice face, depth 60 cm	9.1	8.4	7.7

samples were retrieved from four drillholes located in and adjacent to the badland topography. All cores indicated that ice-rich silty sediments underlie the whole area. Excess ice values of 15 to 30 per cent and natural water (ice) contents of between 45 and 150 per cent were not uncommon. In the same area, drilling was undertaken to investigate the dimensions of the ice wedges which underlie the well-developed depressions that outline the high centred polygons characteristic of the area. One borehole located at the junction of several ice wedge depressions penetrated more than 6 m of foliated ice and did not "bottom out" into the enclosing sediments. In an adjacent cliff section, an exposure of wedge ice was more than 3 m in width at a depth of more than 7 m below the surface of the surrounding terrain. If typical, these observations suggest that ice wedges of considerable dimensions underlie the area, and may exceed 10-15 m in depth and 4-5 m in width at the surface. Since the average dimensions of the polygon net are between 20-30 m, it follows that ice wedges may underlie 15-20 per cent of the ground surface at shallow depths. The inferred size of the ice wedges and ice-rich nature of the enclosing silts help to explain the magnitude of relief of the area of badlands and the rapidity of the erosional processes operating within it.

Information was also collected on active layer thickness and ground thermal properties in the area. A number of controlled man-induced terrain disturbance experiments were initiated. Soil and surface ground temperatures, collected over the two summer field seasons, are now available for different terrain sites and are presently being analyzed.

Sachs Harbour, Southwest Banks Island

Further investigations in 1973 concentrated upon the man-induced thermokarst terrain adjacent to the airstrip. This terrain has already been described (French, 1973; French and Egginton, 1973). Seven boreholes were drilled to a maximum depth of 4 m along a north-south transect of the airstrip, beginning and ending in undisturbed terrain. Frozen cores were recovered from only four of the holes due to the presence of gravel beds which hindered drill penetration and resulted in a washing out of sediments. All boreholes indicated, however, that ice-rich silty sands interbedded with gravels underlie the immediate surroundings of the airstrip. Nearly all samples contained excess ice, often exceeding 20 per cent and natural water (ice) contents ranged from 30 per cent to several hundreds of per cent (Table III). The presence of ice wedges within the undisturbed terrain, and presumably beneath the airstrip and within the disturbed terrain, was confirmed by borehole F which penetrated relatively pure foliated ice. In the other boreholes, A, C, D, randomly located along the transect, icy sediments and numerous irregular lenses of pure ice were encountered, often several cm in thickness. The origin of the ice is still undetermined but it is presumed to be of a segregational nature.

It is thought that the amount of ground ice within the sediments is sufficient to explain the distinctive thermokarst topography. Following the initial disturbance and thickening of the active layer, maximum subsidence would have developed along the ice wedges to produce the linear depressions. At the same time, the mounds so created between the depressions would suffer further degradation through increased thawing from all sides and the release of excess ice as water. Bodies of standing water would then collect within the depressions and would further accentuate thawing and subsidence.

The rate at which the thermokarst topography develops is being investigated by the detailed levelling of wooden pegs inserted within the top 15 cm of the ground. Only one year of measurements are available at present, and a three-year period of levelling is planned. Measurements are being made of a small circular depression, a well-defined linear depression, and a 3 m by 10 m area which traverses both a mound and a depression. Levelling took place in September 1972 and late August 1973. Provisional results indicate that active ground surface subsidence varies considerably with microtopography. Highest rates of subsidence are found within the depressions, where differences of 5.0-8.0 cm were recorded. When averaged over the whole of the disturbed terrain, ground surface subsidence was of the order of 1.0-2.0 cm. Since the maximum relative relief of the thermokarst terrain is approximately 100 cm, and bearing in mind that this terrain developed from level-floored borrow pits some 10-12 years ago, these maximum rates of subsidence appear to be consistent with the relief. They suggest, moreover, that subsidence has continued at a near-steady rate since the onset of disturbance in 1960, and that disturbed ground has not yet begun to stabilize itself.

The rapid morphological change associated with the thermokarst subsidence implies that the thawed sediment can detach itself and move under gravity. In this respect, consistency limits for sediments were determined for a number of samples (Table IV). All have relatively low liquid limits ranging between 15-25 per cent, and plasticity values vary between 3-7 per cent. In general, natural water (ice) contents exceed the liquid limits. Upon thawing therefore, these sediments will become extremely mobile and will further contribute to the overall efficacy of the thermokarst process.

Big River, South-central Banks Island

At the site of the 1972 Deminex exploratory drill-hole two landing strips have been bulldozed and the surface vegetation destroyed. One area is already showing initial signs of subsidence. An area approximately 100 to 200 metres square has also been disturbed to provide material for the infilling of two sumps associated with the living quarters of the camp. Since the history of this site is well known, and the camp is being abandoned in September 1973, further observation will provide a comparative case study for the Sachs Harbour disturbances. Detailed levelling of selected features was undertaken, and periodic visits to the site in the future are planned.

TABLE III

Borehole	Sample No.	Materials	Depth (cm)	Description[2]	Excess Ice (%)	Natural Water Content (%)
A - Undisturbed terrain, S-side of air strip.	A-2	Sand and gravel	75-110	Vs/Vr	20	63
	A-3	Silty sand	125-150	Vx		27
	A-4	Sand and gravel	200-250	Vx/Vr		26
C- Disturbed terrain; S-side of air-strip.	C-2	Fine sand	75-110	Vx/Vr	60	129
	C-3	Fine sand	110-125	Vr	35	86
	C-4	Sand and gravel	130-145	Vx	35	40
D - Airstrip shoulder.	D-1	Fine sand	95-107	Vr	30	41
	D-2	Silty sands	110-140	Vr/Ice	95	1733
	D-3	Silty sand and gravel	140-190	Vr	90	1188
	D-4	Sand and gravel	190-215	Vr	70	352
F - Undisturbed terrain, ice wedge depression; N-side of airstrip.	F-1	Coarse sand and gravel	70-80	Vr	10	30
	F-2	Ice, foliated	125-150	Ice	95	1874

TABLE IV

Location	Sample No.	Depth (cm)	Consistency Limits: Liquid Limit (%)	Plastic Limit (%)	Plasticity Range (%)
Undisturbed Terrain	A-3	125-150	23.5	18.1	5.4
	A-4	200-250	25.0	20.7	4.3
	F-1	70-80	22.8	16.7	6.1
Disturbed Terrain	C-1	30-45	19.6	16.6	3.0
	C-2	75-110	19.0	13.7	5.3
	C-3	110-125	20.6	15.8	4.8
	C-4	130-145	25.9	18.8	7.1
	G-1	35-50	22.0	14.8	7.2
Airstrip Shoulder	D-1	95-107	18.1	17.5	0.6

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COASTAL EROSION — SEDIMENTATION, SOUTHEAST MELVILLE AND WESTERN BYAM MARTIN ISLANDS, DISTRICT OF FRANKLIN

Project 730020

P. McLaren
Terrain Sciences Division

The purpose of this project is to gain an understanding of the processes operating in an Arctic coastal zone. Such geoscientific information contributes to an assessment of the feasibility of an inter-island gas pipeline route. In addition, the work should elucidate the geological history of the area and provide Arctic sedimentary facies models.

To study sediment types and their rates of change, a series of 19 profiles were established (PO-P18, Fig. 1). Each was surveyed twice during the summer and a frost table profile for each one. Eight areas encompassing regions of geological interest and "typical" stretches of coast were chosen for detailed study. The work in such areas, referred to as "zonals" (Z1-Z8, Fig. 1), consisted of three profiles, one hundred metres apart. Detailed contour maps were made at each zonal and the data will also be developed into sedimentary facies models. Sediments in both profiles and zonal were sampled extensively

Other aspects of the first summer's work included periodic photography of the coast (oblique and vertical), a qualitative and quantitative study of the factors affecting the frost table, a map of the areas of maximum ice push, a detailed study of a raised delta, tide ranges and the effects of ice on the tide, ice conditions in Byam Martin Channel and finally, many observations of the coastal geomorphology.

Since the retreat of the last Wisconsin ice sheet from the area, the coastal zone has been uplifted about 60 m. It is, therefore, a prograding coast due to both uplifted and present depositional processes. The following are the basic coastal types.

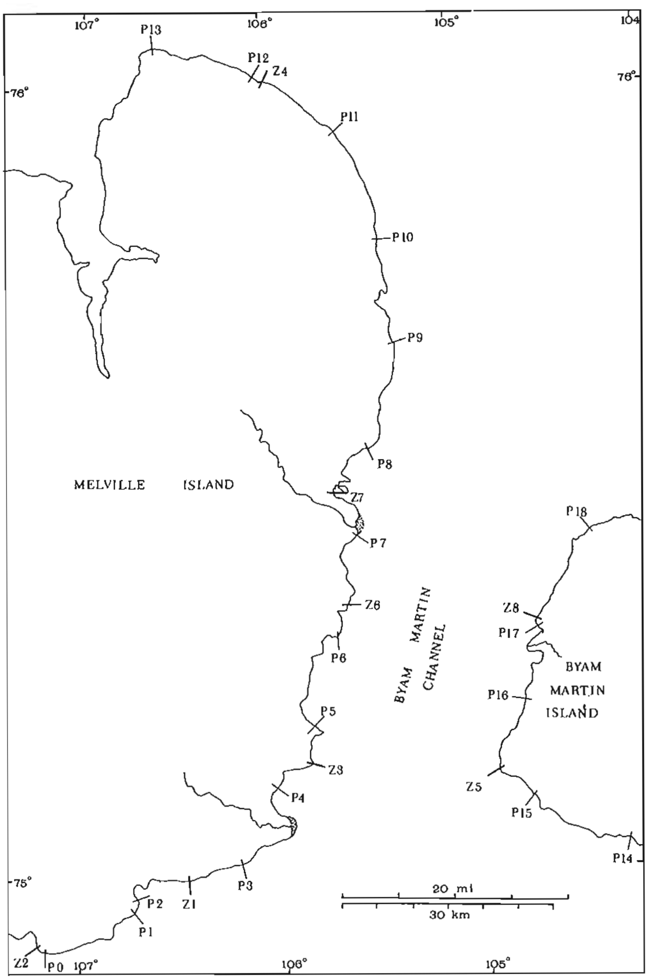

Figure 1. Melville and Byam Martin Islands showing locations of zonals and profiles.

Delta

Present deltas are an important aspect of the coast, and range in size from less than $\frac{1}{2}$ square mile to upwards of 25 square miles. In many cases, the present rivers have cut through raised delta sequences allowing an excellent opportunity for studying exposed sections.

The deltas are of the Gilbert type, consisting predominantly of foreset beds dipping at approximately 20 degrees. It should be noted that Gilbert deltas are not considered an important geological phenomenon, usually being restricted to Pleistocene proglacial lakes and present lakes. This coast demonstrates that such deltas can be present in a marine environment on a large regional scale.

The sediment type is predominantly well-sorted medium to fine sand with interbedded silt. Organics are prevalent and radiocarbon dates to obtain rates of progradation should be easily obtained. It is suggested the silt layers might represent winter deposition.

The frost table on the deltas appeared to lower throughout the summer but remained parallel to the surface. It seldom went below a metre in depth except in the intertidal zone where it dropped off rapidly.

Ice push is not an important modifier to the delta front although it is a common occurrence. The steep forefront restricts the quality of sand available for ice push and those ridges which are formed of sand are quickly redistributed again by wave, current or slumping processes.

Sand and Mud Flats

Areas of coast where the sediment input is too small to form beaches are characterized by sand and mud flats. The offshore is shallow and therefore protects the coastline from major ice push. The frost table lies parallel to the surface and seldom goes below one metre.

Beach

Well-developed beaches are common along much of the coastline. Complex bars and spit formations attest to the importance of longshore drift during periods of open water. In many areas the growth of a beach traps a lagoon behind it which is filled with fine sand, silt and organic matter. Beach sediments range from large boulders found on rocky headlands, to well-sorted sand. Commonly they are poorly sorted sand and fine gravel.

The frost table in these areas tends to lower to depths up to 2 m in the finer material of the lagoons and to become shallow, about 0.5 m, in the poorly sorted beach material. It is suggested that poorly sorted sediments act as a better heat insulator than the more compact finer sediment.

Ice push may play an important role in contributing new sediment to the beach. It was also observed that offshore ice push may be a mechanism for originating a new beach and lagoon system.

Nearshore observations in the study region, involving echo sounding, side scan sonar, and oceanographic parameters, are reported elsewhere in this volume by R.B. Taylor, Project 730021.

A COASTAL INVESTIGATION OF NORTHERN SOMERSET ISLAND, DISTRICT OF FRANKLIN

Project 730021

R.B. Taylor
Terrain Sciences Division

The prime objective of this project is to define and characterize the various coastal environments and to analyze the nearshore processes and their effects on beach stability.

Initially the coastal morphology and relief were mapped between Garnier Bay in the east and Pressure Point in the west (Fig. 1) using aerial photography, topographic maps and a reconnaissance flight. The general study was then followed by a detailed investigation of coastal conditions and beach profile change at one location (Fig. 1) where a set of ten survey stations had been established by the author in July of 1972 (Taylor, 1973). Additional research at this locale involved a systematic sampling of the beach sediments,

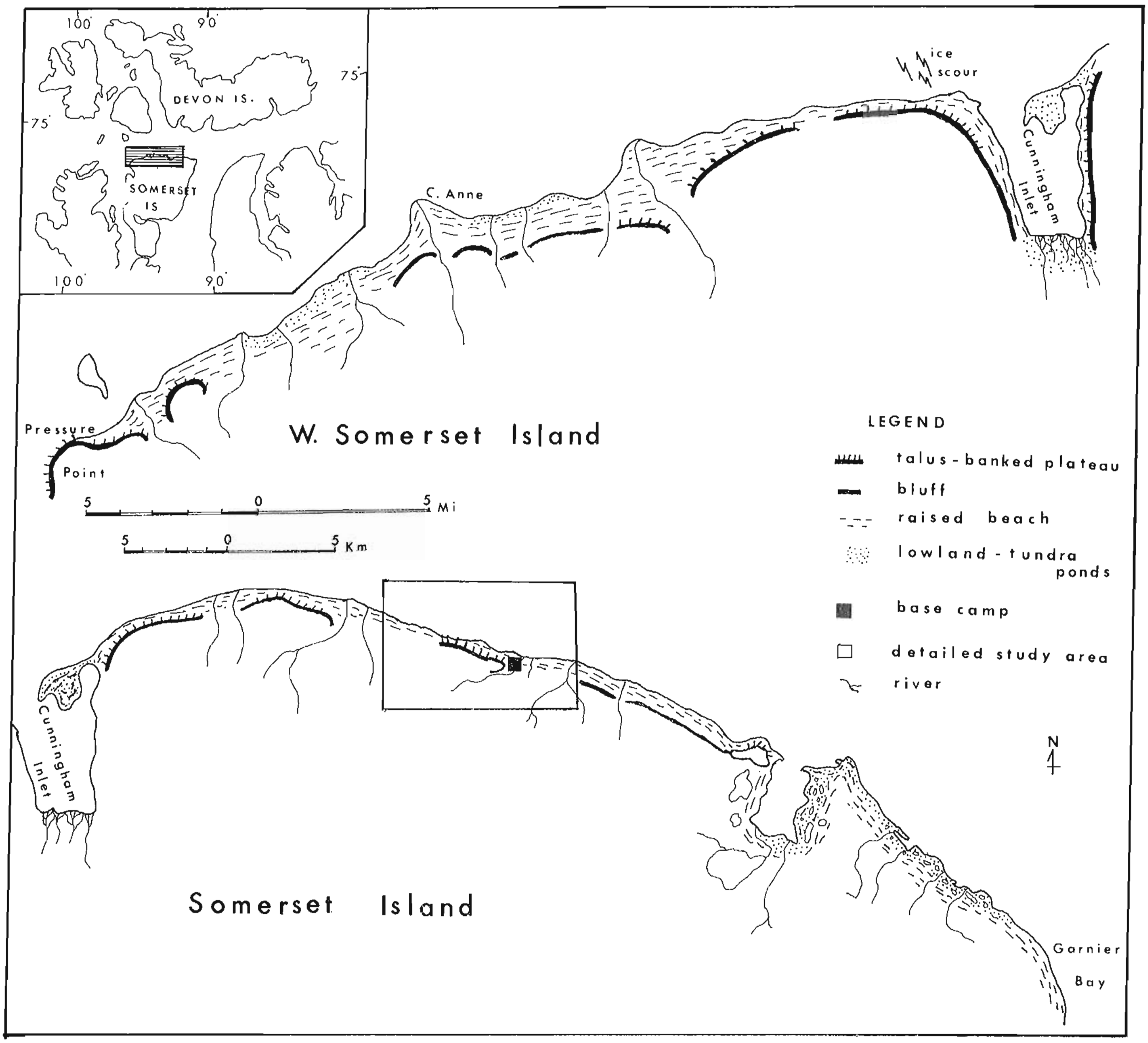

Figure 1. Map of detailed study area, north Somerset Island.

TABLE 1

Mean Frost Table Depths (in centimetres)

Date	Raised Beach Ridge	Top of Active Beach	High Tide Mark	Mean High Tide Mark	Low Tide Mark	Mean
July 13 1972	33.6	47.3	35.2	25.0	19.1	32.2
August 7 1973	50.0	41.4	47.3	49.0	39.8	45.5

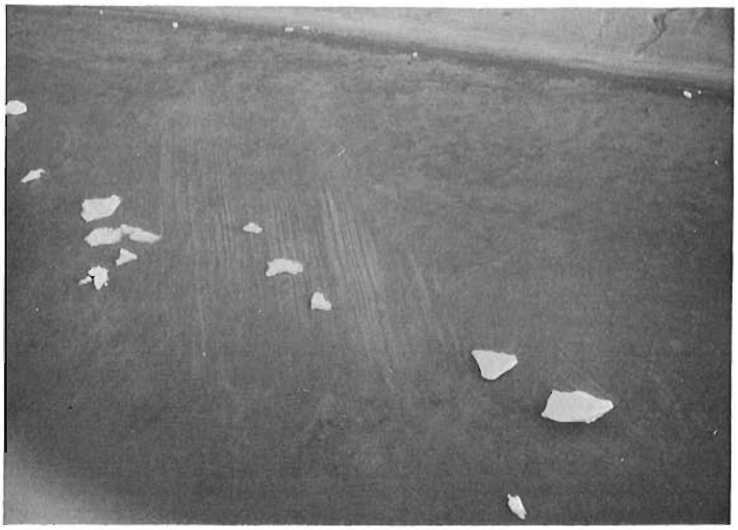

Figure 2. Ice scour in the nearshore, immediately west of the western entrance to Cunningham Inlet, Somerset Island (observed from the air).

observations of the effect of rivers and sea ice on the beach plan and profile, and the determination of the frost table depth at each of the ten survey stations.

Physical Framework: The northern Somerset coast, except for a few steep headlands, is characterized by a well-developed series of raised beach terraces. In the coastal areas of low relief lagoons, tundra ponds and nearshore shoals are common. The general occurrence of ice push ridges and ice pittings above high tide level and the presence of large sea ice scourings (Fig. 2) in the nearshore indicate that this coast is substantially affected by the movements of sea ice and storm wave activity. This may be due to the position of the north Somerset Island coast which is opposite the southern end of Wellington Channel, a principal route for the movement of multi-year ice from the inner seas of the Arctic Archipelago.

Detailed Study Area: The area of detailed research covered a sector of coast 6.0 kilometres long which was characterized by a steep active beach and a well-developed raised beach sequence in the backshore. The beach sediments based on the 1972 analysis (Taylor, 1973) were gravel of a -2.0 to -5.0 phi size with very little sand. The sediments sampled were moderately sorted, disc to bladed in shape, and had a mean roundness of 199.1 and mean sphericity of 0.57 (based on the indices of Cailleux (1947) and Sneed and Folk (1958), respectively). In 1972 opposing trends in grain size and shape were found on the active and non-active beach with distance from the steep plateau headland. On the active beach a longshore drift from east to west was indicated while on the older raised beach, a west to east drift of sediment was implied. Sediment samples collected along the active beach in August of 1973 should either confirm this difference in the present longshore drift or negate it, the latter meaning the sediment samples collected in 1972 only represented the result of a storm from the northeast in the previous fall.

The resurveying of the 1972 beach profiles in 1973 enables one to calculate the rate in beach profile change over a period of one year. The magnitude of the change has not as yet been calculated but it appears that most of the change occurred in the intertidal zone most commonly in the form of ice push features. Frost table depths were recorded across the beach profiles in both the 1972 and 1973 field seasons using a hand auger. The mean depths are shown in Table 1; the mean frost table depth for the whole beach was 32.2 cm on July 13, 1972 and 45.5 cm on August 7, 1973.

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NEARSHORE STUDIES USING SMALL WATER-CRAFT ALONG EAST MELVILLE ISLAND DISTRICT OF FRANKLIN

Project 730021

R. B. Taylor
Terrain Sciences Division

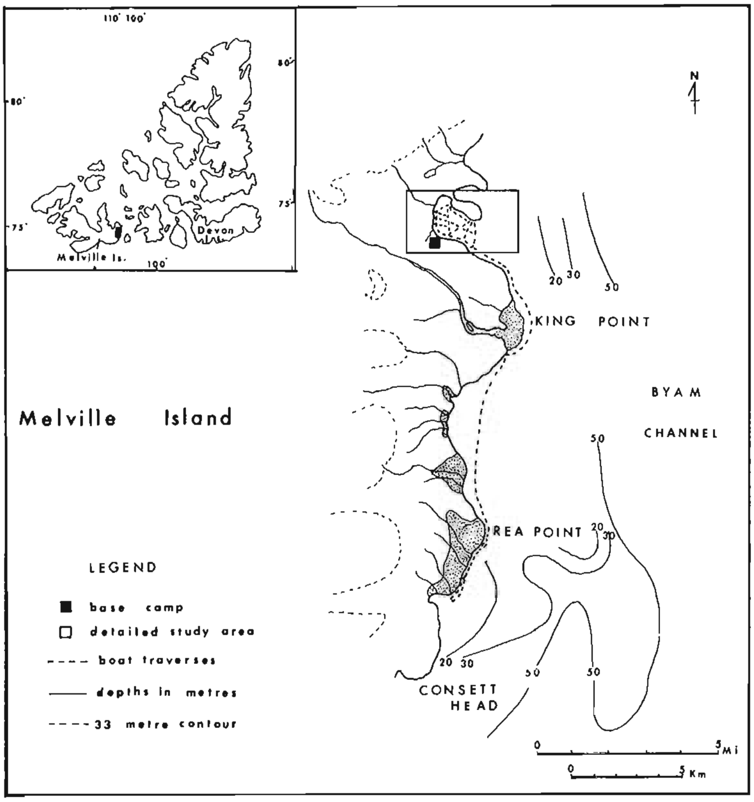

Figure 1. Study area on eastern Melville Island.

The aim of the current research is to test the usefulness of existing instruments and techniques for studying nearshore characteristics and processes in a High Arctic environment. Echo sounding, sub-bottom profiling, side scan sonar, bottom sampling, and measurement of oceanographic parameters were all attempted in support of the "Coastal Erosion and Sedimentation" study on eastern Melville Island directed by P. McLaren, Project 730020.

The detailed nearshore investigations were conducted in a small bay north of King Point on eastern Melville Island (Fig. 1) with additional traverses along the coast as far south as Rea Point. All of the research was done from a 19 foot pneumatic boat (Fig. 2) powered initially by an 18 horsepower motor and later by a 40 horsepower motor.

Preliminary Results: In the detailed study area a gradual sloping nearshore platform was observed which varied in width but usually extended to water depths of only 1. 0 or 2. 0 metres, whereupon a very steep break in slope occurred. This slope terminated at water depths of 12. 0 to 15. 0 metres both within the bay and at the seaward edge of the King Point River delta. Side scan sonar records clearly showed the shoreline, the nearshore break in slope, grounded and floating sea ice, small projections or depressions on the sea bed including scour and the larger marine life i. e., seals. Few ice scours were observed at the head of the bay and along the open coast. The largest scour, approximately 35. 0 metres long and 2. 0 metres wide, was found off the King Point River delta in a water depth of 12. 0 metres. Grounded multi-year sea ice was commonly observed along the steep sloping foreset beds of the larger deltas.

Salinity, water temperature, current velocity and bottom samples were observed in the bay using the small rubber boat. The salinity values there rose from 24 and 26 $^{o}/oo$ ($^{o}/oo$ = parts per thousand) at the surface to a maximum of 29 to 30 $^{o}/oo$ at a depth of 15. 0 to 20. 0 metres. Water temperatures decreased from -0. 68^{o}C at the surface to -1. 3^{o} and 1. 5^{o}C at a depth of 20. 0 metres. The buttom sediments at the head of the bay were composed of very fine sands and silts which were reduced a few centimetres below the surface.

Discussion: Nearshore research using a small open craft is very dependent on weather and local sea ice conditions. The work is further hampered by the short open water season which occurs along the Melville Island coast. Even in seasons with early ice breakup as in 1973, pieces of mobile ice continue to shift back and forth along the

Figure 2. Photo of the small craft used in the nearshore research; shown is the echo sounder and transducer, the hand winch, and boom. The latter was used for lowering the bottom sampler, the current meter and fish of the side scan sonar.

shoreline. Although wide shore leads sometimes exist by early July, water depths are so shallow that they are only navigable at high tide even with a small boat. Alterations could be made to the boat which would improve its utility, but the ultimate feasibility of using a small craft in an Arctic environment will vary from year to year and place to place depending on sea ice conditions. For instance, in the eastern Arctic the longer open water season permits an extended period of operations and can begin before the unsettled weather which is common in late August and early September.

These projects are part of the Environmental Social Program Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada

97. THE EFFECTS OF SURFACE DISTURBANCE ON GROUND ICE CONTENT AND DISTRIBUTION

Project 690054

J.A. Heginbottom
Terrain Sciences Division

In May and June, 1973, a series of holes was drilled in the Inuvik area for the purpose of providing background information on soil and ground ice conditions. The holes were drilled with a split-barrel sampler driven by a drop hammer; the resulting cores were described in the field and numerous samples retained for laboratory examination.

One group of thirteen holes provided some interesting information concerning the effects of surface disturbance on ground ice content and distribution. The holes were drilled in an area north of the town on the broad bench or terrace between the southern Caribou Hills and the Mackenzie Delta. This terrace is mantled with low angled fans of clayey silt. Gravels occur beneath these fans. Of the thirteen holes drilled in this area, seven are in relatively undisturbed terrain while six are in areas that have been quite severely disturbed. Two of the holes are 4 m deep, seven are about 3 m deep, three are about 2 m deep; the last encountered the gravels at only 0.93 m.

The seven holes in undisturbed terrain all penetrated layers of massive ice or icy soil (here defined as soil containing more than 50 per cent visible ice in the core) at a depth between 0.2 and 2 m, and two of the deeper holes encountered similar ice or icy soil at around 3 m. The layers of massive ice include lenses of ice containing less than 10 per cent soil material. Such lenses range from 0.02 to 0.65 m in thickness. Layers of icy soil contain 50 to 90 per cent ice, generally in thin horizontal lenses 1 to 10 mm thick and 1 to 20 mm apart.

Of the six holes in adjacent disturbed areas, one site was burned over and four subjected to bulldozing in August 1968. The remaining hole was in an old vehicle trail cut before 1964, but which has been used repeatedly since. Only one of these six holes penetrated any massive ice or icy soil in the top 1.2 m, and this was in the form of two 10 mm thick lenses at 1.04 and 1.13 m. Significant quantities of ice or icy soil were not encountered until depths of 1.2 to 2.2 m were reached.

In conclusion, surface disturbances such as fire or bulldozing appear to lead to the disappearance of excess ice in the upper metre of the ground and a significant decrease in the quantity of ice in the second metre. In the third metre there is an increase relative to undisturbed areas, while below the 3-metre mark conditions are probably unaltered. These conclusions are summarized in Figure 1.

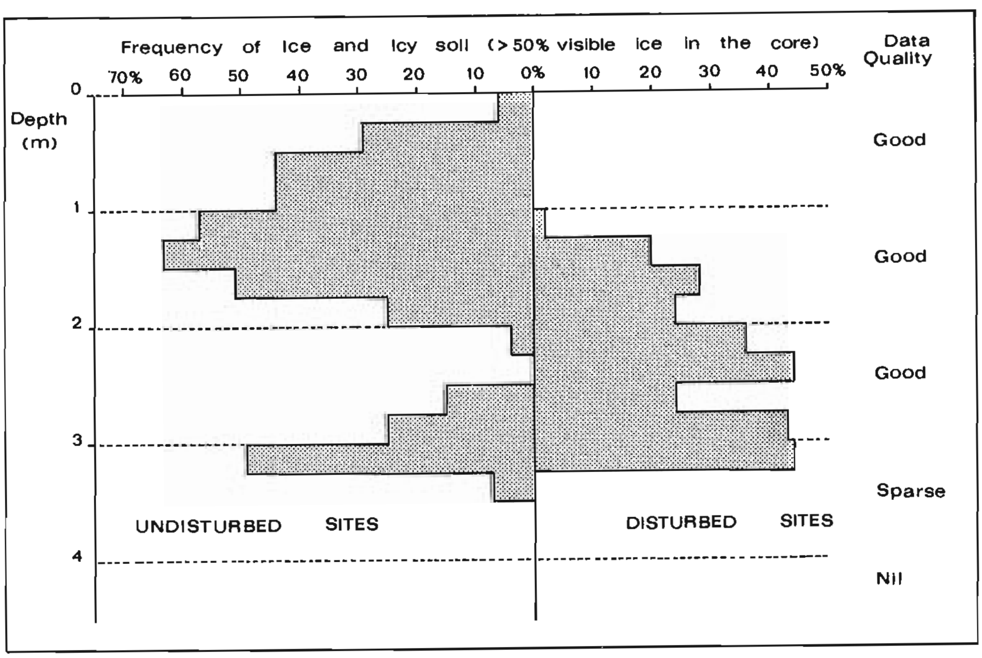

Figure 1.

Effects of surface disturbance on ground ice content and distribution.

SURFICIAL GEOLOGY AND LAND CLASSIFICATION, MACKENZIE VALLEY TRANSPORTATION CORRIDOR

Project 710020

O.L. Hughes, J. Pilon and J. Veillette
Terrain Sciences Division, Calgary

The objective of this project, continued from 1971 (Hughes and Hodgson, 1972) and 1972 (Hughes, Pilon, and Veillette, 1973), is to provide an inventory of surficial geology and permafrost distribution data pertinent to pipeline construction, road building and other land use activities that might take place in the Mackenzie Valley Transportation Corridor.

Hughes together with N.W. Rutter devoted one month to reconnaissance examination of the area encompassed by this project and Project 710047 (see this report). A primary objective was to ensure uniform usage of map-units throughout the two areas. Construction on the Mackenzie Highway was examined in order to evaluate terrain performance of various map-units crossed by the highway. Limited geological studies, including shallow borings and measurement of sections, were conducted to supplement field work of 1971 and 1972.

J. Veillette conducted diamond drilling in permanently frozen surficial deposits during the period mid-March to mid-April. J. Pilon devoted the month of July to field checking of photo-interpretive surficial geology maps of Canot Lake (106 P) and part of Mahony Lake (96 F). K.W. Savigny, under the direction of Pilon, examined, described, and sampled exposures of bedrock and surficial deposits along Great Bear River.

Diamond drilling (J. Veillette)

Winter drilling was conducted mainly on pediment surfaces in the vicinity of Old Crow, Yukon (116 N E/2 & O) and in areas of hummocky moraine near Bathing Lake, N.W.T. (106 N).

Objectives: During the summer of 1972 coring was attempted on pediments in the Old Crow area, using a modified CRREL barrel (1 m long, 4½" O.D.) powered by a Haynes earth drill. Coring was successful in the 1 to 2 m of permanently frozen silt that typically mantles the pediment surfaces, but unsuccessful in lag gravel or bedrock detritus below the silt. The CRREL barrel was likewise unsuccessful in coring till and met refusal upon encountering pebbles more than a centimetre or so in diameter. The winter drilling was therefore designed (1) to test the effectiveness of a light-weight diamond drill with diesel fuel as drilling fluid, in coring stony, permanently frozen material to shallow depths (8 to 10 m); (2) to supplement field observations on the character, thickness, and ground-ice content of pediment surficial materials which occur widely in unglaciated terrain west of Richardson Mountains, and in hummocky moraine belts that are extensive in glaciated terrain east of Richardson Mountains.

Equipment: A specific requirement was that the drill should be readily portable by a helicopter with a sling-load capacity of about 900 pounds. The drill used was a GW-15 Winkie drill manufactured by J.K. Smit and Sons, Toronto. A collapsible frame allowed the rapid removal of the drill head from above the hole so that the string of rods could be lowered and lifted without having to break each rod. The drill frame was anchored with frost pins driven into the permafrost. A Robbins and Myers progressing cavity pump, mounted on the drill base, was used for circulation of drill fluid. The drill and pump constituted a single sling load.

Because of possible deleterious effects of the drilling fluid on vegetation and the cost of flying the fluid to the drill site, special precautions were required to minimize fluid loss. A small slush pit was designed with a collar extending about 18 cm below the bottom of the pit (Fig. 1c). The outside diameter of the collar was slightly larger than that of a 4½" CRREL barrel. Holes were started with the CRREL barrel to a depth of 20 to 30 cm. The slush pit collar could then be inserted tightly into the drill hole. With this technique BX size holes could be drilled to a depth of 6 to 7 metres using about 25 gallons of oil, a major part of which could be recovered after completion of the hole.

Core barrels consisted of BXF, BXL and NX sizes. All core barrels were reduced in length to accommodate about 90 cm of core. Bits were of face-discharge type, with blank reaming shells and spring ring core catchers. A combination work-bench-tool box, equipped with a vice, facilitated the breaking of core barrels and rods and carried tools and accessories during moves. The box plus tools and accessories constituted a second sling load.

Core examination: All cores were bagged in plastic sleeves at the drill site and flown at the end of each day to a field laboratory. A styrofoam box was used to preserve the cores in frozen state while in transit.

In the field laboratory, an unheated building with temperature below 32°F, each segment of core was scraped to avoid contamination by the drilling fluid. The core was then described in detail and finally photographed at close range. All cores were then sealed in cans for later moisture content determinations and further analysis.

Sampling results: Forty-four shallow holes were drilled, the deepest to 9 metres. Core recovery averaged about 85 per cent over the entire project. Three holes in loose granular material had to be abandoned due to loss of circulation. Melting on the outside of the cores generally occurred at temperatures above 20°F. Excellent cores of stony tills and weathered bedrock were obtained, and the best results occurred at ambient temperatures between -20°F and 0°F (Figs. 1

Figure 1a. Sand and fine gravel; no visible ice.

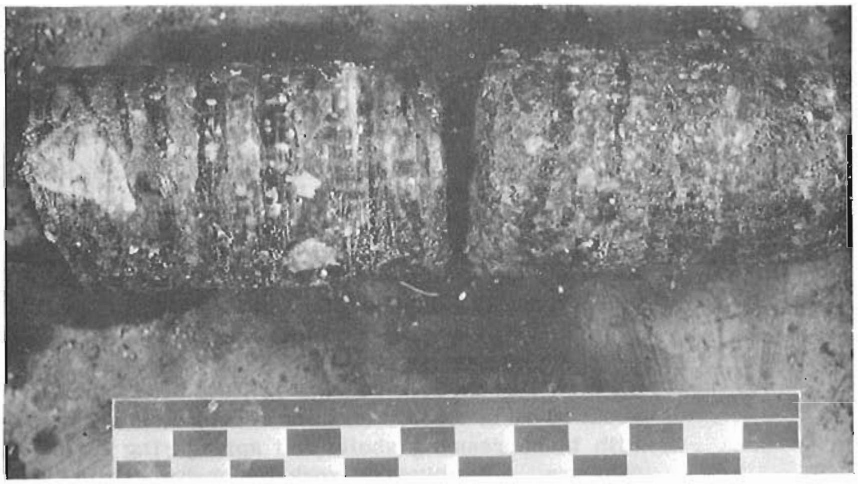

Figure 1b. Weathered granitic bedrock with stratified ice.

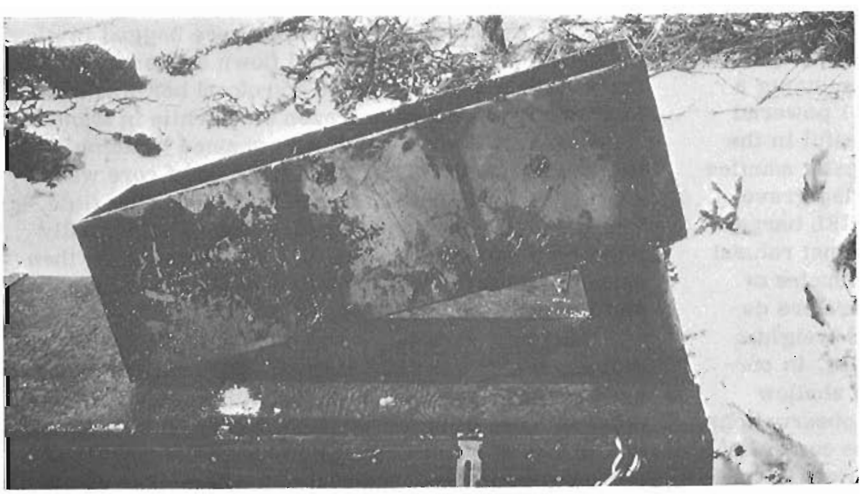

Figure 1c. Slush pit. Dimensions (75 cm x 25 cm x 25 cm).
Note: Scale at bottom of cores in centimetres.

and 2). BXL coring equipment proved to be the most successful; early damage to the NX barrel prevented adequate testing of this barrel.

Geological results: Drilling in pediments in the vicinity of Old Crow in general confirmed field observations that the pediments are remarkably uniform, despite the fact that they are developed on a wide range of bedrock types (carbonates, sandstone, shale, quartzite, granite) (Hughes, Pilon, Veillette, Zoltai, Pettapiece, 1973). Typically, 1 to 3 m of ice-rich silt and organic silt overlies 1 to 3 m of silty lag gravel that in turn lies on bedrock. Particularly in the case of granite, the bedrock may be so deeply weathered that there is no sharp demarcation between lag gravel and weathered bedrock.

Drilling in hummocky moraine demonstrated that there is considerable local variation in both texture and ground-ice content of material comprising the moraine. The material is mainly clayey silt till, but with local gravel lenses together with silt and peat fillings in depressions.

Summary: The light-weight diamond drill proved to be effective in obtaining undisturbed core from permanently frozen, stony material. An obvious application is in obtaining samples for thaw consolidation tests where the material is too stony for coring by the CRREL barrel together with its various modifications. Use is restricted to temperatures below about 20°F, although refrigeration of the drill fluid would be possible (at higher cost and with reduced mobility). The material must be frozen throughout the drilling depth and non-permeable, that is with intergranular porosity filled with pore ice. Use of drilling mud, although not attempted in the tests, might permit drilling through restricted permeable horizons. The same or a heavier drill mounted on a tracked vehicle would have application where closely spaced sampling is required in areas accessible from highway or winter trails.

Canot Lake map-area (J. Pilon)

Field work was devoted mainly to helicopter field-checking of a 1:125,000 scale photo-interpretive map prepared in advance of the field season. Shallow borings were made to obtain bog bottom samples for radiocarbon dating, using

Figure 2a. Till with silty shale and sandstone fragments, low ice content.

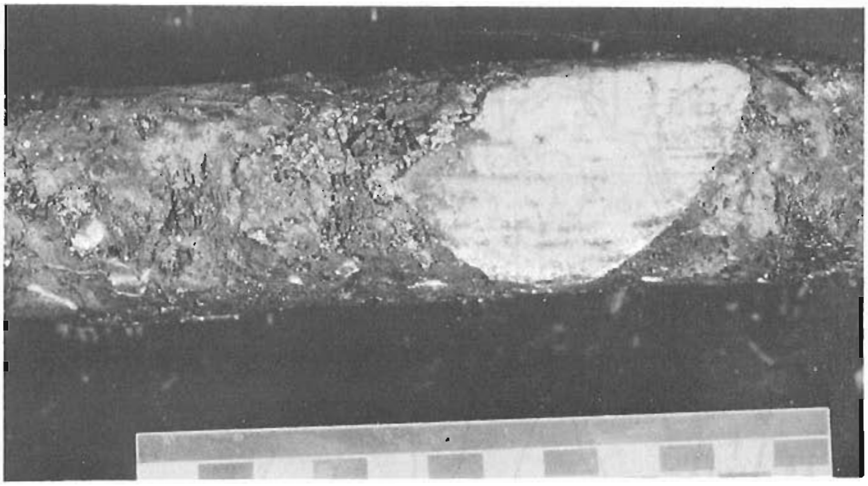

Figure 2b. Clay till with limestone pebble.

Figure 2c. Clay till with quartzite cobble, visible ice around cobble.
Note: Scales at bottom of cores in centimetres.

a modified CRREL barrel, powered by a Haynes earth drill.

The southern part of the map-area (Fig. 3) is occupied mostly by hummocky dead-ice moraine with restricted areas of ice-contact glaciofluvial deposits (kames, eskers). Numerous large meltwater channels extend northward from the sharply defined digitate northern margin of the moraine. The largest of the channels, those now occupied by the Iroquois and Carnwath rivers, contain extensive glaciofluvial outwash plains (sandurs).

The northern part of the map-area consists mainly of a thin veneer of till, in part drumlinoid, over bedrock. The area east of Iroquois River is a broadly rolling plain dissected by the system of meltwater channels. The area west of Iroquois River is a glaciated upland with more pronounced relief.

Till of the moraine belt has about 10% coarse fraction (+4 mm), including abundant pebbles of Shield origin; till north of the moraine belt is conspicuously less stony (about 2% coarse fraction) with relatively few pebbles of Shield origin.

The northern margin of the moraine belt marks the limit of a significant glacial advance, possibly the main Wisconsin advance. The moraine is traceable northwestward into Travaillant Lake map-area (106 O) (Hughes and Hodgson, 1972).

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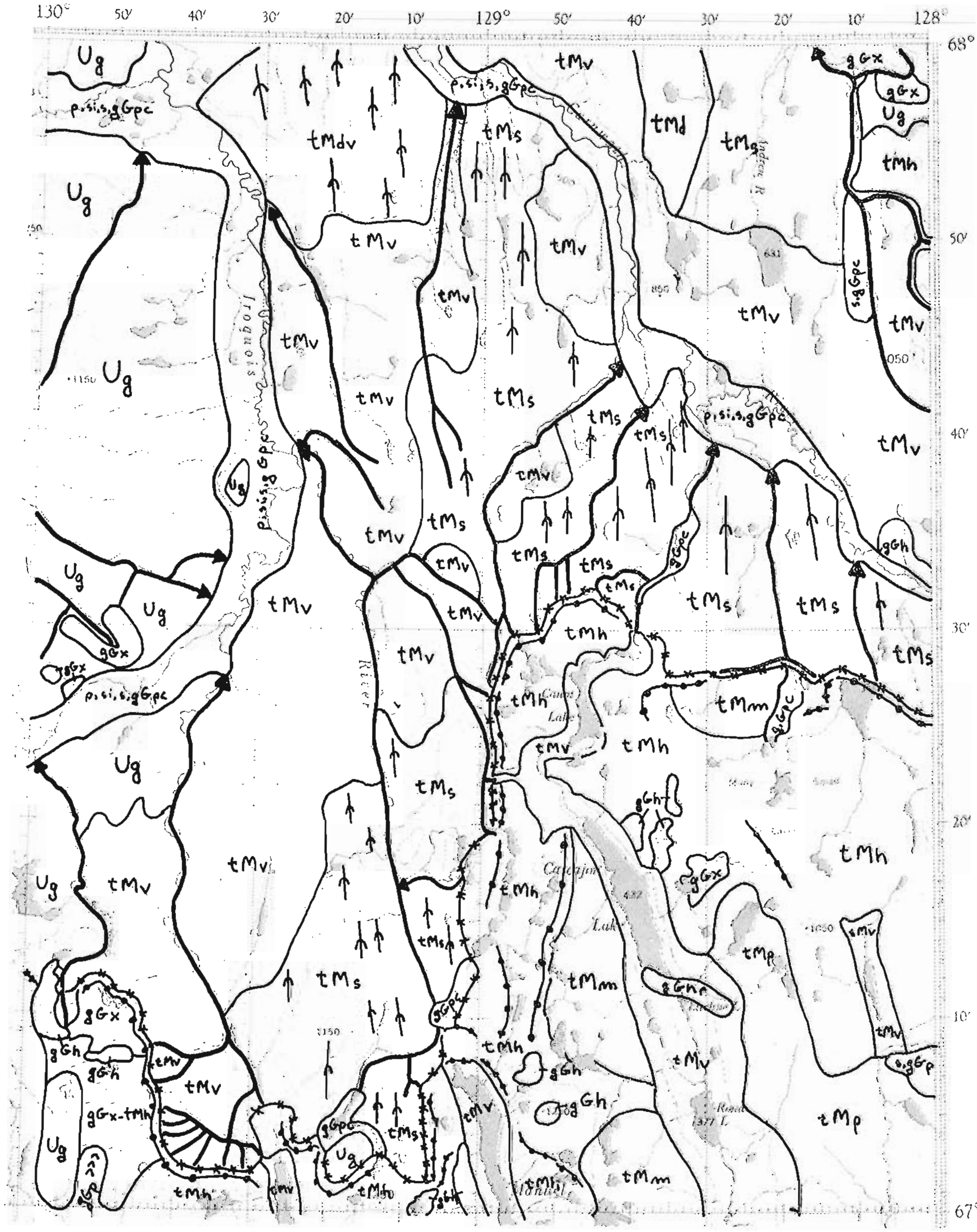

p, si, s, gGpc — Glaciofluvial plain, channelled

gGh, gGr, gGhr — Hummocky and ridged glaciofluvial deposits (kames and eskers)

gGx — Glaciofluvial deposit complex (hummocky and Rigid

Glacial advance limit

Frontal moraine ridge

Drumlinoid ridge

Major meltwater channel

Ug — Upland glaciated

tMr — Ridged moraine

tMdv, tMs — Drumlin and drumlinoid moraine plain

tMm — Subdued hummocky moraine

tMhm, tMh — Hummocky moraine

tMp, tMv — Moraine plain

Figure 3. Surficial geology and geomorphology Canot Lake 106 P.

99. TERRAIN SENSITIVITY EVALUATION AND MAPPING, MACKENZIE VALLEY TRANSPORATION CORRIDOR

Project 710077

P.J. Kurfurst
Terrain Sciences Division

A shallow drilling program was carried out in the Northwest Territories in June, July and August 1973. The main objectives of the project, continued from 1971 (Heginbottom and Kurfurst, 1971, 1972), were threefold:

1. to validate or modify as appropriate terrain sensitivity rating systems that have been developed by the Division,
2. to investigate local variability of ground ice occurrence along the Mackenzie Highway route, and
3. to evaluate and correlate, in co-operation with the Resource Geophysics and Geochemistry Division of the Geological Survey, the geophysical techniques for delineating zones of frozen and unfrozen ground.

A total of sixty holes, ranging from 2 to 6 metres in depth, were drilled at seven different sites between Fort Simpson and Fort Good Hope. The materials encountered varied from sands, silts and clays in the Fort Simpson region to predominantly tills around Norman Wells and Fort Good Hope. The underlying bedrock, when encountered, was shale.

Most of the holes were located in the disturbed areas on the highway centreline while the remaining holes were situated in the vicinity in the undisturbed zones.

Some 400 unfrozen chip-samples were collected and retained for further engineering properties tests in the Soil Mechanics Laboratory; the results are being evaluated.

Peat is generally of low strength with moderate to high ground ice content. Sands and silts have low ground ice content, increasing with increased percentage of fine particles. Clays, commonly mixed with fine silts, are usually highly plastic with moderate to high ground ice content in the form of a reticulated network of segregated ice. Silty to clayey till has low to moderate ground ice content with ice occurring as thin seams and lenses. In the Fort Good Hope area, ground ice content in till is generally very low.

The preliminary evaluation of field data shows that the ground ice content is related not only to grain size, but also to terrain conditions and local topography. Increased terrain damage causes a proportionate decrease in the ground ice content; the effect of local topography seems of lesser importance.

The drilling operation around Fort Simpson, which was done in co-operation with the Resource Geophysics and Geochemistry Division of Geological Survey of Canada confirmed that the geophysical techniques used, consisting of seismic and electric methods, are able to delineate the zones and thicknesses of the frozen ground fairly accurately.

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Project 730026

D.E. Lawrence
Terrain Sciences Division

The objective of this project is to gather and assemble all geotechnical data available in the Mackenzie Valley and Delta in order to assess permafrost and ground ice occurrence and distribution. Also an attempt will be made to correlate these parameters with the geological, hydrological, topographic, climatic and vegetation conditions.

Ultimately it is anticipated that the results of this study will indicate which are the most significant geotechnical test procedures in the delineation and/or the prediction of permafrost and ground ice conditions and also which geological and other natural phenomena are indicative of, or are likely to be associated with permafrost. This information would be useful in predicting the presence of permafrost in areas where geotechnical data are sparse.

Approximately 6,000 boreholes have been drilled for geotechnical purposes in the Mackenzie Valley in the past five years. Borehole logs and test records of various degrees of detail are available for these holes, drilled principally for the following purposes:

1. Investigation of the alignment and materials for the Mackenzie and Dempster Highways. These investigations have been carried out by the Department of Public Works of Canada and their consultants.

2. Investigations for the alignments of various proposed gas and oil pipelines. These investigations have been carried out by several large gas and oil consortia.

3. Investigations carried out by the Department of Indian and Northern Affairs and their consultants in making an inventory of the granular materials suitable for construction use.

Recording of the borehole information on data record sheets is the first step in the transfer of the information from the drill logs. Over 35 parameters can be recorded. Information recorded on the above sheets is then keypunched, verified and transferred to magnetic tape. A retrieval system using COBOL programming is now underway. To date approximately half of the available data have been recorded and stored in the data bank.

Comments on permafrost and ground ice occurrence cannot be made at this stage of the investigation. However, in recording data from reports of various consultants significant discrepancies with respect to permafrost become apparent.

The frequency and amount of ground ice reported when using disturbed sampling methods is considerably less than those investigations using continuous undisturbed sampling methods or estimated by geological observation. These discrepancies may in part be explained by the following:

a) The vast majority of holes have been drilled during the winter, by auger or reverse air return rotary drilling (both methods give chip samples). The results of permafrost and ground ice appraisal based on this type of sample tend to give underestimates of ice contents as compared to undisturbed samples. The structure of the soil is destroyed during drilling and thus accurate estimates of ice content cannot be made. Those reported would tend to be conservative as there is the possibility of the ice melting and of small ice lenses being broken up in the drilling process and not observed.

b) When the active layer is frozen in mid-winter, (when most geotechnical investigations are, of necessity, carried out due to land use regulations) there is a continuous substrate of frost. The identification of the boundary between annual frost and permafrost would be almost impossible even with continuous undisturbed sampling. Thus depth to permafrost figures based on observations of winter drilling programs must be treated with utmost caution.

c) It has been observed that in many cases where continuous sampling (split-spoon) has been carried out adjacent to holes producing disturbed samples the amount of ice reported with the continuous undisturbed sampling is never less, but frequently more than reported when recovering disturbed (chip) samples.

d) The description of permafrost used by most investigators has been according to the method described in NRC Technical Memorandum No. 79. This system was designed for the description of undisturbed samples. It has however been used indiscriminately by many in the description of disturbed samples resulting in the erroneous classification of samples.

QUATERNARY STRATIGRAPHY AND GEOMORPHIC PROCESSES ON THE ARCTIC COASTAL PLAIN AND ADJACENT AREAS, DEMARCATION POINT, YUKON TERRITORY, TO MALLOCH HILL, DISTRICT OF MACKENZIE

Project 690047

V.N. Rampton and J.B. Dugal
Terrain Sciences Division

Quaternary stratigraphy

Two weeks were spent examining coastal and river exposures from Nicholson Point to Malloch Hill, and re-examining critical sections along the Eskimo Lakes.

In the Eskimo Lakes a few sections on islands, where glaciofluvial sands form the surface material, were re-examined to locate and collect organic material for radiocarbon dating. In addition logs and beaver-chewed wood, located north of the present treeline at the northeastern end of the Eskimo Lakes, were collected.

Between Stanton and Maitland Point and along the bay southeast of Ikpisugyuk Point, an interglacial sequence of oxidized sand, colluvium, peat, soil or thinly bedded sand and silt containing wood overlies marine clay and underlies a sequence of thinly bedded sand, silt, and clay. The marine clay in many places lies directly on Cretaceous shale. North of Harrowby Bay the interglacial sequence is absent from exposed sections. Till overlies the upper sand, silt, and clay sequence southwest of the Mason River within the limit of glaciation. Massive ice is, in many places, present at the base of the till. Along many cliffs, lacustrine sediments with peaty layers cap this sequence; frequently a peaty layer will contain wood indicating warmer climatic conditions than at present. For example, at Baillie Island a peat bed in a lacustrine sequence contains wood identified as *Populus* (id. by L. Wilson). The upper 5 to 10 feet of sediment in most sections contained an abundance of excess ice (30 to 70% by total volume).

Set into the above sequence along the Old Horton Channel, Mason River, the major creek flowing into the bay southeast of Ikpisugyuk Point, and adjacent to the Amundsen Gulf are glaciofluvial and postglacial fluvial terraces. The upper terraces are generally composed of gravel, the intermediate terraces of sand, and the lowest terraces of thinly bedded sand, silt, and clay. Some terraces are capped by a silt (loess?) with peaty layers; this unit occasionally can be found overlying other materials in the area.

During this summer's work, it became obvious that in the area north from Cy Peck Inlet to Cape Bathurst much of the surface sand previously mapped as marine sand (Rampton, 1972a, b), is of glaciofluvial origin.

Geomorphic processes

Wooden dowling and painted rocks that were installed in the British and northern Richardson Mountains during the 1972 field season were resurveyed. On steep scree-covered slopes (slope $\gtrless 25^{o}$) surface materials moved an average of about 2.5 cm during the past year, the maximum measured movement being 5.8 cm; steep, vegetated slopes occasionally showed no movement. On more gentle slopes, surface movement was irregular, but movements of 1.5 to 2 cm during the past year were common, the maximum measured movement being 4 cm. The movement on the upper surface of solifluction lobes was often found to be negligible although parts moved 2 to 5 cm. Blocks of turf are often dislodged in wet weather and individual clasts occasionally roll down the steep fronts of the lobes.

Trenching of solifluction lobes and bouldery terracettes was carried out to collect peat covered by these features and to examine internal structures. Dates on the peat underlying the solifluction lobes should indicate whether the lobes are continuously or only sporadically active; radiocarbon dates obtained to present would suggest that the latter is true. An interesting phenomena observed during the summer on gentle slopes, was detachment failure that caused material to flow a short distance downslope leaving a scar above. The material that slid came to rest in a form identical to many solifluction lobes in the area.

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SURFICIAL GEOLOGY AND LAND CLASSIFICATION, MACKENZIE VALLEY TRANSPORTATION CORRIDOR (85D, E, 95A, B, G, H, I, J, K, N, O)

Project 710047

N.W. Rutter
Terrain Sciences Division, Calgary

One month was spent in the field completing the field work started in 1971 (Rutter and Minning, 1972; Rutter and Boydell, 1973). The objective was to examine this field area, the southern Mackenzie Valley and the northern Mackenzie Valley (Project 710020), with O. L. Hughes for the purpose of ensuring uniformity in mapping methods and regional geological interpretation and to finish any uncompleted field work, examine recent construction in order to evaluate previous recommendations made to various agencies and to become more familiar with construction methods to aid in further assessments.

It was found that for the most part there was a uniform use of map symbols between the two areas. The main problem, that of defining the symbols was brought about by variation in the distribution and thickness of permafrost and subsequently in volume and nature of ice. By using a concept of "zones" based on broad aspects of climate and ecology, the same symbols and definitions can be used for similar deposits in all parts of the Mackenzie Valley. Permafrost characteristics of the deposits are indicated by what zone they are in.

Six major sections were sampled and measured in the southern area, for the purpose of giving a general description of surface and subsurface deposits characteristic of the area and to aid in deciphering the Quaternary history.

Another objective that was successfully carried out was to continuously core six drill holes through frozen peat on the latest Laurentide till sheet for pollen analysis and radiocarbon dating. The objective was to obtain a post-glacial pollen record from the entire Mackenzie Valley. Two holes each were drilled in the Sibbeston Lake, Dahadinni and Norman Wells map-areas. C. Schweger, University of Alberta, has agreed to undertake the identification and interpretation of the pollen.

R. Van Everdingen, Inland Waters Directorate, accompanied the writer for several days in order to locate, inspect and identify springs that may cause problems during and after construction of the Mackenzie Highway. In the southern area he concentrated his work between Willow Lake River and the Ochre River. Results indicate a great variety of natural springs. They vary between 0.5 and 25°C in temperature, 150 and 15,000 mg/1 in dissolved solids and flow from less than 1 to more than 100 gallons per minute. The highest concentration of salt is either calcium carbonate, calcium sulphate or sodium chloride.

Evidence is present for two Laurentide ice advances in both the southern and northern areas. One problem this field season was to trace the western limit of the "Classical" Wisconsin and the earlier ice sheet from the northern into the southern area. In the northern area, the "Classical" Wisconsin limit is marked by well defined, discontinuous meltwater channels and the earlier limit by Shield erratics, both of which increase in elevation toward the south. Just south of the northern area in the Wrigley Lake map-area, the "Classical" Wisconsin limit is at about 4,250 feet and the earlier limit at about 5,000 feet. It is difficult to follow these limits into the mapped area to the south because mountains in the Dahadinni map-area (95N) are for the most part too low to record the limits. However, further south in the Root River map-area (95K) the mountains are higher and the limits should be possible to trace. Eastern erratics have been found up to about 5,000 feet in the Sibbeston Lake map-area (95G) to the south, and if the elevation of "Classical" Wisconsin glacial erratics and meltwater channels increases at a constant rate, 5,000 feet is about the expected elevation for the "Classical" Wisconsin limit in this area. It may therefore be, that the maximum elevations for "Classical" Wisconsin and early glacial erratics converge to the south so that both limits lie at about the same elevation.

Inspection of the route of the Pointed Mountain Pipeline and Mackenzie Highway between Fort Simpson and Camsell Bend shows that environmental damage is relatively minor after a wet fall and a relatively mild winter. Problems along the Pointed Mountain Pipeline route include: floating of the pipe in low areas; settling of material with subsequent ponding and collapse along the filled trench; and gully erosion down steep scarps of major river crossings adjacent to the pipeline. The major problem along the Mackenzie Highway is the presence of a few retrogressive thaw flow slides in the right-of-way. Minor problems include gullying along ditches and accumulation of sand in the right-of-way by deflation of road-cuts. Along both the pipeline and highway the problems are being rectified.

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103. STRUCTURE AND STRATIGRAPHY, RINGNES ISLANDS AND NEARBY SMALLER ISLANDS, DISTRICT OF FRANKLIN

Project 710003

H. R. Balkwill
Institute of Sedimentary and Petroleum Geology, Calgary

Five weeks were spent in the central part of the Sverdrup Basin. Reconnaissance bedrock maps (scale 1: 125, 000) of Cornwall and King Christian Islands were completed, as were detailed maps (scale 1: 50, 000) of Ellef Ringnes Island; reconnaissance mapping (scale 1: 125, 000) of Lougheed Island was initiated, and studies of the regional structural geometry, and kinematics and chronology of Mesozoic and Tertiary tectonism were continued. Some significant regional data are summarized in the following paragraphs. (See also related projects by K. J. Roy, and W. S. Hopkins, Jr.).

Cornwall Island

Northwest-plunging Cornwall Arch (Balkwill, in press) dominates the structural geometry of Cornwall Island. The arch resulted from Late Cretaceous - early Tertiary uplift, probably in response to basement-controlled tectonism. The eastern flank dips 10 - 14 degrees, and is interrupted locally by small folds and normal faults. The western flank is a gently dipping (4 - 8 degrees), uninterrupted homocline.

Oldest paleontologically dated rocks in the crestal region are abundantly fossiliferous sandstones and sandy shales that contain Late Triassic (late Norian) faunas (E. T. Tozer, pers. comm., 1973); these rocks and overlying non-fossiliferous, partly coaly sandstones are assigned to the Heiberg Formation (see Tozer, 1970, p. 578-579). But, below the fossiliferous beds, there are at least 1, 000 metres of dark grey shale, in which macrofossils have not been found, and which are more similar, lithologically, to the shale-dominated Blaa Mountain Formation than they are to the sandstone-dominated Heiberg Formation; in eastern parts of the Sverdrup Basin Blaa Mountain Formation is Middle and lower Upper Triassic (Anisian, Ladinian and Karnian; Tozer, 1970, p. 578).

Greiner (1963, p. 535-536), in a brief reconnaissance investigation of eastern Cornwall Island, divided rocks above the non-fossiliferous Heiberg Formation sandstones in the following way: a lower interval of buff sandstones and red-weathering pebbly sandstones was assigned to the Jaeger Formation; the base of the formation was picked at the lowest red-weathering pebble bed at the type section along Jaeger River, and the top was designated at the base of an interval of shale, about 1, 000 feet above the base; Greiner assigned all rocks above the Jaeger Formation to the Awingak Formation. But the type section of the Jaeger Formation is transected by normal faults, with repetition of part of the succession. In other parts of the island there are lenses of fossiliferous, red-weathering, pebbly sandstones below the interval that Greiner picked as the base of the Jaeger Formation; moreover, detailed mapping and stratigraphic studies indicate that elements of other units that are widespread in the Sverdrup

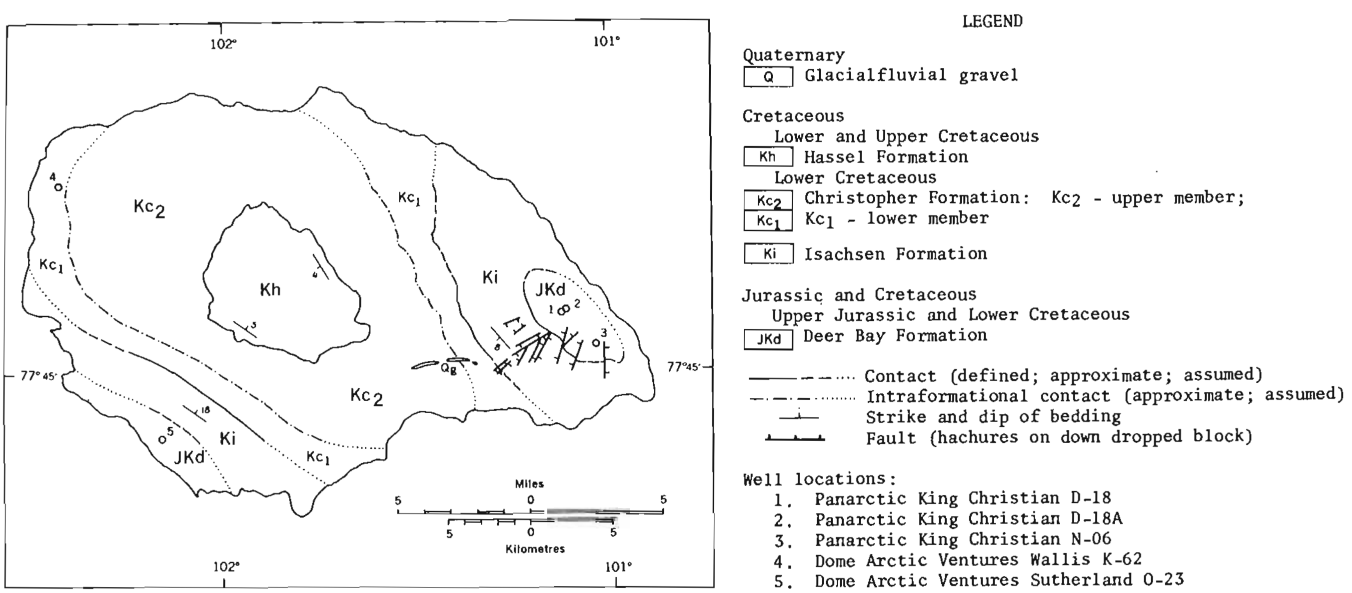

Figure 1. Geological sketch map, King Christian Island, District of Franklin.

Basin - the Borden Island, Savik, Deer Bay, Isachsen, and Christopher Formations - are present in the interval that Greiner assigned to the Jaeger and Awingak Formations. The nomenclature of this succession should be reassigned, but this must await forthcoming paleontological determinations.

Ellef Ringnes Island

Detailed mapping of this island allows subdivision of the thick intervals of marine shale (Stott, 1969) according to the format employed previously in mapping Amund Ringnes Island (Balkwill, 1973).

1. The Kanguk Formation (Upper Cretaceous) is divisible into upper and lower parts at the base of an escarpment-forming interval of red-brown weathering siltstone. The lower part of the formation is black, very slightly silty shale, which characteristically has secondary growths of gypsum on weathering surfaces, and almost completely lacks ironstone nodules; beds near the base are locally pink and brick-red because of oxidation of iron-sulphate minerals. The upper part of the formation is dark brown-grey shale, which is moderately silty and has abundant ironstone nodules. Macrofossils collected about 15 m above the base of the upper member were assigned by J. A. Jeletzky (pers. comm., 1973) a Santonian or early early Campanian age.

2. A mappable interval of glauconitic sandstone near the middle of the Christopher Formation (Lower Cretaceous) permits separation of that unit into upper and lower intervals. The lower part, which includes beds to the top of the glauconitic sandstone, consists of dark greenish grey, silty shale, with large (about 2 m long), characteristically buff-weathering concretions. The upper interval is dark grey shale, which is silty only near the top, and has sparse, dark red-brown concretions that are mostly less than 1 m long; concretionary beds near the base of the interval contain abundant molluscs that Jeletzky (pers. comm., 1972) assigned to the middle Albian.

3. The succession of Middle and Upper Jurassic and Lower Cretaceous marine shales in the northern part of the island, defined by Heywood (1957; also Stott, 1969) as the Deer Bay Formation, comprises lithologic intervals that were recognized later, in central and eastern parts of the Sverdrup Basin, as the upper part of the Savik Formation, a shaly facies of the Awingak Formation, and the 'Deer Bay Formation' - the latter restricted to shales above the Awingak Formation (Balkwill, 1973; and see Tozer, 1970, p. 501). Heywood's definition of the Deer Bay Formation preceded introduction of the terms Savik and Awingak; but the latter represent lithologically distinctive, regionally significant intervals, and should be retained. Redefinition of the Deer Bay Formation is therefore necessary, but must await additional paleontological determinations. Beds believed to be representative of the upper part of the Savik Formation are dark grey to black shales with small (0.5 m or less) red-brown concretions; dark grey, silty shales of the 'Awingak' shale facies are distinguished by very large (greater than 2.0 m) yellowish buff concretions; and the Deer Bay Formation, considered herein as shales lying on the Awingak Formation (see Tozer, 1970, p. 581) consists of medium to dark greenish grey, silty shales with increasing amounts of silt and very fine grained sand toward the top, and with small to medium-size (less than 1 m) red-brown and buff concretions.

King Christian Island

Discoveries of natural gas at well locations 1, 3 and 4 (Fig. 1) have prompted much interest in King Christian Island and environs.

The oldest parts of the Mesozoic succession are black shales of the Deer Bay Formation (Upper Jurassic and Lower Cretaceous) which are exposed in structural culminations near the eastern and western coasts; thereabove, the conformable Mesozoic succession includes buff sandstones of the Isachsen Formation, grey shales of the Christopher Formation, and buff sandstones composing the lower and possibly middle parts of the incompletely exposed Hassel Formation - probably latest Albian to Cenomanian (Hopkins and Balkwill, 1973). In the manner proposed for Ellef Ringnes Island and other parts of the central Sverdrup Basin (Balkwill, 1973), the Christopher Formation may be divided informally into lower and upper parts (Fig. 1). The lower part consists of dark grey and dark green-grey silty shale with large (commonly greater than 2 m (buff-brown nodules, and with a conspicuously green-coloured, fine-grained glauconitic sandstone at the top; the upper part of the formation comprises dark grey to black shale with small and medium-size (mostly commonly less than 1 m) dark red-brown nodules. Sinuous eskers, formed of heterogeneous boulder gravels, locally overlie the Mesozoic rocks.

A broad, ovate, vaguely northwest-trending structural depression, with gently dipping limbs, dominates the geologic structure. The depression is flanked on the east by a dome with northwest elongation - site of the initial gas discoveries on the island - and on the west by east-dipping, poorly exposed strata which may be part of an analogous fold along the western coast.

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104. INTERPRETATION ET SYNTHESE DES DONNEES DE SONDAGES DE L' "UPPER ELK POINT" (DEVONIEN MOYEN DU CANADA OCCIDENTAL): GENESE DES EVAPORITES ET RAPPORTS AVEC LES CARBONATES

Project 720065

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INTRODUCTION

Au cours de la recherche d'hydrocarbures, un capital énorme de données est accumulé, tant par les explorations géophysiques que par les sondages (diagraphies, échantillons, carottes). Ces données sont en général soigneusement analysées et synthétisées par les sociétés d'exploration pétrolière. Toutefois l'effort de ces dernières est primordialement axé sur la découverte et l'exploitation d'hydrocarbures. De surcroît une bonne partie des résultats obtenus dans des domaines plus généraux (processus de dépôt et d'évolution des couches sédimentaires en particulier) garde le caractère confidentiel qui est normalement attaché à un rapport interne. Pour ces raisons, les données ainsi accumulées peuvent encore faire l'objet d'études fructueuses de la part des services publics de recherches. Du fait du nombre, de l'importance et de la qualité de ces données, du fait également qu'elles permettent d'accéder à des parties de bassin qui échappent à l'observation directe, on peut même estimer qu'il est du *devoir* de ces services d'en faire entreprendre une réinterprétation scientifique minutieuse. Dans le cas présent, celui de l'étude des problèmes posés par les *évaporites*, il est évident que les données de sondages apporteront des informations irremplaçables, la qualité des affleurements étant le plus souvent déplorable.

L'intérêt de la succession des couches du sous-groupe de l' "Upper Elk Point" (Dévonien moyen) est considérable en vue d'une meilleure compréhension de la genèse et de l'évolution des évaporites, ainsi que des édifices carbonatés entre lesquels et dans lesquels ces évaporites apparaissent et enfin des rapports mutuels de ces deux groupes de faciès. Cet intérêt prend sa source dans la convergence de certaines conditions naturelles et de certaines conditions de l'exploration pétrolière et de la mise aux archives de ses données. Du point de vue des conditions naturelles, je rappellerai la taille exceptionnelle de ce bassin évaporitique (plus de 1500 km du NW au SE, en l'état actuel d'érosion des marges), la gamme et l'étalement géographique également exceptionnels des faciès représentés (depuis les carbonates du NW jusqu'aux énormes accumulations de sels potassiques du SE dela Saskatchewan en passant par l'anhydrite et l'halite). Or les déformations tectoniques qui ont pu affecter ces énormes masses salines sont si faibles, sur cette plateforme de l'Ouest canadien -- où le pendage moyen du Dévonien est inférieur à 1° --, qu'aucun dôme de sel, aucune tectonique halocinétique n'a jamais pris naissance: rien n'est venu perturber la nature et la disposition originelles des différents faciès (hormis des phénomènes d'évolution diagénétique), ni la répartition de leurs épaisseurs (hormis quelques phénomènes de dissolution et une inévitable compaction). Qu'en est-il de la qualité des informations existantes? Le bassin dans sa quasi-totalité est percé par un réseau de sondages d'une densité si élevée qu'elle est peut-être unique au monde eu égard à la taille du bassin. Les diagraphies enregistrées constituent des instruments irremplaçables par leur quantité et leur qualité: au niveau de l'Elk Point supérieur, dans les puits récents, il est courant de disposer d'une diagraphie électrique ainsi qu'un microdispositif focalisé de résistivité, d'un diamétreur, un gamma ray, un neutron, un sonique et un log "density". Le nombre de carottes prélevées dans ce bassin, tant dans les niveaux carbonatés que dans les couches évaporitiques, est, lui aussi, probablement unique au monde. Enfin il se trouve que ces données sont admirablement archivées en particulier à Calgary (Institut de géologie sédimentaire et pétrolière; Core storage center of Energy Resources Conservation Board of Alberta) où leur consultation est on ne peut plus aisée. La conjonction de telles conditions, naturelles et humaines, fait de ce bassin évaporitique un des plus beaux modèles d'étude qui puissent exister et j'en ai entrepris l'étude depuis juillet 1971, comme suite à mes travaux sur le Mésozoïque saharien également riche en évaporites.

A cette étude se trouvent associés depuis 2 ans MM. J.M. Rouchy et J.C. Tranchant, assistants de recherches au laboratoire de Géologie du Muséum (Paris). Ce travail n'aurait pu démarrer sans l'aide que m'a apporté en 1971 la Compagnie française des pétroles (grâce à une intervention de M.P. Burollet) tant pour mes frais de séjour que pour disposer d'un bureau et de la collection de logs de Total N.A. Par la suite, Shell Canada grâce à M. Peter Moore, m'a fait gagner un temps considérable, en triant à l'ordinateur le millier de puits ayant atteint les niveaux qui m'intéressaient, parmi plus de cent mille existant au Canada occidental. Diverses autres sociétés m'ont déjà apporté leur aide, en particulier dans la reproduction de documents (Elf, Aquitaine). Efin, récemment, Shell et Imperial, grâce respectivement à MM. P.F. Moore et R.P. Glaister, en me fournissant des photos de carottes, m'ont apporté une aide inestimable.

LOCALISATION DE L'ETUDE

Verticalement l'étude est limitée au sous-groupe de l'Upper Elk Point. C'est-à-dire (fig. 2) à l'intervalle

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compris entre le toit de la formation Chinchaga ou Contact Rapids et le toit de la formation "Watt Mountain" ou "First Red Bed". La plupart des auteurs on considéré ces contacts lithologiques comme des lignes-temps, au moins approximatives, opinion que je partage. Les dits contacts isolent donc une unité dont le faciès peut varier du tout au tout mais qui, néanmoins, reste synchrone sur toute son aire d'extension. Son attribution au Dévonien moyen ou à une partie du Dévonien moyen manque de précision, sinon de certitude. C'est donc typiquement une unité "parastratigraphique" (Busson, 1972), dont la considération peut être pleine d'enseignements du point de vue des processus sédimentaires.

Géographiquement la zone *en cours* d'étude est précisée sur la figure 1 ci-jointe. Les diagraphies ont déjà été exploitées sur plus de la moitié de la zone qui s'y trouve délimitée et qui renferme 6 à 700 puits. On remarquera que les zones de Rainbow et de Zama ne s'intégrent pas, pour l'instant, à l'aire en cours d'étude: le nombre de forages y est si élevé que la considération des champs de Rainbow et de Zama aurait demandé à elle seule un temps considérable. Or il s'agit d'une zone d'intérêt économique primordiale, qui, de ce fait, a fait l'objet d'études les plus détaillées de la part des sociétés d'exploration pétrolière. En ce qui concerne les carottes, pour l'instant, seul un nombre infime ont été examinées, du moins en comparaison du nombre total qui existent.

PRINCIPES ET METHODES DE L'ETUDE

La plus grande partie de l'étude consiste pour l'instant en une réinterprétation méthodique des diagraphies, réinterprétation faite avec deux objectifs. Tout d'abord la mise en évidence de corrélations *aussi indépendantes que possible de la nature lithologique des successions traversées dans les différents puits:* de telles corrélations s'avèrent possibles, sinon aisées, grâce; 1) à l'existence de certains marqueurs (vraisemblablement synchrones sur la plus grande partie de leur aire d'extension); 2) à l'existence de certains phénomènes homologues apparaissant dans des domaines lithologiques différents; 3) à l'existence de cycles (fig. 3) qui peuvent également se retrouver dans ces domaines différents. Des corrélations aboutissent à la mise en évidence d'une succession d'unités parastratigraphiques, dont la considération est capitale pour tenter de rétablir un certain nombre de paléogéographies successives. Le deuxième objectif consiste en une tentative pour reconstituer la colonne lithologique dans chaque puits, *uniquement* à l'aide des diagraphies (et des logs de carottes éventuellement), à l'exclusion des logs stratigraphiques établis sur déblais dans des conditions de fiabilité insuffisamment homogènes.

Au total, cette réinterprétation des diagraphies doit permettre l'établissement, pour chaque unité parastratigraphique, de cartes à la fois en

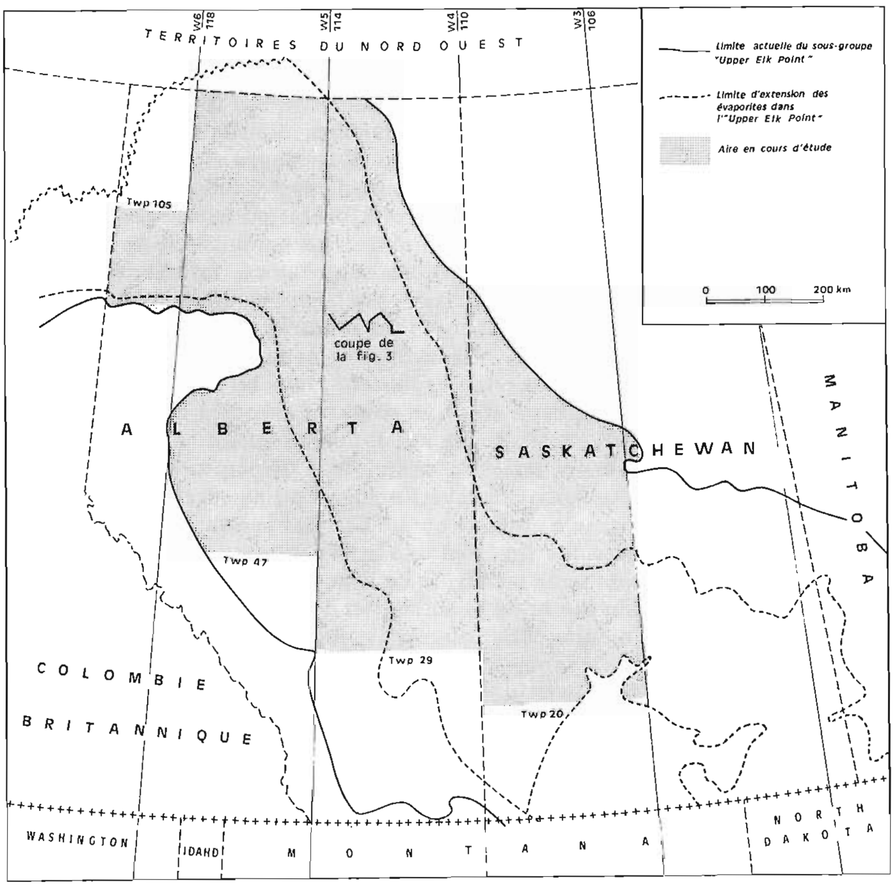

Figure 1. Localisation géographique de la zone en cours d'étude (en grisé). Les limites du sous-groupe Upper Elk Point et des évaporites qu'il comporte ont été tracées d'après la fig. 5.5 (p. 53) de l'Atlas: "Geological History of Western Canada" (R.G. McCrossan et R.P. Glaister, 1964).

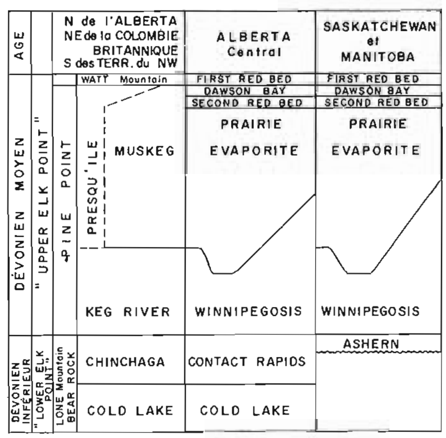

Figure 2. Nomenclature du groupe "Elk Point" d'après la fig. 5.1 (p. 50) de "Geological History of Western Canada". Seul l'"Upper Elk Point" fait l'objet de l'étude présentée ici.

isopaques et en faciès: cartes qui constituent les fondements de l'interprétation des paléogéographies et des environnements successifs. De plus cette réinterprétation des diagraphies, les coupes et les cartes qui en seront issues, permettront la localisation immédiate des carottes dont l'examen s'avérera capital, soit pour préciser le faciès de tel ou tel domaine, soit, au contraire, au passage entre deux domaines différents pour préciser les modalités du passage de faciès.

LES RESULTATS

L'état d'avancement de l'étude ne permet que d'évoquer certains des résultats qui peuvent être escomptés.

1) Rapports entre carbonates et évaporites. Dans le monde entier, de nombreux grands bassins, souvent d'intérêt économique considérable, montrent la même coexistence de constructions carbonatées (réellement récifales ou non) et d'importants dépôts évaporitiques. Les relations chronologiques entre le dépôt des uns et des autres constituent toujours un problème difficile et très controversé. En Alberta septentrional, où l'étude est la plus avancée, il apparaît que deux dispositions différentes existent suivant les points considérés. Dans un premier cas, *il n'y a pas antériorité* complète des édifices carbonatés par rapport aux évaporites déposées entre ces édifices. Il s'est simplement déposé des carbonates sur certains sites donnés, alors que se déposaient des évaporites entre ces sites: carbonates et évaporites sont simplement séparés par un passage de faciès. Dans le second cas, il y a au contraire antériorité manifeste des constructions carbonatées par rapport au remplissage évaporitique qui les sépare. L'exemple de certains récifs authentiquement construits en tant que tels, puis ennoyés dans le sel est classique dans la région de Rainbow. J'illustre ci-joint (fig. 3) un cas différent. Les faciès carbonatés de base ici nommés Keg River (KR) sont surmontés des évaporites du Muskeg (Mu). Le Keg River, d'abord isopaque sur la *plateforme* de l'ouest, s'amincit beaucoup vers l'est (originellement et non pas sous l'effet d'un passage de faciès) dans une zone où la subsidence est largement plus forte ("fosse"); au-dessus apparaît une lentille de sel (A) très pur, elle-même surmontée d'une succession très homogène et très régulière sur toute la coupe. Il semble que les phénomènes aient été les suivants: individualisation à l'W d'une plateforme où l'élaboration carbonatée a pu combler la subsidence au fur et à mesure et à l'E d'une "fosse", très légèrement plus subsidente dès le début, et où, de ce fait, la construction carbonatée (organismes benthiques, photosynthèse algaire) a dû être gênée; la profondeur d'eau n'a donc fait que s'accroître dans cette fosse, par un mécanisme d'autoaggravation irréversible. On peut penser que l'eau "profonde" de la fosse était euxinique et n'admettait qu'une infime sédimentation planctonique élaborée dans la tranche d'eau supérieure. A la fin du dépôt des carbonates, la plateforme devait toujours être aux alentours de la cote O, tandis que la fosse présentait une profondeur de plusieurs dizaines de pieds. Cet intervalle s'est alors trouvé comblé par le dépôt, vraisemblablement rapide, de sel gemme quasiment pur. Le domaine, ainsi totalement nivelé, a vu le démarrage et l'installation d'une sédimentation uniforme.

2) La ségrégation très lente et très progressive des faciès. Un certain nombre des cartes établies pour les unités stratigraphiques montrent: i) par leurs isopaques, la régularité et l'homogénéité de la subsidence et ii) par leur expression des constituants lithologiques, l'extrême progressivité du passage des carbonates à l'anhydrite, puis de l'anhydrite au sel, etc. Ces résultats qui demandent encore à être précisés, militent du point de vue de la genèse des évaporites, en faveur de processus hydrodynamiques sur une plateforme (Busson, 1968, 1972), plutôt qu'en faveur d'une interprétation invoquant de façon exclusive le jeu d'une barrière récifale, éventuellement d'une barrière récifale à l'amont de laquelle se serait produit un assèchement plus ou moins total (Maiklem, 1971).

3) Les laminites. Parmi les nombreux faciès dont il importe i) de préciser la situation, verticale et horizontale, dans le bassin et ii) d'étudier la nature pétrographique la plus fine, je ne citerai que les roches carbonatées, souvent riches en matière organique, à très fine lamination planparallele. Ce faciès, naguère interprété de façon totalement erronée, a déjà fait l'objet d'études locales (Daves et Ludlam, 1971), ou plus générales (Busson et Noel, 1972). La connaissance des conditions d'élaboration des laminites (nécessité de la superposition au moment de la sédimentation de deux corps d'eau aux caractéristiques différentes) et de la signification bathymétrique qu'elles impliquent, confèrent à ce faciès une importance non négligeable. Ces laminites carbonatées aident à préciser l'interprétation des évaporites qui, dans de si nombreux cas, leur ont fait suite immédiatement.

4) Les différentes couches de sel. Sur la coupe ci-jointe (fig. 3), les évaporites du Musket sont surtout constituées de sel et secondairement d'anhydrite. Dans l'aire très limitée couverte par cette coupe, il n'est pas possible d'étudier le passage de cette succession à celle du domaine anhydritique, puis carbonaté. Par contre on pourra noter le contraste entre la première couche de sel (A), en général très pure, et les couches suivantes (C, D, etc.) qui présentent toujours des intercalations d'anhydrite et parfois de dolomie. A plus grande échelle ce contraste coincide avec une autre différence. Les isopaques du sel A montrent des variations *rapides* et *importantes* d'épaisseur; c'est à dire que le sel A se présente comme une formation de remplissage de fosse (bassin "affamé" des auteurs). Au contraire les formations salifères suivantes montrent des variations d'épaisseurs *régionales, lentes* et *régulières*. Elles se présentent comme des couches ou des nappes qui ont recouvert d'immenses régions, sur une épaisseur infime eu égard à leur aire d'extension. Notons au passage que cette régularité de l'évolution des épaisseurs ne donne pas à penser que les phénomènes de dissolution du sel ont eu une grande importance dans la région en question, à l'inverse de ce qui a été signalé autour des champs de Rainbow. Par ailleurs, cette succession d'un sel de fosse, pur, puis de sel de nappes, plus impur et de signification bathymétrique peut-être différente, n'est

pas propre au seul bassin de l'Upper Elk Point, mais pourra être retrouvée dans bien d'autres bassins évaporitiques.

CONCLUSIONS

Le bassin de l'Upper Elk Point fournit un exemple particulièrement précieux pour l'étude des mécanismes de la sédimentation, grâce à une chaîne de faciès allant des franges continentales aux dépôts marins francs et épais et en passant par une ségrégation et un étalement à l'échelle géographique des sels marins successifs. On peut espérer qu'il y sera possible, moins difficilement qu'ailleurs, de débrouiller ce qui revient aux différents facteurs (morphologiques et bathymétriques, hydrodynamiques) habituellement envisagés dans le contrôle de la sédimentation.

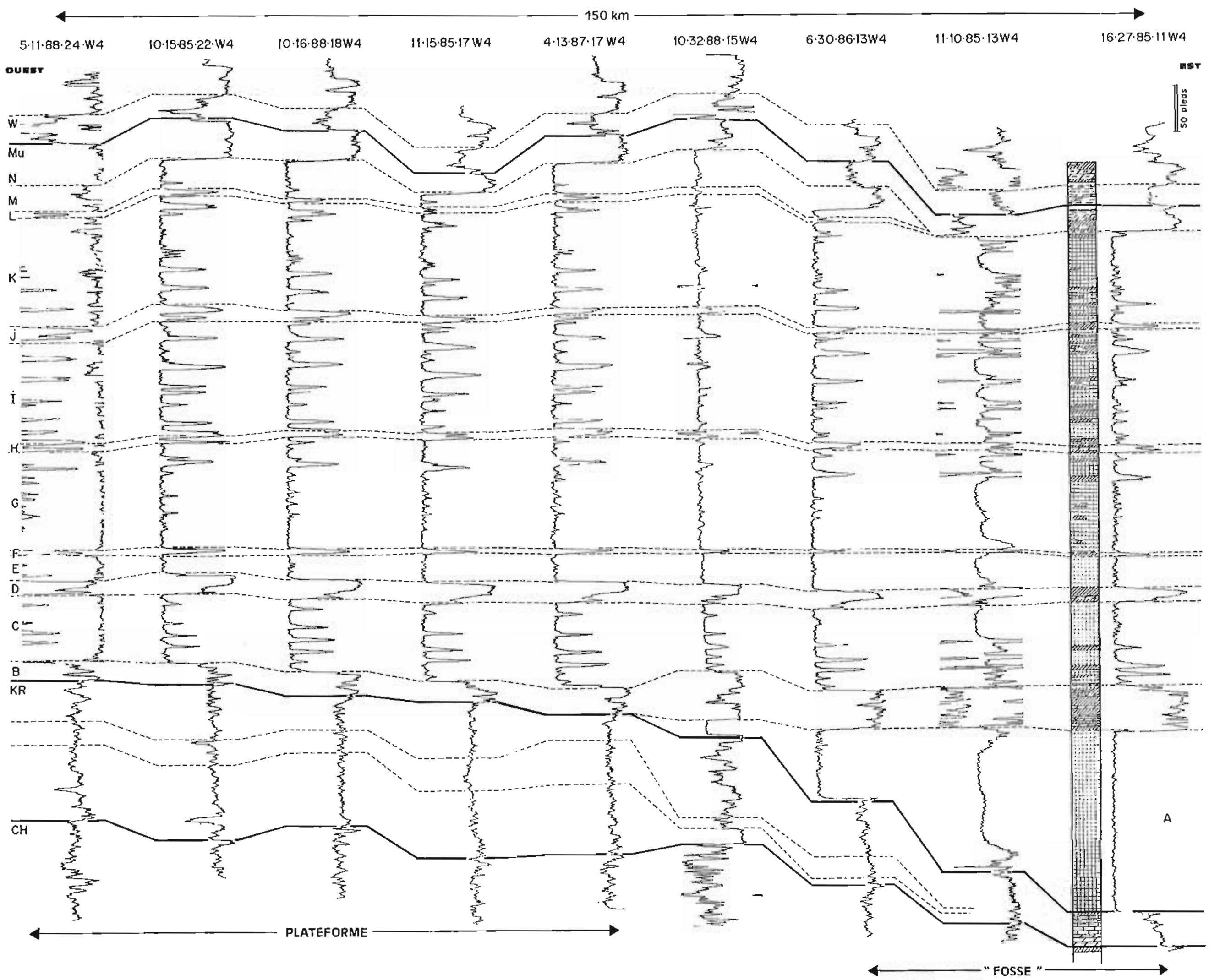

Figure 3. Coupe basée sur des logs "density" (sauf 10. 32. 88. 15W4: Sonic) en Alberta septentrional, avec colonne lithologique pour un des puits figurés.

CH: Chinchaga, formation sous-jacente à l'Upper Elk Point;

KR: Keg River, faciès carbonatés de la base de l'Upper Elk Point;

Mu: Muskeg, surtout évaporitique;

W: Watt Mountain, avec intercalations argileuses, terminant l'Upper Elk Point.

On remarquera:

1. La qualité et la précision des corrélations possible sur une faible superficie ici, il est vrai, avec les seuls logs "density".
2. L'existence de cycles que met en évidence l'enveloppe des pics d'anhydrite au sein du sel, en particulier dans la moitié supérieure du Muskeg.
3. Le constrate entre le sel A, très pur, et les nappes salifères suivantes, toujours interstratifiées d'anhydrite et parfois de dolomie.

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NORTHEASTERN ELLESMERE ISLAND: LAKE HAZEN REGION AND JUDGE DALY PROMONTORY

Project 630003

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Introduction

About three weeks of field work was carried out on Judge Daly Promontory and in the Lake Hazen region of northern Ellesmere Island during August, 1973. This was a continuation of work done in 1965 and 1966 during 'Operation Grant Land' (see Christie, 1967) and extends mapping by J. Wm. Kerr in 1961 and 1962 (Kerr, 1967, 1968).

Judge Daly Promontory

A structurally conformable sequence of upper Precambrian and Paleozoic clastic and carbonate sedimentary rocks is well exposed on Judge Daly Promontory. Overlying the older sedimentary rocks with great angular unconformity are poorly consolidated Tertiary sandstone beds. The Paleozoic and older strata are folded into open structures while the Tertiary beds are relatively little disturbed. Major faults displace all formations. Faulting, probably along the major lineaments, also may have occurred before the deposition of Tertiary beds, thus accounting in part for the Tertiary basins.

Lower Paleozoic Beds

Ellesmere Group: The oldest rocks in the map-area are those of the Ellesmere Group (Kerr, 1967). These are mainly dark grey quartzites and phyllite, weathering dark grey to dark brown. A white quartzite unit is exposed in the core of the large anticline south of Cape Baird and along the seacoast south of the mouth of Daly River. Elsewhere, the quartzites appear to be impure, dark green-grey, and phyllitic. Load casts and other 'bottom' features suggest a flysch-type, basinal environment for these beds.

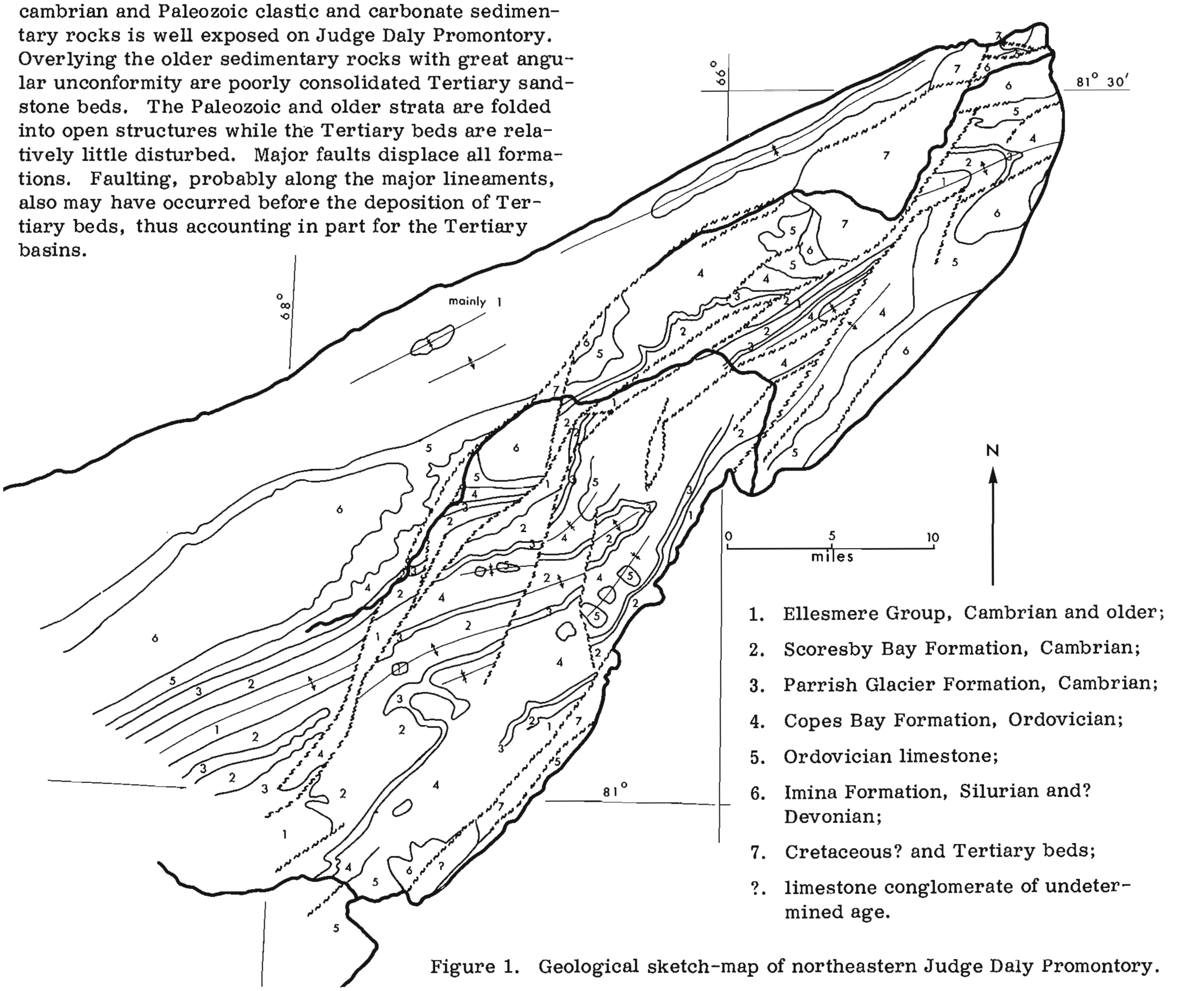

Figure 1. Geological sketch-map of northeastern Judge Daly Promontory.

Much of the uniformly folded terrane south of Archer Fiord (the 'Archer Fiord Terrane'; see Christie, 1964) may be assigned to the Ellesmere Group; lower beds include impure, dark grey quartzitic sandstone and black, calcareous argillite or argillaceous greywacke. The argillaceous beds, when weathered, have a distinctive coating of white, efflorescent salts.

Scoresby Bay Formation: Overlying the quartzite beds with apparent structural conformity is the Scoresby Bay Formation (Kerr, 1967), a carbonate unit comprising dark to light grey, well-bedded limestone. Characteristic of the lighter rocks are coarse, sugary textures and breccia or pseudobreccia structures with abundant 'sparry' white carbonate mineral. The darker rocks are mainly mottled, blue-black limy dolomite with lighter tubules and amoeboid carbonate patches.

Parrish Glacier Formation: The Parrish Glacier Formation (Kerr, 1967) conformably overlies the Scoresby Bay Formation. This unit comprises mainly light yellow to orange-weathering limestone with some dark brown weathering beds and two intervals of distinctive, pink-weathering shaly limestone. The Parrish Glacier Formation makes an excellent marker unit for mapping purposes. It appears to thin eastward or southeastward from about 1, 500 feet to 500 feet.

Middle Paleozoic Beds

Copes Bay Formation: The Copes Bay Formation (Kerr, 1968), composed mainly of light grey weathering limestone, conformably overlies the Parrish Glacier Formation. Some dark grey weathering beds are present, and the lower part of the unit is distincly banded, the well-bedded carbonate rocks weathering alternately light yellow and grey or dark grey when well exposed in cliff faces.

The unit is about 2, 500 feet thick at a measured section in the central part of the promontory.

'Ordovician Limestone' Unit: Conformably overlying the Copes Bay Formation are thick-bedded, competent limestones weathering dark grey to brownish grey. This unit probably includes both the Eleanor River Formation and the Cornwallis Group (see Kerr, 1968).

A gypsiferous member, about 400 feet thick, is included with thick-bedded carbonates in sea-cliffs north of Carl Ritter Bay; these probably are Bay Fiord Formation (of the Cornwallis Group). Gypsum beds were not observed in other parts of the region studied; evidently the gypsum-anhydrite unit observed is a northeasterly extension of the narrow anhydrite belt described by Kerr (1968, Fig. 9, p. 37).

Upper Paleozoic Beds

Imina Formation: Impure limy sandstone or greywacke beds of the Imina Formation (see Trettin, 1971) conformably overlie the 'Ordovician mottled limestone' unit. These are the flysch beds formerly included in the reconnaissance unit, the 'Cape Rawson Group'. These rocks occur in widely scattered but limited areas, and are generally poorly exposed. Graptolites were obtained near the base of a section about 8 miles south of Cape Baird.

Tertiary Beds

Tertiary beds were not examined in detail in 1973, although areas underlain by these beds were delineated. Poorly cemented shales and impure sandstones with woody and coaly material form a narrow, topographically low belt trending northeast from the head of Carl Ritter Bay. Coarse conglomerate in the same belt exposed immediately northeast of Carl Ritter Bay is of uncertain age; from structural or areal association it seems Tertiary in age but from its lithological character – well indurated, mainly limestone clasts in a sandy matrix – it may be of pre-Tertiary, perhaps Devonian, age.

Structure

Two structural features dominate northeastern Judge Daly Promontory: northeast-trending folds of large wave-length; and strong faults of north-northeast to northeast trend that transect the bedded rocks. The folds tend to be tight or near-isoclinal in the northwestern part of the promontory, and broad and open to the southeast. Some folds are box-shaped: large axial areas of gentle dips with steep to vertical flanks. Certain faults – especially those very oblique or parallel to the regional structure – form conspicuous lineaments. None of the faults seem to have displaced major structure more than a few miles. The strongest lineament of the promontory is that trending southwestward from Cape Baird, about parallel with Kennedy Channel. The Tertiary belt northeast of Carl Ritter Bay is bounded by faults and is obviously an extension of this lineament.

Lake Hazen Region

Field work in the Lake Hazen region was carried out as opportunity allowed from the 1963 base camp (reoccupied in 1973) at 'Amber Point' near the mouth of Gilman River. Numerous scattered, small outliers of Tertiary beds were identified on the uplands of folded Paleozoic rocks south of Lake Hazen. Debris probably derived from the outliers was discovered by A.W. Greely in 1882 (Greely, 1886, v. I, p. 373) and some outcrops were visited in 1966, but it had not been realized how numerous and widely scattered are these tiny patches of Tertiary rocks. Most outliers, usually isolated knolls, comprise white sand beds with interbedded coal or coaly shale. Petrified wood, including logs up to 200 inches in diameter, is present in some outliers.

The upper beds of the Tertiary section northeast of Lake Hazen, exposed in the western 'boulder gravel hills' (see Christie, 1964, p. 28; 1967, p. 14-16) were measured. About 1, 100 feet of section is exposed; the nearly flat lying beds are mainly unconsolidated to poorly lithified fine to coarse sand and sandy mud. Numerous interbeds of coal and coaly shale are present. The uppermost 450 feet of section are coarse boulder conglomerate, the boulders well-rounded and up to 200 inches in diameter. Permo-Carboniferous and lower Paleozoic carbonate rocks and diabase seem well represented. A few thin beds of sand and coaly shale occur about in the middle of the conglomerate beds.

The boulder beds probably represent a final phase of Tertiary sedimentation and may mark the important tectonic episode responsible for the rise of the Grantland Mountains to the northwest.

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LOWER AND MIDDLE PALEOZOIC BIOSTRATIGRAPHY, GASPE, QUEBEC, AND MARITIME REGION

Project 690006

W. T. Dean
Regional and Economic Geology Division

Field work was continued on the Lower Paleozoic, particularly Cambrian and Ordovician, rocks of Newfoundland. In the east, studies on the Clarenville Formation at Random Island indicate that no Ordovician strata younger than Tremadoc Series are present, and that the predominantly trilobites, which include abundant Parabolinella together with Niobella and Beltella?, exhibit affinities with contemporaneous faunas in South America and the Anglo-Welsh area.

At New World Island, north-central Newfoundland, collecting was continued as part of a long-term project aimed at elucidating the stratigraphy of the local Ordovician rocks and the affinities of their shelly faunas. Recently-published researches on the brachiopods of the Summerford Group suggest that during much of Ordovician time the area was the site of volcanic islands, each of which may have been surrounded by its own individual marine fauna. Work on the trilobites has not yet fully confirmed this hypothesis, but certainly some geographically discrete faunas of approximately similar age within the Lower Ordovician display differences in generic composition. Descriptions of some of the trilobites are now in press but further work is needed to test the validity of the apparent faunal differences.

During part of the summer, field work was carried out in the Taurus Mountains of southern Turkey in collaboration with geologists from Université de Paris-Sud, a project initially undertaken as part of a France-Canada cultural exchange program. Work was directed particularly to the Lower Paleozoic stratigraphy and faunas of the Taurus and the results will form part of a wider study aimed at assessing the distribution and affinities of Cambrian and Ordovician faunas in the Mediterranean region and Middle East, and their relationship to corresponding faunas in easternmost Canada and U. S. A. It is known that certain early Paleozoic rock types and faunas have an extensive lateral distribution from Florida through New England and the Maritimes to the eastern Mediterranean or beyond, and their study is relevant to theories concerning the relative position of Gondwanaland and other continental masses during Cambro-Ordovician times.

Project 730054

L. D. Dyke[1]
Institute of Sedimentary and Petroleum Geology

In continuing a study of uplifts in northern Yukon Territory, Barn Uplift was examined for four weeks during the 1973 field season under the supervision of D. K. Norris. Together with Romanzof, Campbell and White Uplifts, Barn Uplift exhibits great structural relief in a relatively small area. These structures were outlined during Operation Porcupine in 1962 (Norris, D. K. et al., 1963) and may well represent extreme cases of possible, less strongly expressed counterparts in northern Yukon and adjacent Beaufort Sea. The likelihood of associated structural closure and updip truncation of strata overlying uplift cores would made such counterparts prime targets for hydrocarbon exploration.

Mapping, with a view to final compilation on a scale of 1: 50, 000, was carried out by means of a series of stratigraphic traverses and measured sections. The accompanying sketch map (Fig. 1) covers an area slightly greater than that mapped, indicating the extent of extrapolation at the 1: 50, 000 scale. Structural fabric, as well as being revealed by mapping, was sampled at the mesoscopic scale and oriented specimens were collected for microscopic fabric examination. Access to information on Triassic outcrop localities from Triad Oil Company is gratefully acknowledged.

Barn Uplift is located between British and Richardson Mountains, 120 miles (190 km) almost due west of Inuvik. That part having greatest structural as well as topographic relief is roughly oval in outline and elongate in the north-south direction. On the map this is the lightest stippled area. Somewhat less topographic and, probably, less structural relief is shown by an eastward-protruding lobe roughly centred around Mount Fitton. Together these form the core of the uplift which is fault bounded on the north and east sides, the whole being roughly 16 miles (26 km) long and 12 miles (20 km) wide.

Stratigraphic Setting

The core of the uplift has a thickness of 10, 000 feet and is composed dominantly of chert and slaty argillite interspersed with minor amounts of limestone and quartzite (see Fig. 2). In all probability a much greater thickness is present, very likely close to 20, 000 feet. The existence of fault repetitions and fault-bounded blocks together with a scarcity of paleontological control makes a more accurate figure difficult to achieve.

Chert intervals are composed of either medium to dark grey to green-weathering beds, generally one inch to one foot thick, showing slightly undulating bedding surfaces and faint laminations or in olive-grey to olive-brown weathering beds, generally one inch thick or less and very well bedded. The well-bedded units contain, in places, partly argillaceous intervals weathering to lighter shades. These commonly grade into olive-brown weathering slaty argillites, moderately to extremely fissile and rarely containing a cleavage. There are few intervals, up to 600 feet thick, of fissile slaty shales containing interbeds of quartzite or argillaceous siltstone up to ten feet thick, with bedding surfaces in the quartzite often showing load casts. These intervals, combined with distinctive beds immediately above and below, were used in conjunction with available fossil control as marker beds to identify fault repetitions. A few 100- to 200-foot-thick intervals of limestone and quartzite complete the major rock types. The limestone is commonly in beds less than a foot thick, is finely crystalline and generally shows fine laminations and crossbedding. Rarely seen are beds composed of lime mud-chip clasts. The quartzite tends to be massive and usually medium- to fine-grained, rarely conglomeratic.

The true stratigraphic relationship of these rock types is obscured by deformation. However, graptolite dates (Martin, 1959, p. 2414; Norford, 1964, p. 137; Lenz and Perry, 1972, p. 1131) together with interpreted fault repetitions suggest that the more massively bedded chert units and the argillites dominate the lower third of the succession. These are thought to be overlain by increasing amounts of argillite and thin-bedded chert together with the quartzite and limestone. Though less well exposed, the eastward-protruding lobe seems to be composed mainly of dark bluish grey weathering slaty shale and dark grey chert with lesser amounts of limestone. This component is thought to comprise the youngest strata of the core succession because of its position to the east of a group of related, steeply west-dipping reverse faults. The graptolites have yielded Early Ordovician through Late Silurian dates for the core succession.

A Devonian or earlier age for rocks of the core is suggested also by radiometric dating of one of two granitic stocks outcropping on the east side of the core (Wanless et al., 1965, p. 22-23). Though precise contact relationships are obscured, the age relations suggest that the granite intrudes the core rocks. Contact metamorphic effects are most pronounced about the more northerly and smaller of the two stocks where slaty argillites and quartzites weather bright orange-red and a skarn exists containing some pyrite and sphalerite; wolframite occurs in quartz veins further away.

These age indications and, to a lesser extent, the observed lithologies, suggest equivalence of the core rocks to the Road River Formation. The core succession seems distinct from the very thick intervals of lithic sandstone and slaty argillite along with smaller

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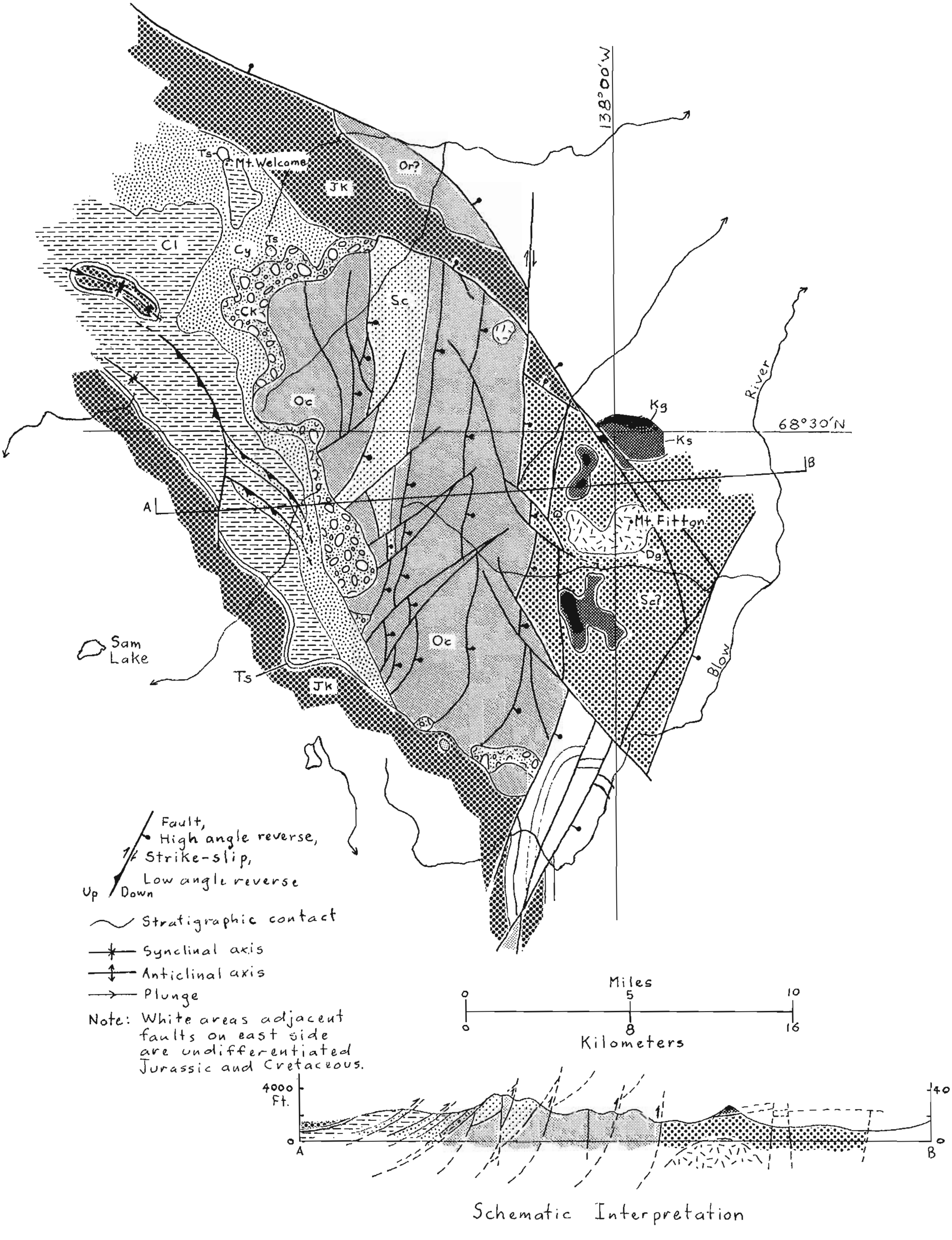
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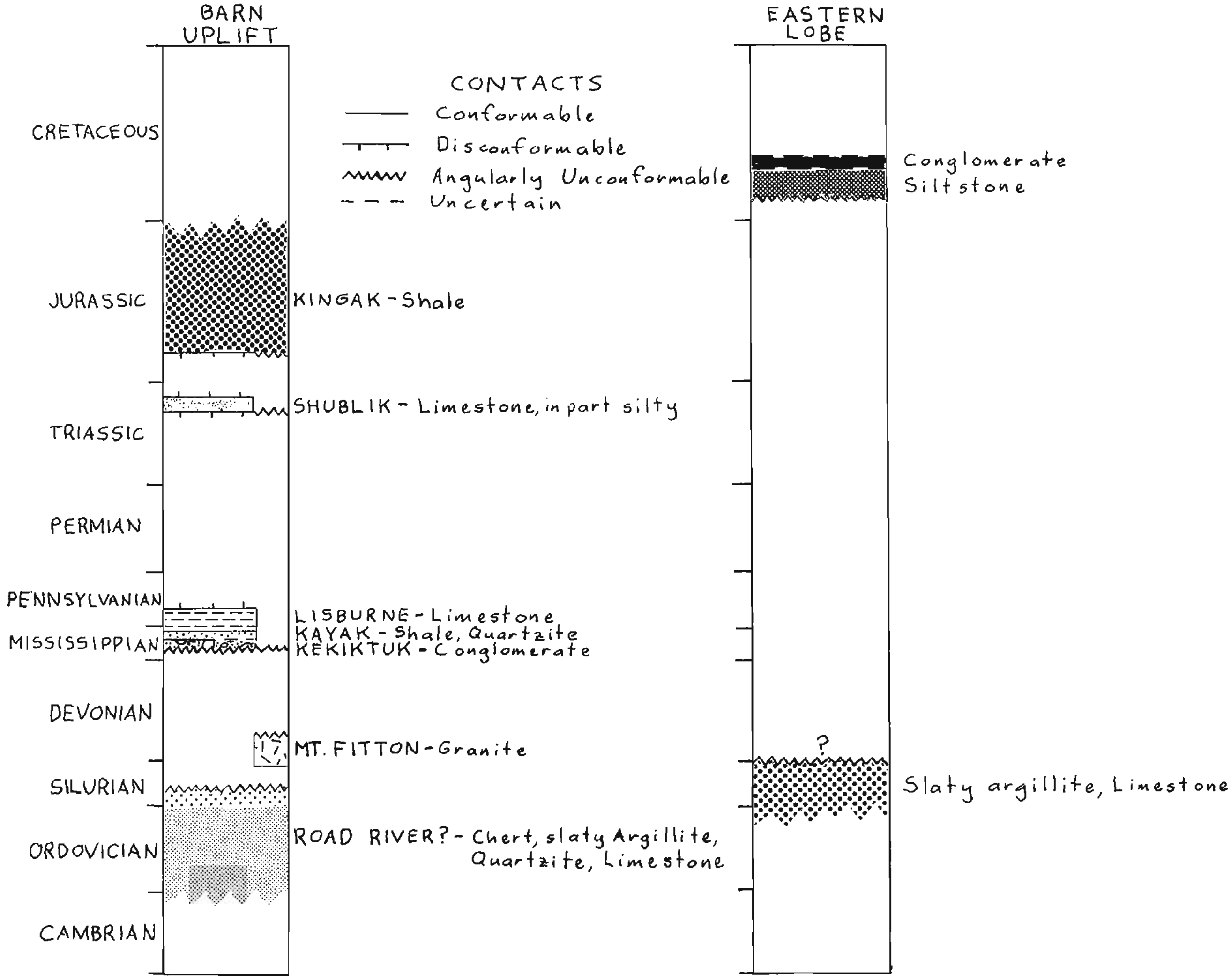

Figure 2. Stratigraphic relations in Barn Uplift.

thicknesses of chert and limestone characterizing the Neruokpuk Formation in British Mountains. There, the Neruokpuk locally is overlain unconformably by Cambrian agglomerates (Norris, D.K., 1972). The slightly metamorphosed nature of the core succession in Barn Uplift suggests assignment to the Neruokpuk but similar lithologies identified as Road River may be seen in Nash Creek Map-Area in Wernecke Mountains (Green and Roddick, 1962).

Mississippian and Pennsylvanian rocks overlie unconformably core rocks on the west flank (Bamber and Waterhouse, 1971). beginning with the predominantly chert-pebble Kekiktuk conglomerate. At one place where this contact is well exposed, clast size in the conglomerate dramatically increases towards it, pointing to some local derivation. The dominantly quartzite and chert lithologies of the clasts make cone-type

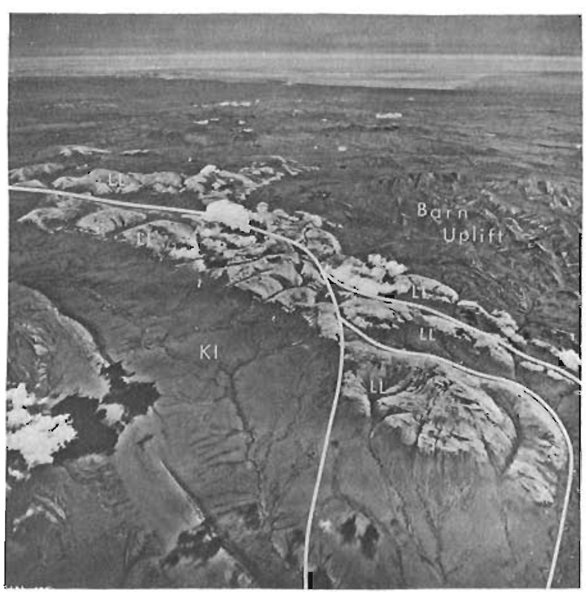

Figure 3.

Mississippian Lisburne Group (LL) repeated by thrust faulting on the west flank of Barn Uplift and overstepped by Shublik, Kingak and younger undifferentiated Mesozoic rocks on the north flank of the uplift. View looking northeast. NAPL Oblique Photo T13L-105 (after Norris, 1973, Fig. 5).

rocks a likely source. A late stage of the Ellesmerian Orogeny is probably represented.

The Kekiktuk is overlain in turn by shales and quartzites of the Kayak Formation and limestone of the Lisburne Group. Kekiktuk and Kayak strata also are seen on a small structural high a few miles southeast of the uplift (not shown in Fig. 1). There they unconformably overlie slaty argillites and limestones that are probably related, stratigraphically at least, to the core rocks of Barn Uplift. This suggests a possible blanketing of the uplift area by part of the Carboniferous succession which, later, was overstepped in turn by shale and limestone of the Upper Triassic Shublik Formation and shale of the Jurassic Kingak Formation (Norris, D. K., 1973), as illustrated on the northwest and southwest flanks of the uplift (see Fig. 3).

The presence of Lower Cretaceous siltstones and chert-quartzite pebble conglomerates (Young, 1973) overlying core rock of the eastern lobe suggests that this part had undergone some uplift prior to the Laramide because of the absence of the intervening strata present elsewhere. Moreover, some of the conglomerate may have been derived from re-unroofing of the core rocks during this earlier tectonic event. Laramide deformation was more severe, resulting in faulting of the conglomerate as well as continued uplift of the core rocks.

Structural Setting

On the west flank of Barn Uplift, strata structurally conformable with the core form a northwestward continuation to the uplift. They are important because they exhibit effects of the Laramide Orogeny, the stage of deformation that probably brought the uplift to its present configuration. However, they are subordinate in terms of structural relief to the more complexly deformed core. They display a northwesterly-trending structural grain parallel with that of the southeastern Romanzof Uplift. The uplift separates this trend from the northerly one shown on the east flank, subparallel with that seen in the Richardson Mountains and components of Aklavik Arch.

Closer examination of the core reveals a division into two parts according to the superposition of deformation from at least two orogenies. The structural fabric of the western two thirds of the core, dominated by steeply west-dipping reverse faults, is truncated by bounding faults or by the flanking Carboniferous strata, indicating a possible Late Devonian (Ellesmerian) age for this fabric. The block-forming faults and bounding faults of the eastern lobe cut the Cretaceous clastics, indicating Laramide activity. However, the clastics are only moderately folded. They have been protected perhaps by the low internal response to later deformation of the core, and have suffered only minor rotation of the fault-bounded blocks. Within the rest of the core little further internal deformation is indicated. It does appear, however, to have experienced some translation, perhaps concordantly with the west flank, and rotation, probably about a north-south or northwest-southeast axis.

Because of the difficulty in establishing the distribution of pre-Devonian strata, the magnitude of discordancy about the core and type of deformation interpreted within it retain an element of uncertainty. However, some general observations can be made that help clarify the nature of the aspects in doubt above.

Predominantly westward dips within the core give it an asymmetric appearance which is complemented by shallow westward dips in the Carboniferous strata of the west flank (see Fig. 3). Dips in the Kekiktuk conglomerate are generally away from the core, seldom exceeding 30 degrees. At the south end of the core, a band of the conglomerate fills what seems to be a narrow trough running across the structural grain. This, together with a few remnants of core rocks surrounded by conglomerate, suggests expression of the original depositional surface of the Kekiktuk on the core rocks. At one place on the southwest flank probable Kayak strata seem to display this relationship. Some post-Ellesmerian internal deformation of the core is indicated by the presence of a few steep dips in the conglomerate of the trough.

Outlining the extent to which the core is fault bounded involves determination of the contact relations with the Kingak. On the south end of the core the Kingak oversteps the Mississippian and Upper Triassic strata to lie with probable angular unconformity on core rocks, with a moderate dip away from the uplift. The truncation of core fabric seems much more abrupt on the north end and is thought to be caused by a high-angle reverse fault contact with displacement dying out rapidly to the west. Somewhat greater displacement seems to be taken up by another high-angle reverse fault located slightly beyond the north end of the core. It brings Kingak and an inlier of core-type strata onto probable Cretaceous clastics. This fault appears to be offset along a major north-trending strike-slip fault that separates the eastern lobe from the rest of the core. Furthermore, some dip-slip motion is implied on this north-trending fault as the rest of the core has very likely been uplifted relative to the lobe along it. The reverse fault's continuation on the east side of this fault appears to accomplish decreasing stratigraphic separation. To the northwest, beyond the core, this reverse fault probably becomes one of the family of southeast-trending reverse faults in Romanzof Uplift. Together, movement along these two faults is responsible perhaps for much of the structural relief expressed as Barn Uplift. Translation and uplift of the core and enclosing rocks likely have been accomplished largely by them.

Kingak strata seem to be absent about the eastern lobe, suggesting, at first sight, that the lobe is completely in fault contact with younger clastics. That the lobe seems to have been involved in an Early Cretaceous period of deformation, as discussed earlier, allows its contact relations with the surrounding rocks to be different from those of the rest of the core. The Cretaceous conglomerates, etc., deposited on the lobe may well be in part structurally conformable with the surrounding Mesozoic clastics, and covering a fault that separates the core from older clastics at a deeper level. This relationship would apply to the northeast side of the lobe. The rest of its boundary on the east side is likely a fault. In short, the eastern lobe may be the centre of earlier expression of Barn Uplift with the larger western part of the core being formed during the Laramide.

A more thorough analysis of structural fabric will be necessary to determine the apportionment of deformation to the at least two orogenies responsible for these fabrics. The existence of deformation confined to pre-Mississippian strata is confirmed by the strong, truncated structural grain seen in similar rocks nearby the uplift and to the northwest in Romanzof Uplift (Norris, D.K., 1973). The core shows faults that offset the dominant north-trending fabric but which do not obviously cut younger strata. A family of northeast-trending vertical faults showing left-lateral separation cut the westernmost portion of the core (see Fig. 2). Similarly a family of northwest-trending faults with the left-lateral separation offset the central portion of the core. Both families seem to die out towards the centre of the uplift. The spatial relationship of the two families with respect to the core suggest that they are genetically and kinematically related to some stage of uplift. The northeast-trinding family is comple mented by a faint, parallel family of fractures visible on air photographs. The linearity of these together with offset of core strata by the larger faults imply a post-Ellesmerian development.

One member of the northwest-trending family seems to be bounding the southern end of the eastern lobe. Indirect evidence is that relatively resistant Jurassic units exposed in a faulted syncline against the south end of the core are not present where the hinge area should be.

Comparison of Barn and White Uplifts

Even greater structural relief is seen in White Uplift (Dyke, 1972) where a roughly rectangular core consisting of a thick sequence of lower and middle Paleozoic carbonate is in fault contact with Permian and Mesozoic clastic rocks. Situated 50 miles (80 km) southeast of Barn Uplift, White Uplift is one of a series along the trend of Aklavik Arch (Norris, D.K., 1973). Like Barn Uplift, the core of White Uplift is asymmetric, in the form of a faulted dome with a steeply dipping west side. The core, having no identifiable pre-Laramide structural fabric, appears to have been deformed totally during the Laramide, later undergoing slight dissection by two regional strike-slip faults. The core's boundary seems to have no relation to any pre-existing structural grain.

Barn Uplift, on the other hand, is bounded by structures having regional extent as well as direct connection with uplift. Also, the structure of the core may have influenced development of the uplift. The core is bounded on the north by a reverse fault that is parallel to those flanking the southwest side and others continuing towards British Mountains. Slight strike-slip dissection of Barn Uplift is evident on the fault separating the eastern lobe from the western part of the core. However, dip-slip motion that may have transferred greatest structural relief from the earlier-formed lobe to the western part of the core also is evident. It is possible that this fault was originally one of the family of high-angle reverse faults of the core, reactivated during the Laramide. Though obscure, the eastern boundary of the lobe may have had such a genesis but slightly earlier than the Laramide.

Speculations

White and Barn Uplifts may be outcomes of a very basic phenomenon, the influence of sedimentologically or tectonically formed bodies with restricted lateral extent on the positioning and style of deformation in an otherwise uniformly bedded sequence. In the case of White Uplift, the carbonates composing the core are represented in sections close by the south and east, and in the vicinity of Barn Uplift, by fine clastics. The coincidence of White Uplift with what seems to be a carbonate accumulation of local extent suggests that this geometry and lithologic contrast controlled deformation.

Though the evidence is far more speculative, Barn Uplift also may be related to the presence of a local lithologic contrast. In this case the original body is perhaps of tectonic origin. The core shows a probable Ellesmerian tectonic thickening, accomplished by repetitions on high-angle reverse faults of what may be already an abnormally thick Road River equivalent. That the suspected Road River equivalents of the core do seem comparatively thicker and more highly deformed than most other exposures of Road River in northern Yukon is suggestive of a relationship between the earlier tectonic thickening and later Laramide deformation when the core had its post-core rock covering. In both cases the features seen may be examples of the localization of deformation by lithologic contrasts of restricted areal extent. Such contrasts may take the form of sedimentological facies changes, thickness changes, tectonic thickenings or combinations of such features.

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CAMBRIAN BIOSTRATIGRAPHY, NORTHERN YUKON TERRITORY AND ADJACENT AREAS

Project 650024

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Regional and Economic Geology Division

Eight Cambrian sections were measured in the northern Yukon Territory, one in the District of Mackenzie, and outcrops were sampled near the Tatonduk River, Alaska. The work was done in conjunction with Operation Porcupine (see reports by Dyke, Macqueen and Norris, this publication). Figure 1 locates the Cambrian outcrops visited and summarizes the biostratigraphy.

The oldest Cambrian strata data in the region belong to the uppermost zone of the Lower Cambrian, the *Bonnia-Olenellus* Zone. At the site of five sections (locs. 1, 3, 7, 8 and 10), strata of this zone can be seen to directly overlie Precambrian Helikian strata, and at nearby outcrops (oral comm., D.K. Norris) the Cambrian overlies Precambrian Hadrynian strata. Different rock types below the Cambrian-Precambrian unconformity and an angular relationship at section 8 indicate tilting and deep erosion of the Precambrian strata before transgression of the Cambrian seas. The transgression must have been rapid and over a surface of low relief, as (1) no conglomerate and only a minor amount of sandstone was noted at the base of the Cambrian, (2) the oldest fossils belong to the same portion of the *Bonnia-Olenellus* Zone, and (3) the lowest unit, a siltstone unit, does not change appreciably in thickness composition over the study area.

The basal siltstone is similar in age and composition to the Adams Argillite exposed along the Tatonduk River in Alaska (loc. 9). There the Adams Argillite differs from the siltstone unit in Canada in having small

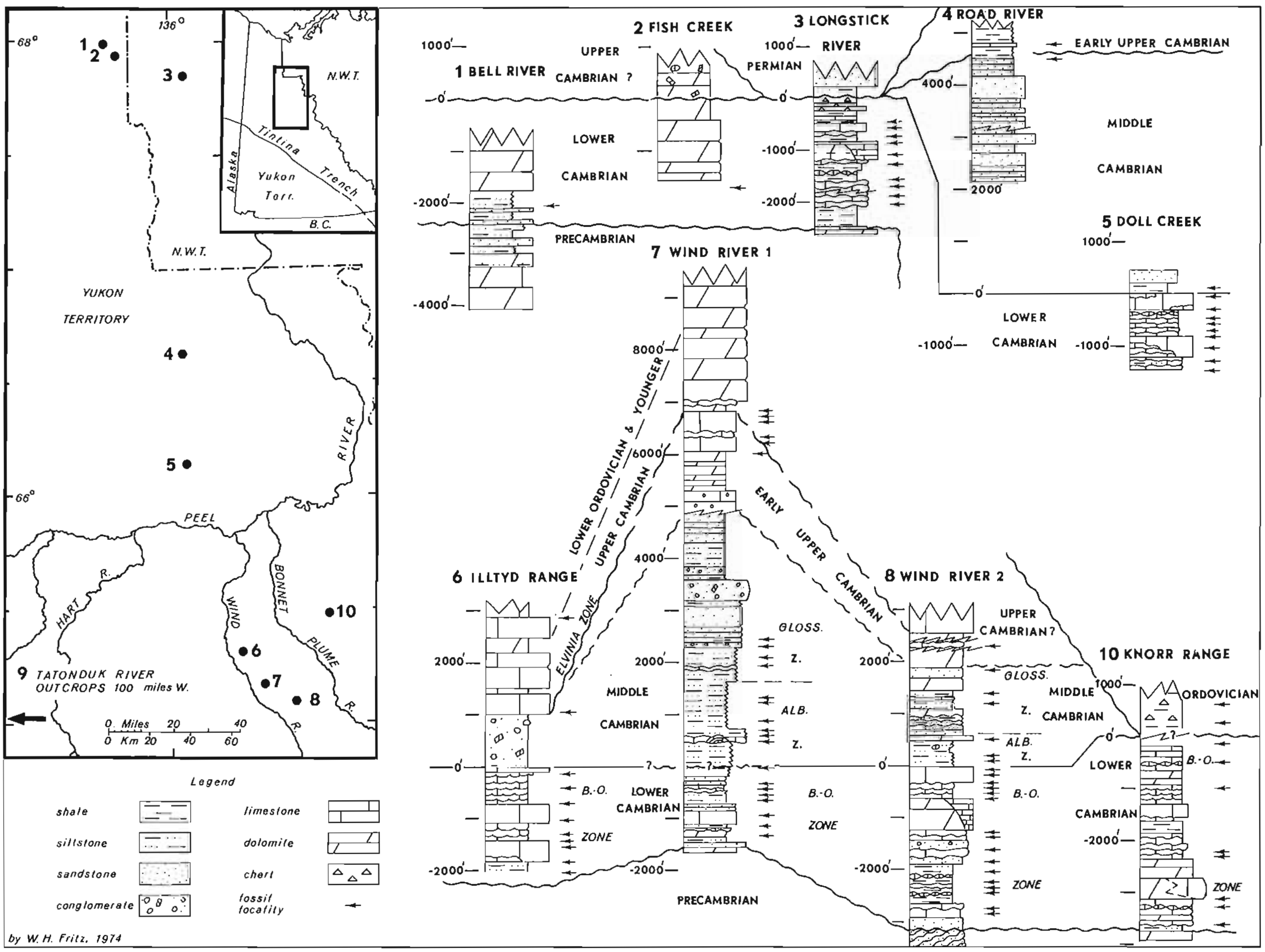
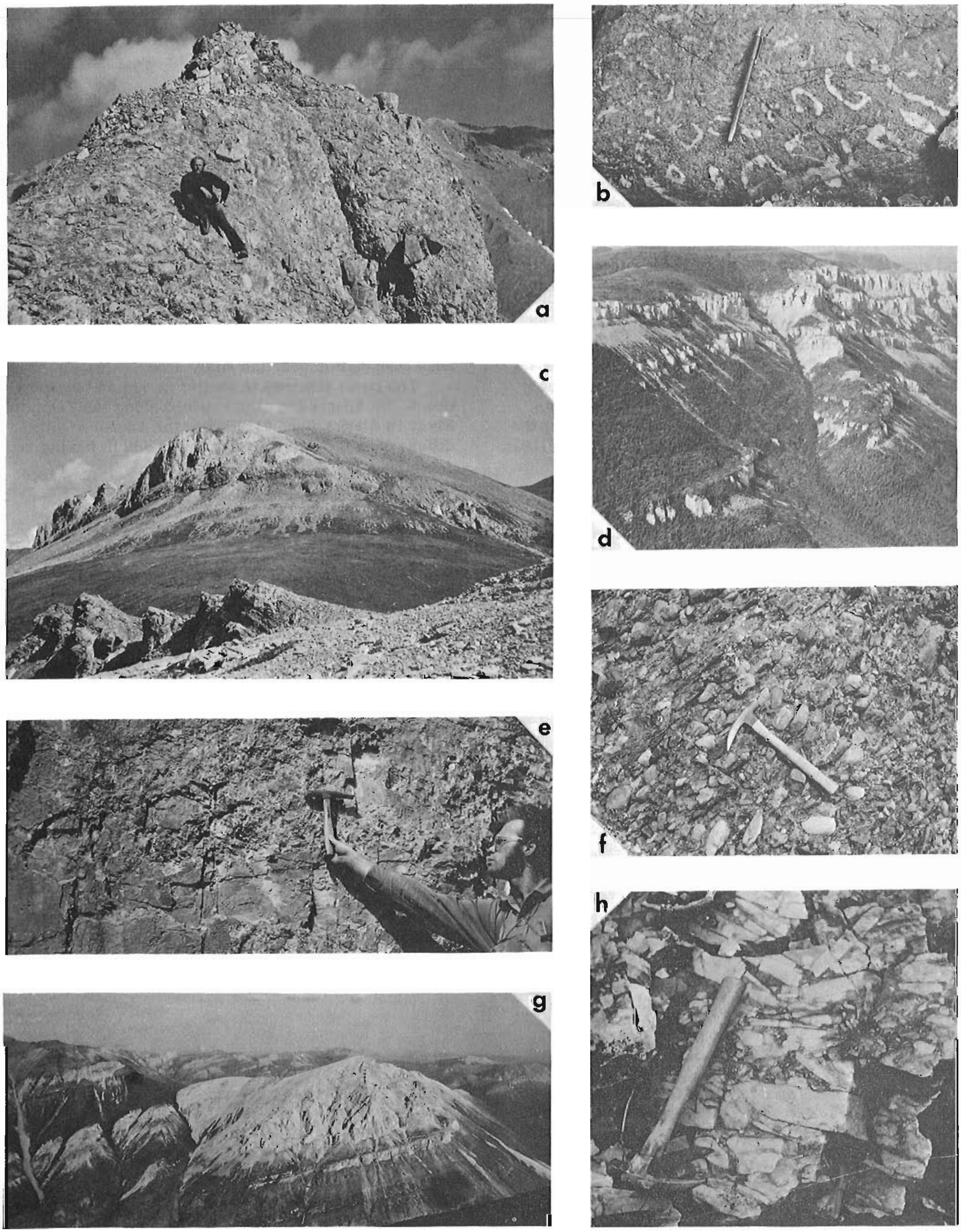


Figure 1. Cambrian stratigraphic sections, northern Yukon Territory and adjacent areas.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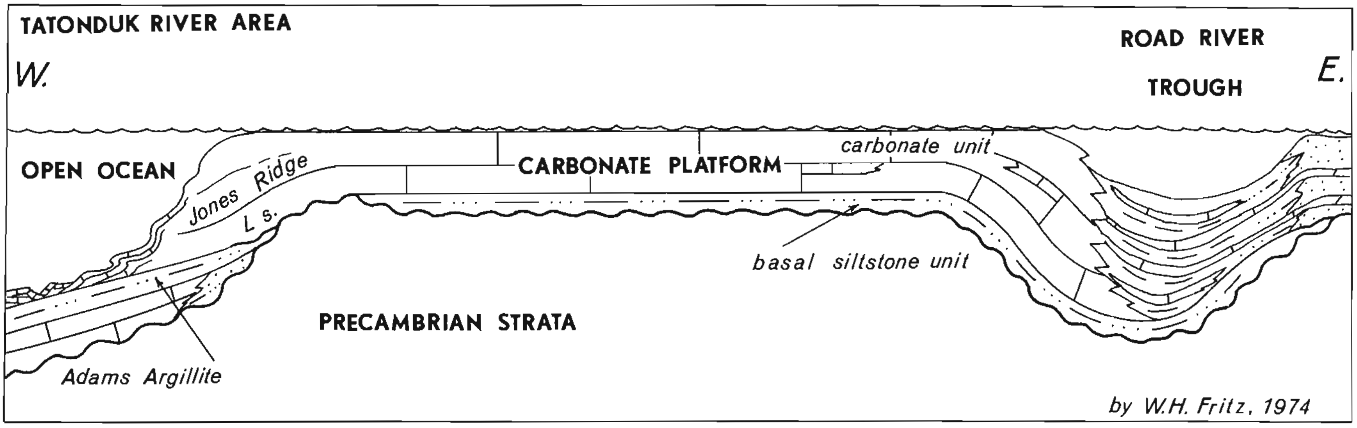

Figure 3. Diagramatic cross-section showing the distribution of Lower Cambrian strata at the end of Lower Cambrian time.

Figure 2. (opposite)

a) Upper Cambrian(?) carbonate breccia(?), Fish Creek section, locality 2 (GSC photo. 201307-C).

b) Archaeocyathids(?), Lower Cambrian carbonate unit, near Fish Creek section, locality 2 (GSC photo. 201307-B).

c) Lower Cambrian bioherm, carbonate unit, Longstick River section, locality 3 (GSC photo. 201307-G).

d) Castellate weathering of Lower Cambrian carbonate unit, Illtyd Range section, view north, locality 6 (GSC photo. 201307-M).

e) Pseudo-breccia, Upper Cambrian, Illtyd Range section, locality 6 (GSC photo. 201307-D).

f) Middle Cambrian conglomerate, Wind River 1 section, locality 7 (GSC photo. 201307-F).

g) Lower Cambrian bioherm, carbonate unit, ridge immediately northwest of Wind River 2 section, view northwest, near locality 8 (GSC photo. 201307-H).

h) Lower Cambrian limestone, interpreted as slump breccia by the writer, Hillard Limestone, Tatonduk River area, locality 9 (GSC photo. 201307-I).

archaeocyathid bioherms near the top. Unlike the siltstone unit in Canada, the Adams Argillite is underlain by a light grey limestone, the Funnel Creek Limestone, that was not seen among the Precambrian units underlying the Cambrian in adjacent Canada. Although no fossils are known from the Funnel Creek, Brabb (1967, p. 7) has placed the formation in the Lower Cambrian and sees no evidence for an unconformity between it and the overlying Adams Argillite.

Above the basal siltstone unit is a Lower Cambrian carbonate unit of variable composition. In the Illtyd Range (loc. 6) and near Doll Creek (loc. 5) thin-bedded limestone alternates with massive, cliff-forming limestone to produce a castellate topography on steep slopes (Fig. 2, d). Near the headwaters of the Bell River (loc. 1) and Fish Creek (loc. 2) is a uniform succession of thick-bedded dolomite that is tentatively assigned to the Lower Cambrian, and which probably correlates with the late Lower Cambrian carbonate unit. No fossils were found in the dolomite except for possible archaeocyathids (Fig. 2, b) located near the Fish Creek section in strata that can be projected into the lower portion of the dolomite succession.

East of the above mentioned localities, the carbonate unit near the headwaters of Longstick River (loc. 3), near the Wind River (loc. 8), and possibly in the Knorr Range (loc. 10) grades eastward into large bioherms that are up to 600 feet thick (Fig. 2, c, g). At the first locality a bioherm abruptly terminates against dark, platy limestone and shale, suggesting a trough to the east. The alignment of these bioherms, plus similar bioherms as far south as the headwaters of the Bonnet Plume River (S.L. Blusson, oral comm.) may mark the position of a late Lower Cambrian hinge line that separated clean carbonates to the west from trough deposits of dark, platy limestones and shales to the east. The lack of the carbonate unit at the Wind River 1 section (loc. 70) is attributed either to nondeposition or erosion during late Lower Cambrian time or to later erosion during early Middle Cambrian time.

Rocks belonging to the Middle Cambrian are predominantly siltstone and very fine sandstone, but locally these strata are displaced by thick conglomerates.

Diagnostic fossils found in these beds belong to the early Middle Cambrian *Albertella* and *Glossopleura* Zones. At the Road River and Doll Creek sections (locs. 4, 5) these strata are almost exclusively fine grained sandstone. They are underlain at the first locality by latest Lower Cambrian trilobites, and Upper Cambrian fossils of the *Cedaria-Crepicephalus* Zone were found several hundred feet above the sandstone at the second section. The long ranging sponge *Protospongia* was found in the basal sandstone beds and in beds immediately overlying this unit, but is of little present value in providing a more exact date for the sandstone deposition.

At the site of Wind River sections 1 and 2 (locs. 7, 8) the lower portion of the Middle Cambrian clastic succession consists of siltstone bearing fossils of the *Albertella* Zone. The lack of oldest Middle Cambrian fossils (*Plagirua-"Poliella"* Zone) is attributed either to an unconformity at the Lower-Middle Cambrian contact or to the presence of a thin zone in which fossils have yet to be found. Supporting the first concept is the already noted fact that the late Lower Cambrian carbonate unit is missing at the Wind River 1 section.

The upper half of the Middle Cambrian in the Wind River 1 section is composed of very fine grained sandstone and thick beds of conglomerate (Fig. 2, f). Fossils belonging to the *Glossopleura* Zone were found immediately below and within the lowest conglomerate layers. Almost all of the large clasts at the Wind River 1 section and at the Illtyd Range section are of rock types identical to those seen in the Precambrian Helikian strata nearby.

Upper Cambrian strata are probably separated from Middle Cambrian strata by an unconformity, but this is difficult to prove because of a lack of fossils and the presence of faults at critical horizons. Faults at the Wind River 1 and 2 sections could be mistaken for minor bedding faults as there is little or no repetition of beds. However, major folds associated with the fault at the first locality, and a tectonic sliver of fossiliferous Lower Cambrian strata within a fault zone separating Upper (?) Cambrian strata at the second, dictate caution in using what would otherwise be the best two sections to observe the Middle-Upper Cambrian boundary.

At the Wind River 1 section, fossils belonging to the early Upper Cambrian *Cedaria-Crepicephalus* Zone were found in the 1,120- to 1,900-foot interval above the fault. Directly overlying rocks in this interval are barren strata that are correlated with lithologically equivalent (?) strata in the Illtyd Range that contain fossils of the medial Upper Cambrian *Elvinia* Zone. If this correlation is correct, then the intermediate *Dunderbergia* Zone is missing in the Wind River 1 section either because of nondeposition or because of erosion below a sub-*Elvinia* Zone unconformity. In the Illtyd Range strata of the *Elvinia* Zone directly overlie Middle Cambrian conglomerates, so there can be no question that the sub-*Elvinia* unconformity exists and is at least of local importance.

The *Elvinia* Zone through Lower Ordovician strata exposed in the Illtyd Range consist of light grey limestone which locally weathers to a pseudo-breccia (Fig. 2e) that extends for several inches or more into the rock and is present at various horizons throughout the lower 870 feet of the unit. A correlation between this "breccia" and a more striking but unexplained breccia (?) (Fig. 2, a) at the top of the Fish Creek section is tempting, but the origin of the breccia-like structures need study in order to test their relationship.

A tentative interpretation of the present Lower Cambrian data is shown in Figure 3. The basal siltstone unit is believed to represent widespread, shallow water deposition after a rapid initial transgression over a surface of low relief. Throughout the remainder of Lower Cambrian time three environments may have existed. To the east is postulated a north-south trending trough that was semi-restricted (suggested from faunal content) from the ocean. This late Lower Cambrian trough may have been a precursor of the Upper Cambrian through Lower Devonian Road River trough as described by Lenz (1972). West of the trough, beginning with bioherms along its western hinge-line, are clean carbonates of the middle carbonate belt or platform. These carbonates are thought to have been removed by post-Lower Cambrian erosion in the Ogilvie Mountains, but their outer (seaward) edge is preserved in the light grey limestone of the Jones Ridge Formation near the Tatonduk River in Alaska. West of the carbonate bank the strata abruptly change from thick-bedded limestone to shale and thin-bedded limestone. The writer interprets the latter rocks as being slump deposits (Fig. 2h) that came to rest in waters much deeper than those covering the nearby bank. Fossils from the thin-bedded limestones are diverse (Palmer, 1968) and contain open marine types as contrasted to those of the semi-restricted trough to the east.

A Middle Cambrian environment of small, fast-filling basins separated by areas of uplift is suggested by an abundance of clastic sediment, numerous red siltstone interbeds, and rapid lateral changes in grain size. Coarse clastics in the Wind River 1 section suggest a source to the west in the western Wernecke Mountains and Ogilvie Mountains. Very fine sands in the Road River and Doll Creek sections indicate a northward movement as well. No appreciable amount of sand is recorded in Middle Cambrian strata to the west in the Tatonduk River area (Brabb, 1967).

Sparse Upper Cambrian fossil collections date a change from clastic deposition in the Middle Cambrian to carbonate deposition in the Upper Cambrian. Carbonate belonging to the *Cedaria-Crepicephalus* Zone in the Wind River 1 section is thought to have been deposited in shallow water. Numerous intervals exhibiting cyclic sedimentation are present in which a given cycle starts with thin-bedded limestone, is followed by orange weathering dolomitic limestone, and then by light coloured argillaceous limestone. Strata of the same age at the Road River section consist of dark shales and platy limestone that were probably deposited in deeper water.

Elvinia Zone through Lower Ordovician strata exposed in the Illtyd Range are composed of light grey limestone similar to that in the Jones Ridge Formation in Alaska which contains fossiliferous Upper Cambrian strata, and to that of the lower Vunta Formation that overlies the breccia (?) beds in the Fish Creek section (Norford, 1964, p. 10) and has yet to be dated with fossils. These clean limestones are interpreted as carbonate bank deposits, and the platy limestones considered to be slump-deposits that moved seaward off the bank.

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AN OCCURRENCE OF PALEOGENE SEDIMENTS IN THE OLD CROW STRUCTURAL DEPRESSION, NORTHERN YUKON TERRITORY

Projects 680068 and 690005

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Introduction and geology

Unconsolidated sediments are exposed on the left bank of Johnson Creek, near its headwaters on the east flank of the Old Crow Structural Depression. They occur at Longitude 138°18.8'W, Latitude 68°06.3'N, in the south-central part of the Blow River Map-Area (GSC Map 1171), and may be identified readily on N.A.P.L. aerial photograph A14406-26 at the point whose coordinates are: X = -0.72 cm, Y = -0.43 cm measured with respect to the centre of the picture with the north direction coinciding with the positive Y-axis. These sediments first were reported in the literature by J.A. Jeletzky (1972).

The best exposures are at the point indicated but it would appear from the aerial photograph that these sediments actually may underlie a much wider area on the south side of Johnson Creek.

The sediments comprise unconsolidated conglomeratic muds, pale orange silty and sandy clay (volcanic ash?) and mildy resistant brown peat containing abundant, variably carbonized tree trunks and branches. Where water saturated, the clays are quick. The sediments appear to fill topographic depressions in an erosion surface cut in tilted dark grey shale, dark grey argillaceous siltstone and pale orange, very fine grained quartz sandstone correlated by one of the authors (D.K. Norris) with the Lower Cretaceous (Neocomian) rocks of Aklavik Range. No attitude in the unconsolidated sediments is possible because of acute slumping and external rotation, but the pale orange silty and sandy clay would appear to overlie the peat and they could be considerably younger. The whole assemblage may not be more than one hundred feet thick at this point.

Microflora

A single sample of peat was macerated and palynologically analyzed with the hope of determining age, and perhaps deriving some information about the environment of deposition. This sample yielded a well-preserved and varied microflora which is characterized by an overwhelming dominance of dictyledonous pollen. Ferns (Pterophyta) and conifers (Coniferophyta) are represented only sparsely and were probably a minor part of the flora. A checklist of identified forms is itemized below.

- Division Pterophyta
  - Order Filicales
    - Family Osmundaceae
      - Genus *Osmunda* sp.
      - Genus *Baculatisporites* sp.
    - Family Polypodiaceae
      - Genus *Laevigatosporites* sp.
- Division Conferophyta
  - Order Coniferales
    - Family Pineaceae
      - Genus cf. *Pinus* sp.
      - Genus cf. *Picea* sp.
    - Family Taxodiaceae
      - Genus cf. *Glyptostrobus* sp.
- Division Anthophyta
  - Class Dicotyledonae
    - Family Cornaceae
      - Genus *Nyssa* sp.
    - Family Salicaceae
      - Genus cf. *Salix* sp.
    - Family Betulaceae
      - Genus *Alnus* sp.
      - Genus *Betula* sp.
      - Genus *Corylus* sp.
      - Genus *Castanea* sp.
    - Family Juglandaceae
      - Genus *Carya* sp.
      - Genus *Engelhardtia* sp.
      - Genus cf. *Platycarya* sp.
      - Genus *Juglans* sp.
      - Genus *Pterocarya* sp.
    - Family Ulmaceae
      - Genus *Ulmus* sp.
    - Family Tiliaceae
      - Genus *Tilia* sp.
    - Family Aquifoliaceae
      - Genus *Ilex* sp.
    - Family Onagraceae
    - Family Altingiaceae
      - Genus cf. *Liquidambar* sp.
    - Family Ericaceae
      - Genus *?Rhododendron?* sp.
- Dicotlyledonae *incertae sedis*
  - Genus *Pistillipollenites macgregorii* Rouse
  - Genus *Tricolpites* spp.
  - Genus *Tricolporopollenites* spp.
  - Genus *Triporopollenites* spp.

Age and environment

A Shell Oil, Canada, palynology report, quoted by J.A. Jeletzky (1972, p. 36), concludes that: "The assemblage indicates without doubt a Tertiary age, probably Miocene to possible Pliocene". This Shell report was based on a smaller and less diagnostic microflora than that which we report on here. For the reasons discussed in the following paragraphs, we agree with the Tertiary age assignment, but believe that this Johnson Creek assemblage is older the Miocene.

The abundant, modern-appearing dicotyledonous pollen, a total absence of diagnostic Cretaceous forms, plus a number of identified genera which do not occur in pre-Tertiary rocks confirm a Tertiary age. A Neogene age assignment is unlikely as based on the absence of the families Compositae and Chenopodiaceae which do not appear before latest Oligocene in British Columbia or the Yukon. Furthermore, this pollen assemblage does not show evidence of the climatic deterioration which occurred in the middle Oligocene.

An Eocene age is suggested by the presence of *Pistillipollenites macgregorii* Although this species has been found in Paleocene and Eocene rocks of such disparate areas as Texas and Alaska, it appears restricted to the Eocene in British Columbia. Further evidence of an Eocene age is indicated by the probable presence of *Platycarya* which, in the western hemisphere, appears to be restricted to rocks of Eocene age.

This palynomorph assemblage is very similar to those described by Rouse et al. (1970) for middle Eocene assemblages from the interior of British Columbia. The significant difference is that the Johnson Creek assemblage has a very low conifer pollen content, although several genera of the coniferales are represented. However, throughout North America there was a warming trend from middle to lake Eocene which would have resulted in a decrease in the abundance of the conifers. It seems reasonable to postulate, therefore, that the Johnson Creek assemblage is of late Eocene age. This conclusion is supported by the find of a single onagraceous pollen grain, a family which, in British Columbia at least apparently makes its first appearance in the latest Eocene.

Ecological requirements of these genera, plus the probable British Columbia climate during the Paleogene are discussed elsewhere (see Rouse et al., 1970; Hopkins et al., 1972; Griggs, 1970; Hopkins, 1969; Rouse, 1962; Piel, 1971). It would seem that during the Paleogene the climate of the northern Yukon was not significantly different from that of the interior of British Columbia. Therefore, this assemblage would suggest a temperate to warm-temperate climate, a conclusion consistent with a late Eocene age interpretation.

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110. ORGANIC CARBON ANALYSIS, FRANKLIN MOUNTAIN FORMATION, NORTHWEST TERRITORIES

Projects 710010 and 710013

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The per cent of organic carbon present in dolomites of the Franklin Mountain Formation at the C.D.R. Tenlen Lake A-73 well in the Northwest Territories was determined at about 20-foot intervals throughout its thickness of 4,225 feet.

The mean organic carbon content of limestones collected from many parts of the world is 0.24 per cent (Gehman, 1962, p. 885).

The average per cent of organic carbon present in the Franklin Mountain Formation carbonates is about 1.5; few values were less than 1.0, many were close to 2.0, and some were greater than 2.0. The Franklin Mountain Formation carbonates do not appear to lack hydrocarbon potential through scarcity of organic matter.

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111. RADIOLARIA FROM THE CANOL FORMATION, NORTHWEST TERRITORIES

Projects 670068, 710010 and 710013

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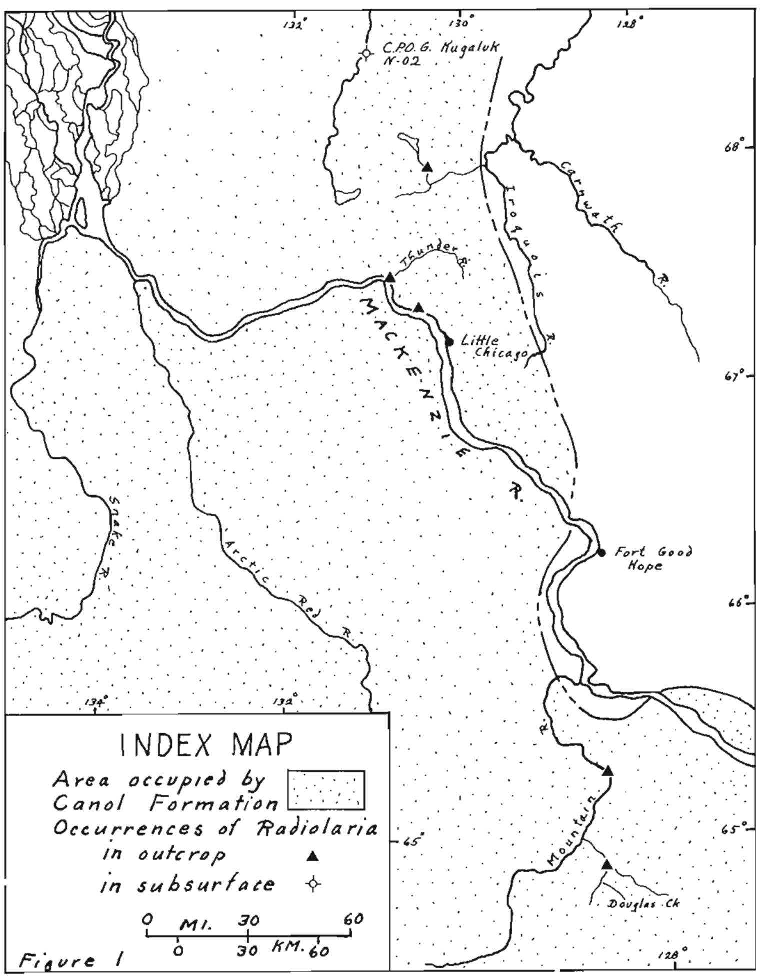
During the course of Operation Norman[1], and in subsequent studies of the subsurface, Radiolaria were found to be present in rock specimens collected from various horizons in the Upper Devonian Canol Formation near such widely separated localities as Iroquois River, Thunder River, Little Chicago, Mountain River, and Douglas Creek (Fig. 1). Elsewhere, within the area occupied by the Canol Formation, almost all outcrops contained poorly preserved vaguely spherical bodies, most likely of Radiolaria, in the more siliceous intervals. Well-preserved specimens, identifiable in thin section, occurred in siliceous nodules and concretions from which they could not be extracted, and in siliceous intervals. Although the Canol Formation is notably unfossiliferous, poorly preserved remains of presumed Radiolaria were reported prior to Operation Norman (Braun, 1966, p. 225) but no attempt was made to classify the fauna.



The following genera have subsequently been identified[2]:

Palaeoscenidium cladophorum Deflandre

Ceratoikiscum sp.

Entactinosphaera sp.

Entactinia sp.

Polyentactinia sp.

Ceratoikiscum sp. and *Palaeoscenidium cladophorum* Deflandre are two genera restricted to the Paleozoic and of possible importance in zonation of the upper Paleozoic.

Entactinia sp. and *Entactinosphaera* sp. are also, at the present state of knowledge, restricted to the Paleozoic, but are less distinctive in appearance.

Radiolaria likely contributed most of the silica associated with the Canol Formation shales.

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[1] A reconnaissance mapping and stratigraphy project carried out in 1968 and 1969 by the Geological Survey of Canada in the general region of Paleozoic sediments lying north of 64°N Latitude and east of 132°W Longitude.

[2] Identifications by Dr. Helen P. Forman, Department of Geology, Peters Hall, Oberlin College, Oberlin, Ohio, 44074.

Projects 710010 and 710013

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The name Hare Indian Formation was first used by Kindle and Bosworth (1921, p. 45B) for a sequence of argillaceous limestone and calcareous shale underlying the Ramparts Formation at the lower end of Ramparts Gorge near Fort Good Hope. Hume and Link (1945, p. 20) later designated a 700-foot sequence of beds described by Parker (1944) in the Imperial Range on Mountain River as the type locality of the Hare Indian Formation. The Hare Indian Formation within the report area comprises a variety of rock types not present at the type locality.

The formation occupies an area of about 18, 000 square miles between 65 and 68 degrees N. latitude. Two main facies are present almost everywhere: a lower unit of black calcareous shale with limestone concretions, fibrous calcite beds, cricoconarids, and algal spore cases – the spore-bearing member (Tassonyi, 1969, p. 71); and an overlying sequence of green-grey sericitic shale, and dark grey calcareous shale, commonly with limestone beds in the upper part.

Algal spore cases referred to the genus *Leioephaeridia* by A.R. Sweet (unpub. report, 1972) are abundant in the spore-bearing member in the east half of the region, and almost entirely absent in the west (Fig. 1). The spore cases, measured for maximum diameter, fall into two groups – one greater than, and the other less than 150 microns. According to A.R. Sweet (ibid.), the different sizes may reflect concentrations of mature and immature specimens or differences in the supply of nutrients. The writer believes that the pattern of distribution of the spore cases can be attributed also to a low energy depositional envrionment in which weak currents were unable to transport the spore cases far from their source. The supply of nutrients also may have been more abundant in the east where there are more spore cases.

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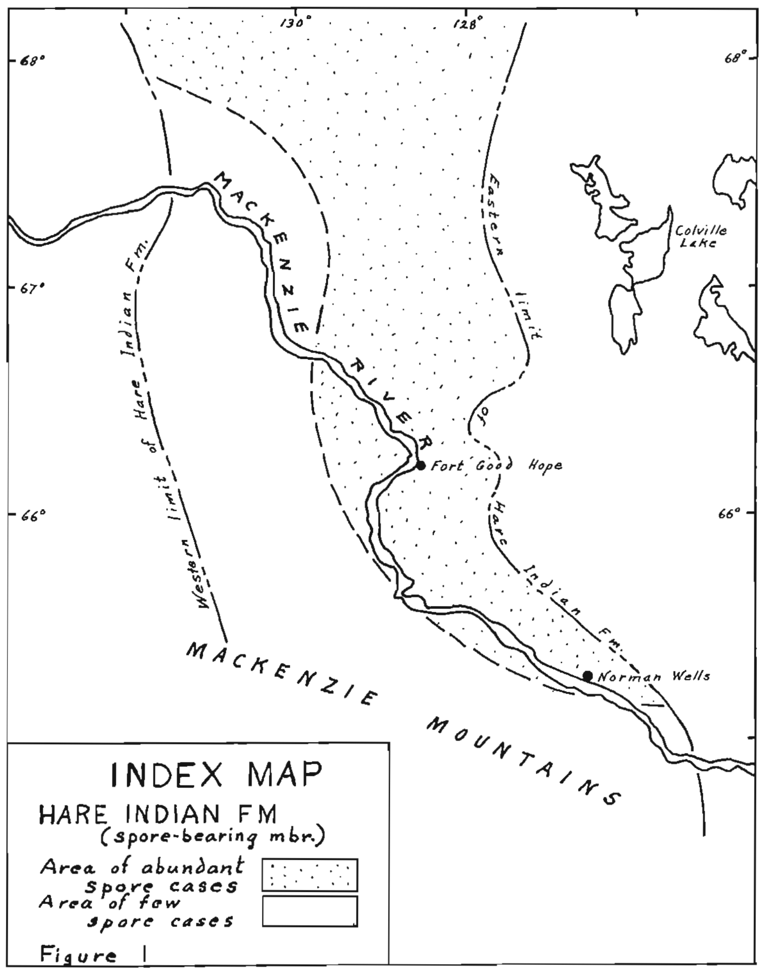

Figure 1

Project 670068

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A one-month visit to the Margaret Lake camp of D. K. Norris and others conducting regional studies in the northern Yukon (see reports by W. H. Fritz and D. K. Norris, this publication) afforded an opportunity to examine the lower and middle Paleozoic succession (Upper Cambrian–Lower Devonian) of the Operation Porcupine area, and compare it with that of the Operation Norman area to the east. Sections studied are located mainly in the Wernecke and westernmost Mackenzie Mountains and are shown in Figure 1.

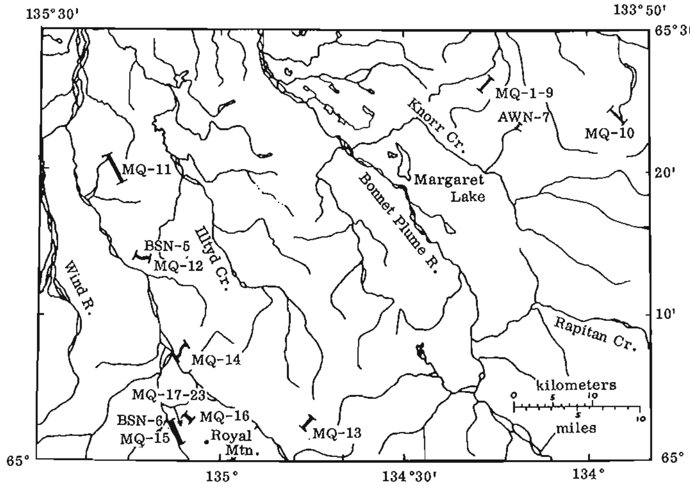

Figure 1. Lower and middle Paleozoic localities, northern Yukon Territory. (MQ = R. W. Macqueen; BSN = B. S. Norford, 1964; AWN = A. W. Norris, 1967).

Unnamed carbonate unit, Illtyd Range and Wernecke Mountains (Upper Cambrian-Upper Silurian or younger)

A monotonous sequence of light grey weathering platform carbonates, earlier described by Norford (1964), Green (1972), and Lenz (1972) and at least 3,500 feet thick (≈1,060 metres), characterizes the Illtyd Range and the Wernecke Mountains. In the northern Illtyd Range (Loc. MQ-11, Fig. 1; W. H. Fritz Loc. 6, this publication), the sequence is more than 1,800 feet thick (≈550 metres), consists largely of pelletoid-grain mictritic limestones characteristic of very shallow water deposition, and contains a medial Upper Cambrian *Elvinia* Zone fauna near the base and an Early Ordovician fauna at about 1,450 feet (442 metres) above the base (W. H. Fritz, pers. comm.). About 6 miles to the south in the southern Illtyd Range (MQ-12, Fig. 1; also section 5 of Norford, 1964), a similar sequence is about 2,200 feet thick (≈670 metres) but contains Lower and Upper Silurian faunas (Norford, 1964). According to D. K. Norris (pers. comm.), the two Illtyd Range sections probably are separated by a northwest-trending, nearly vertical fault with the northeast side up. If the two sections contain no overlap, the total Illtyd Range succession is at least 4,000 feet thick (≈1,220 metres). Both sections are remarkable for their uniform composition throughout, and their lack of physical evidence of unconformities.

At the two Wernecke Mountains localities studied on the north side of the Wind River (MQ-13, 14), cyclic carbonates carrying an Upper Cambrian fauna of the *Cedaria-Crepicephalus* Zone (Fritz, this publication) are abruptly overlain by rocks of the unnamed carbonate unit. Although rocks of the unnamed carbonate unit resemble the Illtyd Range limestones in weathering profile, bedding characteristics and colour, they consist largely of finely to coarsely crystalline dolomite. The more coarsely crystalline beds of dolomite are commonly vuggy, locally appear to have replaced lime-sands, and are as much as tens of feet in thickness. At MQ-13, only the basal 1,135 feet (346 metres) of the succession were examined; there, pelletoid-grain micritic limestones resembling those of the Illtyd Range make up about one-third or less of the interval. Along strike at MQ-14 virtually all of the 3,400-foot-thick interval (≈1,036 metres) consists of dolomite, including beds laterally equivalent to those of MQ-14. To the south in the Nash Creek map-area, Green (1972, p. 33) has reported the occurrence of similar changes in composition over short distances in the unnamed carbonate unit (map-unit 3), which there reaches a thickness of 4,700 feet (≈1,430 metres). No macrofossils were found in these two sections; it is hoped that samples collected for conodont determinations may be productive in determining age relationships.

The unnamed carbonate unit was examined also at Royal Mountain, where it consists of over 3,000 feet (≈900 metres) of well-bedded, cominantly micritic and pelletoid grain limestones, locally oolitic with scattered corals and brachiopods. Some of these beds are clearly of very shallow water lagoonal origin; others appear to be of more open marine aspect and are probably at or near the edge of the carbonate bank facies which is known to grade laterally into Road River Formation basinal shales (e.g. Norford, 1964; Lenz, 1972). Physical evidence of unconformities is unknown within the unnamed carbonate unit in any of the Wind River area sections (MQ-13, 14, 16). The unit is known now to range from Late Cambrian to at least Late Silurian in age. The unnamed carbonate unit, although of the same age, in part, is unlike the Franklin Mountain (Upper Cambrian–Lower Ordovician) and Mount Kindle (Upper Ordovician–Lower Silurian) succession of the Mackenzie and Franklin Mountains and Interior Platform of the Operation Norman area (Macqueen, 1959, 1970; Aitken and others, in press).

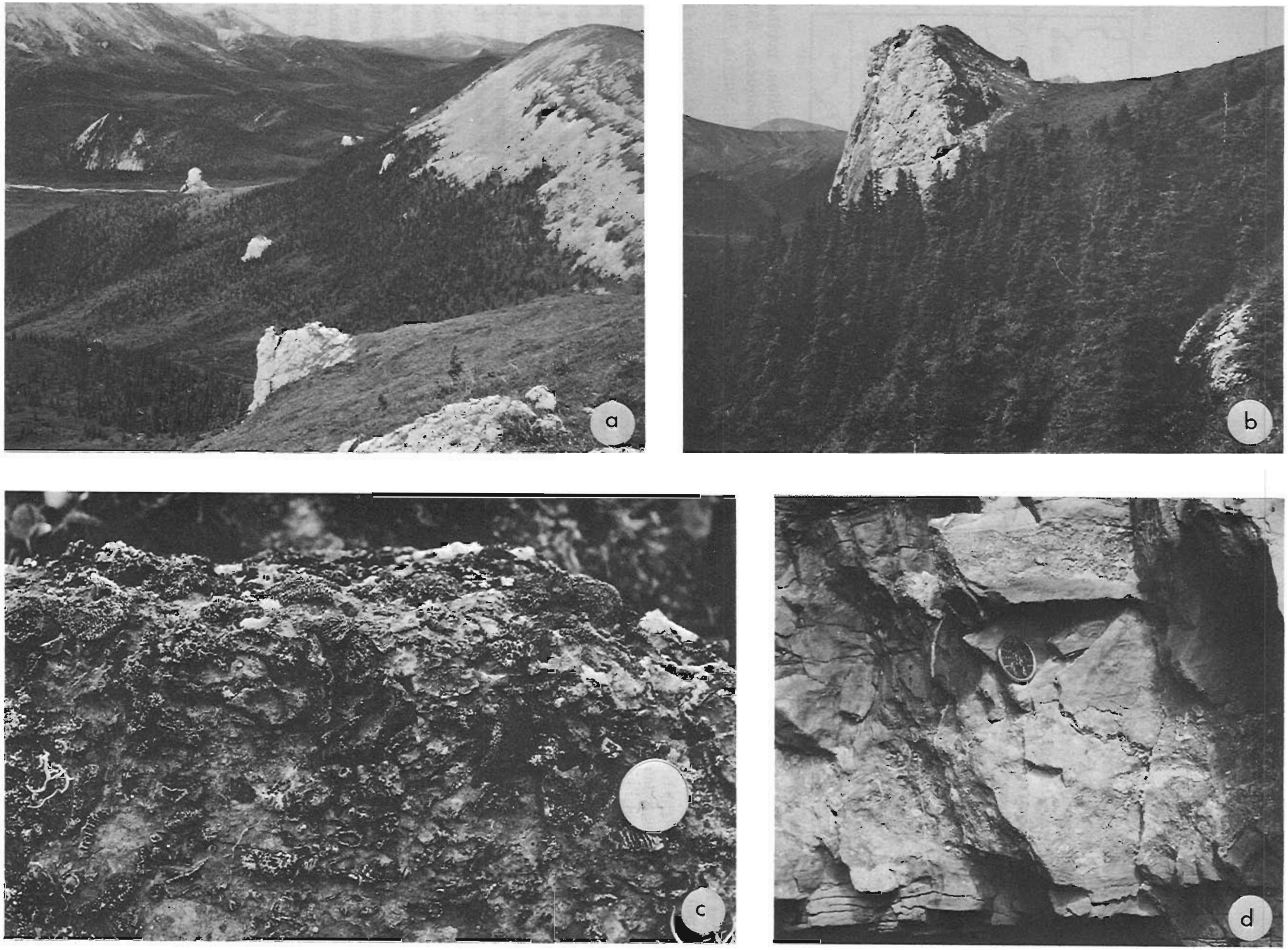

Figure 2.

Mackenzie Mountains lower Paleozoic succession

One section (MQ-10), was examined in the westernmost Mackenzie Mountains. There, the uppermost 453 feet (138 metres) of fossiliferous typical Mount Kindle Formation cherty dolomite beds are exposed. These are overlain by a 300-foot-thick (91 metres) fossiliferous unit of interbedded micritic limestones and very finely crystalline dolomites, and not currently assigned to any formation. This unit is succeeded by a 550-foot-thick (168 metres) unit of poorly exposed red to purple, evaporitic dolomite or argillaceous dolomite including probable solution breccia, and minor amounts of well-bedded micritic limestone. This unit is tentatively identified as the Delorme Formation, and is overlain abruptly by resistant, dark brown fetid dolomites tentatively assigned to the Arnica Formation.

Platform carbonate - basinal shale transition

Norford (1964, Fig. 2, p. 4), A.W. Norris (1968a, b) and more recently Lenz (1972) have outlined, for the northern Yukon, the major lower and middle Paleozoic facies changes from platform carbonates of the unnamed carbonate unit (including Norford's, 1964, presumably equivalent Vunta Formation of the White Mountains, to the north of the area reported on herein) to laterally equivalent Road River Formation basinal sheets. Details of one of these facies changes may be observed in the Royal Mountain - Royal Creek area (MQ-15, 16, 17-23). Royal Mountain is made up of beds of the unnamed carbonate unit which are probably of Early Ordovician or earlier to Late Silurian or ?Early Devonian age. On the west flank of Royal Mountain, the uppermost beds of the unnamed carbonate unit may be observed to change facies into calcareous shales of the Road River Formation which crop out along Royal Creek. The change is abrupt, taking place over one mile or less. Skeletal limestones particularly rich in corals and brachiopids (Fig. 2c) and probably representing submarine slumped material derived from bank margin environments, occur as tongues within poorly exposed argillaceous limestones or calcareous shales within which graded beds occur (Fig. 2d). The tongues may be observed on the west flank of the mountain, but do not persist into outcrops exposed along the east bank of Royal Creek near the level of the creek. Details of the facies change should be clearer following identification of faunal collections and study of lithologic specimens.

Figure 2. (opposite)

a. Lower Devonian carbonate masses, Prongs Creek Formation, east flank of Knorr Range.

b. Single steeply dipping Lower Devonian carbonate mass viewed from along strike, east flank of Knorr Range (*Martinophyllum* sp. collected from uppermost beds of this mass).

c. Profusion of ?Upper Silurian silicified corals and brachiopods in carbonate tongue extending into Road River Formation, west flank of Royal Mountain.

d. Two graded beds within Road River Formation ?Upper Silurian, west flank of Royal Mountain.

Knorr Range Lower Devonian (Emsian) carbonate masses

At least 20 distinctive Lower Devonian carbonate masses occur within the Prongs Creek Formation (Norris, 1968) along a strike length of about 3 miles, on the east flank of the Knorr Range (Fig. 1, Locs. MQ 1-9: National Air Photograph Library air photograph A20673-109). These masses, some of which are seen in Figures 2a, b, occur within the upper third of the approximately 2, 000-foot-thick (≃610 metres) Prongs Creek Formation, over a stratigraphic interval of about 200 - 300 feet (≃60 - 90 metres). More than half of these appear to be less than 50 feet (≃15 metres) in thickness and a maximum of 150 (≃45 metres) or less in strike length. At least six, including three sampled in detail, are up to 75 feet (≃23 metres) thick and as much as 200 to 300 feet (≃60 - 90 metres) in strike length. These larger masses appear to be confined to one stratigraphic level, as seen in Figure 2a. Bedding normally is obscure but, where seen, defines a dip of about 50° - 70° northeast (Fig. 2b), and appears to be concordant with the dip of very poorly exposed adjacent Prongs Creek Formation shales. Those masses examined comprise very pure, pelletoid grain packstones or wackestones with sparry calcite matrix in part. They are fine to coarse grained with rare oolites or compound grains, and contain scattered ostracodes, bryozons, echinoderm ossicles, ?calcareous algae, and colonial corals. No evidence was noted of steep initial dips or talus blocks or debris beds, which could characterize reef flank detritus or submarine slumps. No interbedding with surrounding Prongs Creek shales was observed.

Although Lenz (1972, p. 328) has termed these masses "small reef developments", and interpreted them as having developed on the flanks of the Bonnet Plume High (Lenz, ibid) during Early Devonian time, evidence is minimal that they are either ecologic or stratigraphic reefs (such evidence as whole or fragmented organisms, especially trapping or binding varieties, in quantity; lateral zonation such as core, back-reef, fore-reef facies; debris beds, etc.). The masses appear to be banks or biostromes – in situ accumulations of pelletoid and other non-skeletal grains and loose calcareous skeletal material – which originally may have been continuous. If they were continuous, the present lack of continuity implies either that they are overlain by a Devonian erosion surface, with related sculpturing to achieve the present distribution pattern, or, alternatively, that they are presently continuous beneath the modern erosion surface. The latter interpretation seems unlikely, because no topographic expression is evident in the intervening areas between the masses (Fig. 2a). The problem is unresolved. The masses are lacking in appreciable porosity; no evidence of metallic mineralization (which might be expected in this setting) was noted, despite a careful search.

Several fossil collections made from two of the masses were identified by A.E.H. Pedder, Geological Survey of Canada. From mass MQ-6, GSC Loc. C-25555, Pedder reports the tabulate coral *Occulipora* sp., infested with *Streptindytes* sp., a parasitic worm; this consortium ranges from Ludlovian to Eifelian, but in western Canada is especially characteristic of Siegenian and Emsian strata (Lower Dveonian). From a second mass at MQ-9, GSC Loc. C-26668, Pedder reports the rugose coral *Martinophyllum* sp., and comments as follows: "*Martinophyllum* is widely distributed in late Siegenian and Emsian beds in eastern Australia (Tasmania to northern Queensland) and Siberia (pers. com., S. Cherepnina, 1969). It is also known in the Emsian of Alaska (Salmontrout Formation), Yukon (*Sieberella* sp. cf. *S. weberi* bearing beds at the headwaters of Royal Creek and lower beds of the Ogilvie Formation), and eastern Urals (*Favosites regularissimus* Zone)".

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DEVONIAN STRATIGRAPHY, FACIES CHANGES, AND ZINC-LEAD MINERALIZATION, SOUTHWESTERN HALFWAY RIVER AREA (94B), NORTHEASTERN BRITISH COLUMBIA

Project 680084

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Platform carbonates of Devonian age give way laterally to basinal shales within the Halfway River and adjacent areas of the Cordilleran Orogen and Interior Platform of northeastern British Columbia (Taylor, 1973; and others). Delineation of the nature and location of these facies changes is important both to hydrocarbon exploration in the subsurface of northeastern British Columbia and to exploration for zinc-lead mineral deposits of the Mississippi Valley type (see Brown, 1970; and others), as located near Robb Lake in the northwestern Halfway River area (Sangster, 1973; Thompson, 1973). Accordingly, the present writers are attempting to refine current knowledge of Devonian stratigraphy in the area, following earlier studies by Taylor (1969), Irish (1970), Taylor and MacKenzie (1970), and Taylor and Stott (1973). Five stratigraphic sections (Fig. 1) and a number of regional observations derived from helicopter traverses constitute the 1973 field work.

Stratigraphy and facies changes

Paleozoic stratigraphic units recognized in the Halfway River area are those outlined for the Peace River area by Taylor and Bamber (1970, Fig. 2, p. 49). The Lower Devonian Muncho-McConnell Formation (Taylor and MacKenzie, 1970), an approximately 800-foot-thick unit of light to dark grey weathering dolomite, is underlain unconformably by resistant brownish grey weathering dolomites of the Silurian Nonda Formation (Norford et al., 1966), and overlain unconformably by well-bedded light greyish brown to tan dolomites, sandy dolomites, and sandstones characteristic of the lower part of the Stone Formation (Taylor and MacKenzie, 1970), with a thickness of about 1,500 feet. The upper part of the Stone Formation (Fig. 1) consists of light grey weathering, microcrystalline to very finely crystalline dolomite, slightly sandy and locally containing breccias which appear to be of evaporite solution origin, although these are much more common farther north (Taylor and MacKenzie, 1970). The Stone, which is both Early and Middle Devonian in age, is overlain sharply and unconformably by the Middle Devonian Pine Point Formation. The basal few feet of Pine Point carbonates, where exposed, are rich in quartz silt and sand, presumably reflecting proximity to the Peace River Arch immediately to the south (Taylor and Bamber, 1970). Most of the Pine Point Formation in the area consists of dolomite and contains *Amphiporid* - and stromatoporoid-rich beds (Fig. 2a) indicative of carbonate bank-margin and bank-interior sediments. *Stringocephalus* is common at some levels (Fig. 1).

In the Mount Burden thrust panel (section 4, Fig. 1), the Pine Point consists of only 163 feet of argillaceous limestone and calcareous shale. The limestone contains excellent examples of sedimentary breccias characteristic of debris flows of carbonate slope and basinal environments, as described by Mountjoy et al. (1972). These beds represent the base-of-slope or slope facies of Macqueen (1973), and are the deeper water equivalent of the platform carbonates of the lower Pine Point at sections 1, 2, 3 and 5. Overlying beds at section 4 consist of calcareous and non-calcareous shale of the Besa River Formation, which is of basinal facies and laterally equivalent to the platform carbonates of the middle and upper Pine Point of sections 1, 2, 3 and 5.

Overlying the Pine Point in the area is an unfossiliferous unit of finely crystalline dolomite or micritic or argillaceous limestone which the writers identify tentatively as the Sulphur Point Formation (Fig. 1). This unit appears to be largely representative of a shallow-marine platform or bank-interior environment; it also changes facies laterally to Besa River Formation shales. The contact between the Sulphur Point and the Pine Point in the southwestern Halfway River area is difficult to recognize because of extensive dolomitization of both units.

Sulphur Point beds are overlain unconformably by a few feet of fine- to medium-grained quartz sandstone, argillaceous sandstone, or shale, which is very recessive, and assigned to the Watt Mountain Formation (Taylor and Bamber, 1970, Fig. 2, p. 49) (not indicated on Fig. 1, this paper). These rocks are overlain by argillaceous carbonates of the Slave Point Formation, probably Middle Devonian in age. Slave Point carbonates are of open-marine aspect in the area, and may be seen to change facies laterally into Besa River Formation shale, especially at, and immediately north of, section 5. At sections 2, 3, and 4, the Slave Point interval is represented by Besa River shale (Fig. 1). The presence of this carbonate-shale facies change in the vicinity of sections 1 and 5 at the level of the Slave Point is in contrast to the location of similar change at the level of the Pine Point Formation. The Pine Point facies change must take place farther south and west, as argillaceous carbonates characteristic of deeper-water environments are seen only at section 4 (in the Mount Burden thrust panel) at the level of the Pine Point Formation.

The change from platform carbonates to argillaceous carbonates and/or shales of slope and basinal environments appears to be abrupt, generally taking place within less than a mile for individual formations. One of the objectives of this project is to map the locus of these changes for a given formation or stratigraphic level. It should be possible to delineate the pattern of facies changes in a general way, in part through improved understanding of the geometry and displacement of the major thrusts and folds of the area.

Use of the names Pine Point and Besa River at section 4, and recognition of the boundary between them as shown in Figure 1, is somewhat arbitrary, as is recognition of the limits of the Slave Point Formation, both laterally and vertically, in the vicinity of sections 1 and 5. In general, the presence of at least 50 per cent carbonate in a given interval at least tens of feet thick vertically has dictated the use of the platform facies name "Pine Point" or "Slave Point"; intervals with greater than 50 per cent shale, calcareous or non-calcareous, are designated as "Besa River Formation".

At section 1 near Wicked River, the Slave Point is overlain paraconformably by the Upper Devonian Beaverhill Lake Formation (Taylor and Bamber, 1970). Elsewhere, the lateral equivalents of the Beaverhill Lake are to be found in the Besa River Formation (Fig. 1).

Diagenesis and zinc-lead mineralization

Secondary dolomites: Almost all of the upper part of the Stone Formation, much of the Pine Point Formation of bank facies (sections 1-3, 5), and part of the Sulphur Point and Slave Point Formations consist of secondary dolomite. The dominant micro- to very finely

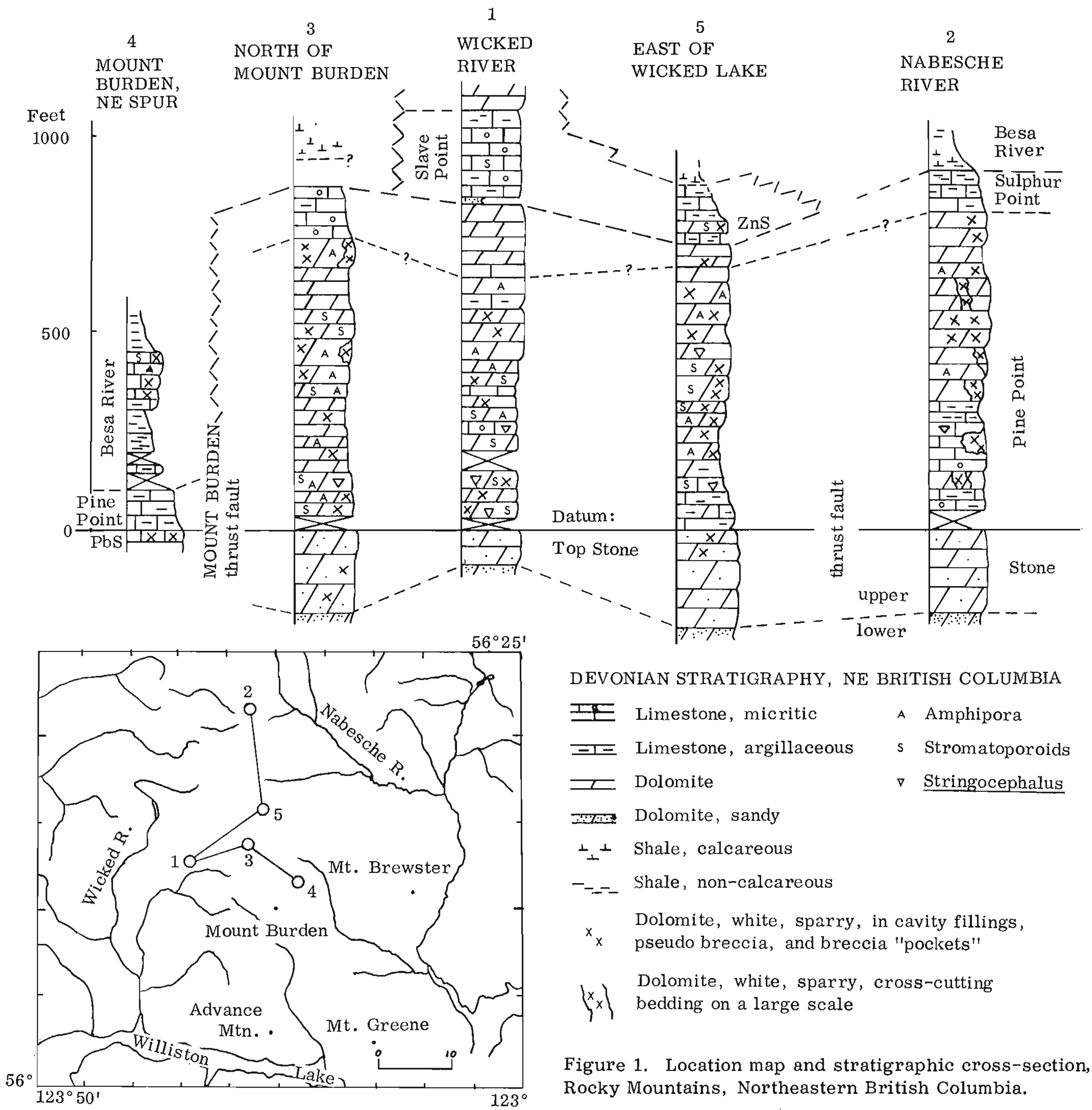

Figure 1. Location map and stratigraphic cross-section, Rocky Mountains, Northeastern British Columbia.

crystalline dolomite of the upper Stone, with evaporite-associated breccias, are of the penecontemporaneous type known to be forming in modern sabkha sediments of the Persian Gulf and Bahamas. Overlying dolomites, which dominate the Pine Point, Sulphur Point, and Slave Point Formations, are of macrodolomite type, finely to coarsely crystalline, and preserving coarse stromatoporoid, *Amphiporid*, and brachiopod fabrics (Fig. 2), although obliterating sand-size and finer matrix constituents originally present.

Presqu'ile-type dolomite and associated "breccias": A third type of dolomite coarsely to very coarsely crystalline in size and of Presqu'ile type (see Belyea, 1970, p. 20, 32; and others) occurs rarely in the platform carbonates of the upper Stone, very commonly in the Pine Point and Sulphur Point, less commonly in the Slave Point, very rarely in the deeper-water argillaceous carbonates of the Besa River Formation, and has not been observed in Besa River shales. This Presqu'ile-type dolomite is intimately associated with a few occurrences of sphalerite, galena, smithsonite, and trace amounts of malachite and azurite which the present writers have seen (all of these occurrences are staked). Commonly white to very pale grey, this dolomite has many varieties of occurrence. It is most abundant in beds of high original porosity where it may laterally replace grains and/or matrix, and/or may cross-cut bedding as a small-scale complex filigree-like network of veinlets (Fig. 2a). Presqu'ile-type dolomite is ubiquitous in the Pine Point Formation, where it occurs as pseudo-breccia infillings (see below), as pore space and vug fillings or linings (Fig. 2a, c, e, f) and breccia fillings (Fig. 2a, e). Where it occurs as vug linings or fillings in the sequence upper Stone through Slave Point, it is associated very commonly with clear to milky quartz euhedra (Fig. 2f). An apparent (but not necessarily real) paragenetic sequence which is widely encountered in vugs is observed as: 1) host rock, 2) Presqu'ile-type dolomite, 3) quartz euhedra, 4) calcite and/or (rarely) bitumen or ?hydrous iron oxides (non-crystalline as determined by X-ray diffraction). In argillaceous carbonates of the Pine Point and Besa River Formations, Presqu'ile-type dolomite is uncommon but, where observed, usually cross-cuts bedding (Fig. 2d).

Study of the textures seen in outcrops and hand specimens leaves no doubt that the Presqu'ile-type dolomite has replaced pre-existing dolomite (or rarely limestone) on a large to small scale. Large-scale replacements may be observed in Pine Point carbonates of sections 2 and 3 (Fig. 1) where whole beds have been replaced by cross-cutting Presqu'ile dolomite for tens to hundreds of feet both laterally and vertically. Bedding is crudely preserved in the replacement mass, and the contact between replaced and unreplaced zones is commonly sharp (Fig. 2b).

Small-scale replacement of pre-existing carbonate may explain the origin of a very commonly encountered pseudo-breccia texture which shows neither rotation of "fragments" nor the karst-like infilling commonly characteristic of evaporite solution (see, for example, solution breccias illustrated by Beales and Jackson, 1968, Fig. 2, p. 872, from Pine Point and other areas; also Beales and Oldershaw, 1969). Much (most?) of the "brecciation" observed in the Pine Point appears to be of this type. True solution-collapse breccias, in which collapse or internal sedimentation of fragments is evident, do occur as pods or pockets (e.g., Fig. 2e), but seem to be rare. In addition, the dolomite, in which the pseudo-breccia occurs widely, appears to have been derived originally from shallow-marine, fossiliferous limestone not normally interbedded or closely associated with evaporites on any significant scale.

For the Robb Lake zinc-lead occurrence, Sangster (1973) observed that the breccias associated with mineralization are defined by white dolomite (Presqu'ile-type dolomite herein), and are of many forms, ranging from "crackle breccia" (minimum rotation of fragments), through recognized collapse breccia, to pseudo-breccia showing almost complete replacement of pre-existing dolostone (dolomite) by white secondary dolomite. Although Thompson (1973) earlier interpreted the mineralized breccia zones of the upper part of the Stone Formation near Robb Lake as of solution-collapse origin, field studies, which he carried out in August 1973. have led him to become skeptical of this interpretation (Thompson, pers. comm., September, 1973).

Semiquantitative X-ray diffraction analyses carried out on 14 samples of Presqu'ile-type dolomite show that quartz and, to a much lesser extent, calcite and ?feldspar are associated closely with the dolomite. It seems almost certain, owing to the diversity of occurrence and relative abundance of Presqu'ile-type dolomite, that several generations of this dolomite are present. Dolomite veins, which cross-cut other dolomite veins, both of Presqu'ile-type, and "late" calcite veins, which are replaced by Presqu'ile-type dolomite, support this conclusion.

Zinc-lead mineralization: Mineralization was noted at two localities, both staked. On the northeast spur of Mount Burden (section 4, Fig. 1), galena occurs as scattered blebs within Presqu'ile-type dolomite cross-cutting micritic limestone assigned to the upper part of the Stone Formation. The galena also is associated closely with quartz replacement of carbonate. On a scale of a few feet at this locality, normal micritic limestone is replaced almost entirely by a tightly interlocking mosaic of quartz crystals, with which some of the galena is associated. Semiquantitative X-ray diffraction analysis of a sample of Presqu'ile-type dolomite from this locality yielded 11 per cent smithsonite ($ZnCO_3$) and 1 per cent sphalerite, neither of which was detected in the field. This locality appears to be one of massive replacement of pre-existing carbonates of the upper Stone Formation by quartz and Presqu'ile-type dolomite, with associated metallic mineralization. The locality is structurally complex, with numerous minor cross-faults evident. There is no obvious evidence of solution brecciation on any scale. It may be significant that the mineralization at this locality, although it occurs in the Stone Formation, is located close to the carbonate-shale facies change in the over-

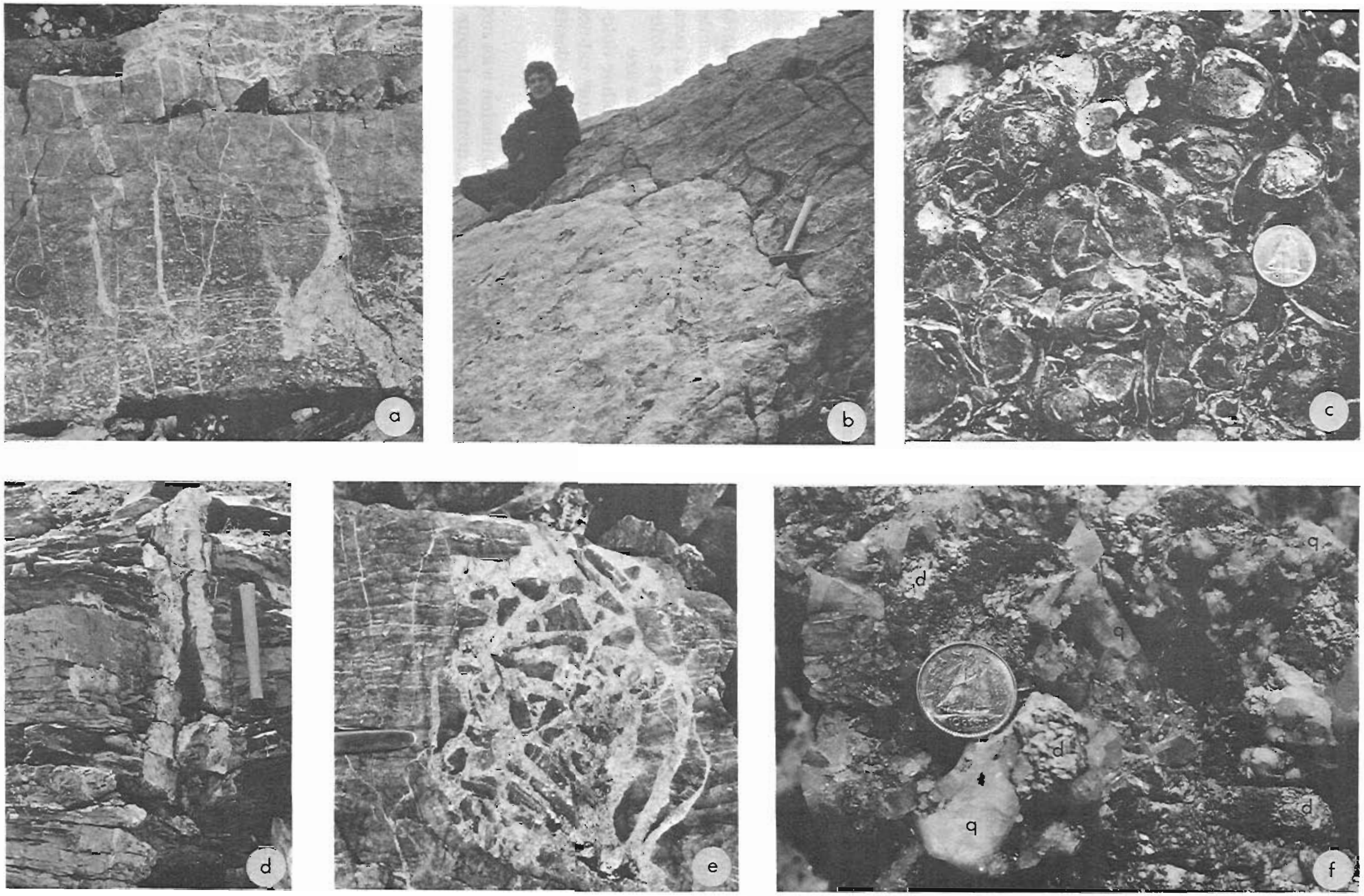

Figure 2

a) *Amphipora* dolomite with cross-cutting Presqu'ile type (for brevity, pqt) dolomite and pseudobreccia at top. Pine Point Formation, Section 1, 137 ft. above base.

b) Cross-cutting pqt dolomite mass replacing micritic limestone. R. Day is seated on limestone; laterally equivalent dolomite mass is in foreground. Pine Point Formation, Section 2, 220 ft. above base.

c) Dolomite bed with large brachiopods showing internal pore space partly filled by white pqt dolomite. Pine Point Formation, Section 5, 275 ft. above base.

d) White pqt dolomite cross-cutting slope beds in Besa River Formation equivalent to Pine Point. Ridge on east side of Lady Laurier Lake, northwestern Halfway River area.

e) Solution breccia "pocket", fragments outlined by pqt dolomite (minute amount of azurite associated with pqt dolomite here). Pine Point Formation, Section 3, 700 ft. above base (pocket knife gives scale).

f) Vug in bedded dolomite of upper Pine Point Formation, Section 5, 560 ft. above base. Apparent paragenetic sequence is 1) host dolomite, 2) pqt dolomite (d), 3) quartz euhedra (q), 4) bitumen or ?hydrous iron oxides (not seen here).

lying Pine Point beds. Alternatively, but perhaps less likely, the mineralization could be related to either the unconformity at the top of the Stone Formation, or to the common cross-faulting, or to all three.

The second locality consists of a stromatoporoid-rich bed in the lower part of the Slave Point Formation at section 5 (Fig. 1). Here crystals of blood-red sphalerite occur in close association with Presqu'ile-type dolomite. Smithsonite also occurs in significant amounts with this dolomite (8 per cent by semiquantitative X-ray diffraction analysis). This bed is one of the very few beds of appreciable porosity within the Slave Point at this locality, and may have provided a channelway along which mineralizing solutions moved. This locality is close to the carbonate-shale facies change at the level of the Slave Point (Fig. 1). No unconformity is in close proximity, nor is there much evidence of cross-faulting, unlike the first locality described above.

New data which appear to bear on any theory of origin of zinc-lead mineralization in the area include the apparent close association of ore minerals with quartz as well as dolomite, and the probable absence of solution breccia on any appreciable scale - breccia which is apparently very common in the classical Pine Point orebodies on the north shore of Great Slave Lake (see Beales and Jackson, 1968; and others).

Malachite and azurite: These distinctive hydrous copper carbonates are extremely rare, but were observed in minute amounts at several localities in close association with Presqu'ile-type dolomite (e.g., Fig. 2e). No other copper mineralization was observed.

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STRATIGRAPHIC RELATIONSHIPS AT THE WESTERN EDGE OF THE MIDDLE CAMBRIAN CARBONATE FACIES BELT, FIELD, BRITISH COLUMBIA

Project 720050

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For the past two summers (1972, 1973) the author has been investigating the nature of the facies changes within Middle Cambrian units (see Fig. 1) described by Cook (1970) near Field, British Columbia. East of the major facies change, a submarine escarpment in the upper part of the Cathedral Formation (see Fig. 1) was investigated in detail. This escarpment was observed first by Ney (1954) on the north side of Mount Stephen and on the opposing south face of Mount Field. Recently, Fritz (1969) observed the same escarpment outcropping on the west side of the ridge line connecting Mount Field to Wapta Mountain. At this last location, Fritz (1971) using trilobite faunules showed that the minimum depth of water at the front of the escarpment was 680 feet during the initial deposition of Stephen shales in the adjacent basin immediately to the southwest. Fritz further concluded that the Burgess Quarry fauna was deposited in relatively deep water near the edge of this steep submarine escarpment.

Observations made by the writer indicate that the escarpment is a regional feature outcropping at various localities within the study area (see Fig. 2). The areal distribution of escarpment outcrops indicates an embayed feature that presumably was laterally continuous prior to deformation. The occurrence of this escarpment on the west side of Mount Stephen is particularly interesting since now it can be demonstrated that the fauna of the Stephen "fossil beds", like the Burgess Quarry fauna, was deposited very close to the actual escarpment edge in the adjacent Stephen shale basin.

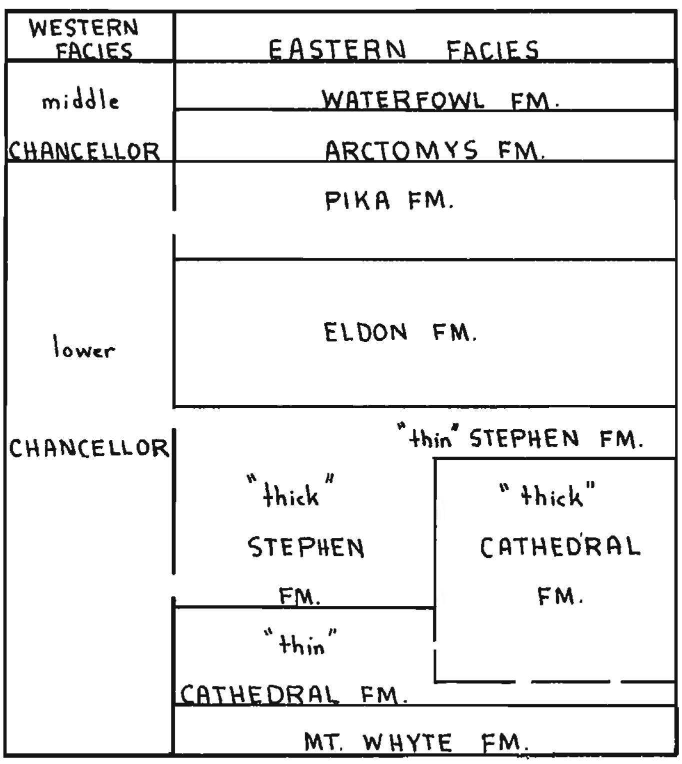

Figure 1. Correlation Chart of Middle Cambrian units across facies change exposed near Field, British Columbia (modified after Fritz (1971) and Cook (1970).

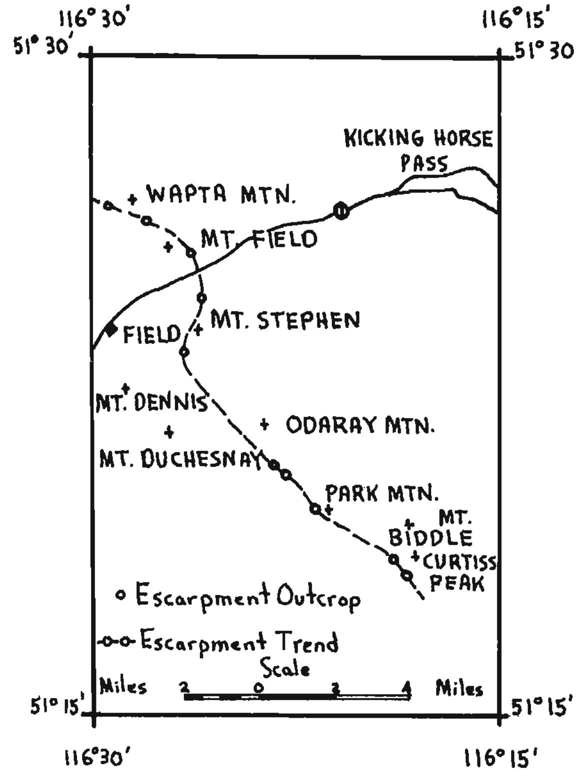

Figure 2. Location map showing escarpment outcrops and trend of escarpment in the Upper Cathedral Formation.

The escarpment began to develop early in Cathedral time after the deposition of a basal unit of dark grey, fine, oolitic packstone. Following initiation of the original escarpment slope, the Cathedral Formation became differentiated into a "thick" Cathedral platform facies (oolitic packstone, cryptalgal laminite and planar birdseye mudstone) to the east and a basal "thin" Cathedral (dark grey lime mudstone) to the west. The development of the escarpment can be inferred from allochthonous mass carbonate breccia flows in the "thin" Cathedral. The thickness of these flows and the size of the derived carbonate clasts increase at higher stratigraphic levels, probably as a result of a steepening of the escarpment edge with growth during Cathedral time. Individual submarine talus blocks, confined to the uppermost part of the "thin" Cathedral presumably were derived from a much steeper slope. The development of the escarpment was terminated by Stephen argillaceous sediments which filled the adjacent basin and eventually covered the "thick" Cathedral.

The original components of the nearly vertical escarpment are obscured by extensive dolomitization. However, further information on the origin and development of the escarpment may result from an extensive petrographic study currently being undertaken on samples of limestone clasts from escarpment derived, mass breccia flows and submarine talus.

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STRATIGRAPHY OF THE ELF ET AL. STORKERSON BAY A - 15 WELL

Project 720061

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This well was released from confidential status on December 10th, 1973. Samples and cores have been logged by the author.

The stratigraphy of this well is summarized in Table 1. Tops have been picked on the basis of lithostratigraphic criteria and micropaleontological studies. It will be observed that the stratigraphy is quite different from that present in northern Banks Island, as described by the writer (this volume) and some of the implications of this fact are noted below.

Core No. 2 was taken near the top of a 339-foot-thick limestone unit at the base of the well. The lithology consists of thinly bedded calcareous mudstones, wackestones, and packstones containing abundant stromatoporoid remains as well as syringoporid and favositid corals, crinoid ossicles, and brachiopod fragments. Conodonts from the core are dated as late Emsian or early Eifelian in age by T.T. Uyeno. This correlates with the oldest Blue Fiord Formation of the Franklinian Miogeosyncline, or to parts of the Ogilvie Formation of northern Yukon.

The limestone is overlain by 695 feet of shale, most of which is siliceous and contains scattered pyrite. The contact with the limestone appears to be gradational. The stratigraphy is perhaps more comparable with that in parts of northern Yukon (Hart River area) where similar Eifelian siliceous shale deposits (Canol Formation type) overlie Emsian limestones of the Ogilvie Formation. Lenz (1972, p. 349) states "the age of the base of the black, siliceous shale varies from Emsian or Eifelian to late Givetian or Frasnian from locality to, and ...these black shales are, in their basal portions at least, lateral equivalents of the Ogilvie Formation".

In the A-15 well the black shales are succeeded by 549 feet of very fine grained, non-calcareous quartz sand interbedded with dark grey, slightly carbonaceous shale. Samples from the succession were processed for spores by A.R. Sweet but all were found to be extremely carbonized and to contain no identifiable material. These beds are tentatively assigned to the Weatherall Formation.

Surface exposures on Banks Island show the Paleozoic strata to be overlain by the Lower Cretaceous Isachsen Formation. The Isachsen is, however, absent in the Storkerson Bay well. Presumably the area remained emergent longer than did the remainder of the island, and the nearby presence of Storkerson Uplift (Miall, this publication, report 117) may have been influential in this respect.

The Weatherall Formation is overlain by 665 feet of beds assigned to the Christopher Formation and these consist predominantly of shale and argillaceous siltstone. These strata have yielded Early to Late Albian foraminifera (identifications by W.V. Sliter) and Albian palynomorphs (identifications by W.S. Hopkins, Jr.). The top of the formation is marked by a very thin dolomite bed containing microscopic spherulitic concretions, which are believed to be of early diagenetic origin. The relationship of this dolomite to the Hassel Formation is at the present time unclear. The Hassel occupies this stratigraphic position elsewhere in the Arctic Islands but is absent in the Storkerson Bay well.

The overlying Kanguk Formation consists of shale and argillaceous siltstone containing cone-in-cone limestone, plant remains and scattered pelecypods. W.V. Sliter has identified a Cenomanian to Campanian foraminifera assemblage from these beds. The "burnt shale" of the basal Kanguk (Jutard and Plauchut, 1973) does not appear to be present.

The overlying Eureka Sound Formation may be subdivided into three members in this well, a lower shale-coal member 508 feet thick, a cyclic unit 1,311 feet thick, and an upper sand-shale member 931 feet thick. The cyclic member consists of repeated coarsening-upward successions, in which the coarsest member is commonly pebble conglomerate. These cycles are believed to be deltaic in origin and similar to those observed at the surface (Miall, this publication, report no. 117). However they are considerably thicker and coarser than the latter, and must therefore be more proximal in origin. A distant easterly sediment source and transport across Banks Basin cannot be invoked for this reason, and it is suggested that an emergent Storkerson

TABLE 1

Table of formations in the Elf et al., Storkerson Bay A-15 well

Age	Formation	log depth	subsea elevation	thickness
Quaternary	Beaufort	0	64	860
Maastrichtian-Tertiary	Eureka Sound	860	-796	2750
Cenomanian-Campanian	Kanguk	3610	-3546	861
Albian	Christopher	4471	-4407	665
Givetian	Weatherall	5136	-5072	549
Eifelian	Shale	5685	-5621	695
Emsian	Limestone	6380	-6316	339
		TD 6719	-6655	

Uplift may have provided much of the detrital material. Many of the pebbles in the Eureka Sound Formation are of siliceous shale very similar in lithology to samples from the Eids Formation lower in the well. Devonian strata thus may have been exposed on the crest of Storkerson Uplift during Tertiary time.

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117. # BEDROCK GEOLOGY OF BANKS ISLAND, DISTRICT OF FRANKLIN

Project 720061

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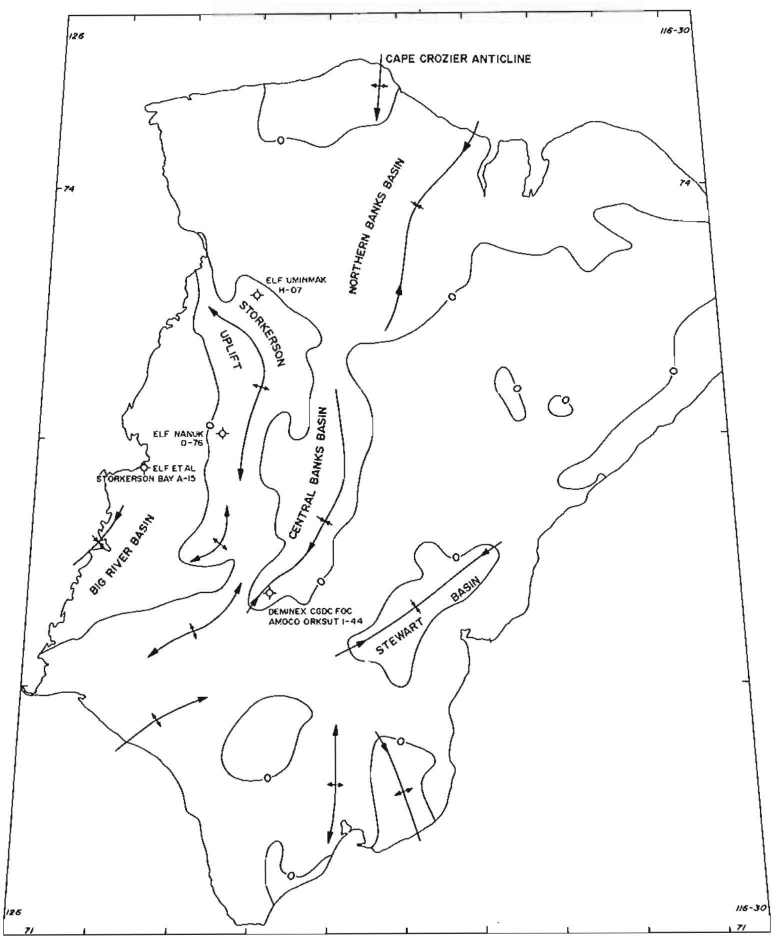

Figure 1. Banks Island, showing line of zero Bouger anomaly and structural elements.

Introduction

Six weeks were spent on northern Banks Island during June and July, 1973, studying the Devonian, Cretaceous and Tertiary strata.

Structural Setting

A recently published gravity map (Stevens et al., 1972), together with a limited amount of other subsurface data, enables an improved structural map to be drawn for the area (Fig. 1). The available data indicate that the Bouger anomalies reflect primarily the configuration of the top Paleozoic erosion surface. Most of the names proposed are already in informal usage amongst geologists in industry.

The southern end of Prince Patrick Uplift (Thorsteinsson and Tozer, 1970) is Cape Crozier Anticline, which does not extend southwards to Nelson Head as formerly thought. Several other highs arranged in an *en echelon* pattern trend south to southwestwards, continue offshore, and may link up with structural lineations that have been recognized in the Tuktoyaktuk Peninsula area. The most prominent of these is named Storkerson Uplift, from Storkerson Lake, which is located near the centre of the feature.

Banks Basin (Thorsteinsson and Tozer, 1960) is closed to the west by Storkerson Uplift, and is divisible into two parts by a small rise at Bernard River. A subsidiary trough in south-eastern Banks Island is named Stewart Basin.

Big River Basin (Fig. 1) is incompletely defined, its western margin lying in offshore regions for which data are unavailable. The history of this basin is very different from that of Banks Basin (Miall, this volume).

TABLE 1

Paleocurrent data for the Isachsen Formation of Northern Banks Basin

Loc. no.	Loc. name	n	$\bar{\theta}$	L	S^2	P
4,5,6,7,9	Antler Cove	26	27	74.5	1940	$<10^{-6}$
24	Able Creek	18	18	96.3	225	$<10^{-7}$
26A	Baker Creek	16	291	83.0	1300	$<10^{-4}$
26B	Baker Creek	28	63	93.4	480	$<10^{-10}$
29	Cape Vesey Hamilton	30	21	71.6	2300	$<10^{-6}$
30	Cape Vesey Hamilton	73	351	89.9	780	$<10^{-25}$
31	Mercy River	25	32	77.5	1680	$<10^{-6}$
35	Colquhoun River	12	176	93.8	440	$<10^{-4}$

$\bar{\theta}$ = vector mean azimuth, S^2 = variance, L = vector magnitude per cent,

n = number of observations, P = probability of randomness (Rayleigh test)

TABLE 2

Paleocurrent data for the Eureka Sound Formation of Northern Banks Basin

Loc. no.	Loc. name	Struct. Scale	n	$\bar{\theta}$	L	S^2	P
19	Survey Lake	ℓ	10	324	96.8	200	$<10^{-4}$
		s	10	341	96.8	200	$<10^{-4}$
20	Survey Lake	ℓ	11	317	79.4	1520	$<10^{-2}$
		s	9	006	71.7	2300	$<10^{-2}$
21	Survey Lake	ℓ	15	330	97.6	140	$<10^{-6}$
		s	5	319	98.1	80	$<10^{-2}$
37	Syncline River	ℓ	3	324	99.0	25	.053
		s	10	002	99.1	30	$<10^{-3}$
38	Syncline River	ℓ	5	145	42.3	5780	.409
		s	22	117	98.1	80	$<10^{-8}$
43	Log River	ℓ	15	201	77.7	1760	$<10^{-3}$
44	Syncline River	ℓ	27	320	34.1	7060	.043

ℓ = large scale (trough and planar) cross-stratification,

s = small scale (climbing ripple) cross-stratification. Other symbols as in Table 1.

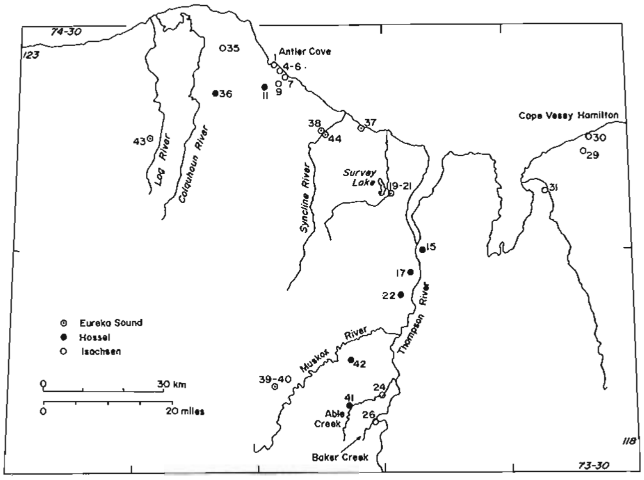

Figure 2. Northern Banks Island, showing localities visited, with locality number. Geographic names in italics are proposed by the author and at present have informal status only.

Paleozoic Stratigraphy

A composite section 363 m (1, 198 ft.) was measured during two days of field work on the exposures of Melville Island Group at Cape Crozier. Shale, siltstone and sandstone are the predominant rock types; plant remains and rare brachiopods the only macrofossils. Sandstones are fine grained and quartzose and are characterized by small-scale internal structures, including ripples, sole structures and parting lineation.

The correlation of this section with the Devonian exposures on northeastern Banks Island (Klovan and Embry, 1971) and in the subsurface (Miall, this publication, report no. 116) is currently under study.

Mesozoic and Tertiary Stratigraphy

The major part of the 1973 field work consisted of detailed studies of the coarser clastic units in the post-Paleozoic succession, in particular the Isachsen, Hassel, and Eureka Sound Formations. The observations reported below largely confirm and expand those of Jutard and Plauchut (1973) and Cassan Evers (1973) whose work was of a more reconnaissance nature. Localities visited in 1973 are shown in Figure 2.

1. Isachsen Formation

A. Thickness and Gross Lithology - No complete exposures of this unit are available, but partial exposures allow the reconstruction of composite sections. At Able and Baker Creeks (Fig. 2, Locs. 24 and 26) the formation is estimated to be 76 m (250 ft.) thick, and at Cape Vesey Hamilton (Loc. 30) 136 m (450 ft.).

Along the east side of Northern Banks Basin the Isachsen may be divided into upper and lower parts on the basis of grain size variations. The lower Isachsen consists of medium- to very coarse grained, pale-coloured quartzose sand, locally gritty and containing

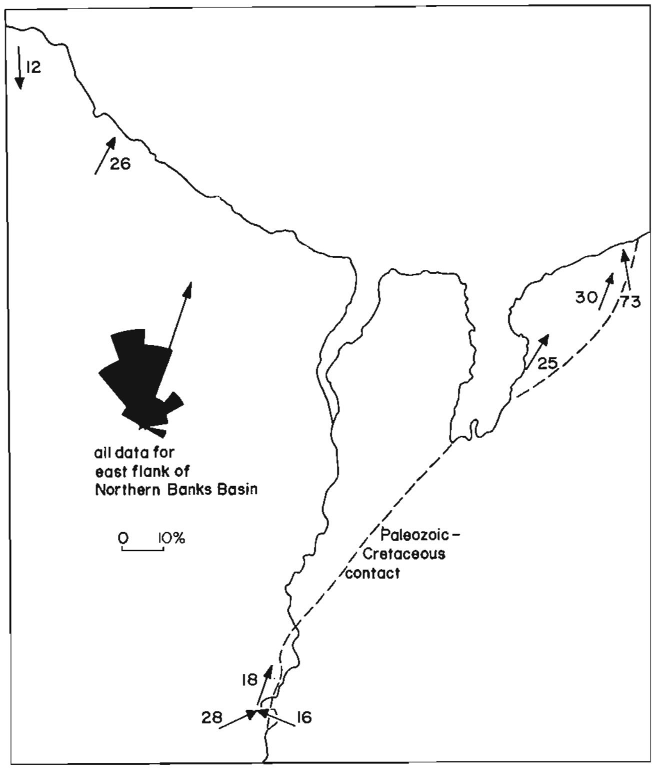

Figure 3. Paleocurrent measurements in the Isachsen Formation, showing outcrop vector means and number of readings.

pebble and boulder beds. Soft black clay lenticles are present in places, as are thin seams and pockets of lignite debris. Large-scale current structures are abundant, in particular planar cross-sets up to 1 m in thickness. The unit is approximately 70 m (230 ft.) thick at Able and Baker Creeks and 108 m (356 ft.) at Cape Vesey Hamilton. The contact of this unit with the underlying Devonian rocks is rarely seen. There is a gradational contact with the upper Isachsen, which consists of fine-grained sand, silty sand and some carbonaceous beds. Small-scale ripples are the most common internal structure. The upper Isachsen is 7 m (23 ft.) thick at Baker Creek (Loc. 26) and 28 m (92 ft.) thick at Mercy River (Loc. 31). The contact with the Christopher Formation is generally abrupt but conformable.

Several exposures of the (upper?) Isachsen were visited in the Antler Cove area of northern Banks Island. The formation was previously believed to be completely absent in this region due to overlap by the Christopher Formation (Thorsteinsson and Tozer, 1962), but its presence was confirmed by the later work of Jutard and Plauchut (1973). At Antler Cove the formation is generally fine to medium grained and is characterized by medium-size trough crossbeds, planar lamination and extremely low-angle planar crossbedding.

B. Sediment Source and Transport Directions - A total of 251 foreset azimuth readings were measured in the sedimentary structures of the Isachsen Formation, 209 of them in the lower Isachsen. Planar crossbedding (alpha and epsilon types of Allen, 1963), plus occasional large solitary troughs (theta cross-stratification) are the dominant structures. The data (Table 1, Fig. 3) have been processed using the vector summation method of Curray (1956) and a weighting process described by Miall (in prep.).

The majority of sedimentary structures indicate northerly transport directions. However, at Baker Creek (Loc. 26) there is a clear example of two distinct mean current directions, one in the lower part of the exposed section and one in the upper part (Fig. 3). The westerly vector in the lower part of the section is anomalous, and suggests a minor stream system flowing from a local source area. Similarly, local sediment derivation from Cape Crozier Anticline is suggested by the data at locality 35 (Colquhoun River).

Three distinctive lithologies were observed in the pebble-grade and larger clasts: quartz sandstones derived from the Melville Island Group, present as clasts up to 73 cm in diameter; a suite of silicified carbonate rock types including flat-pebble conglomerates, oolites and stromatolites, believed to be derived from the lower Paleozoic of Victoria Island; and black chert pebbles containing corals of Pennsylvanian or Permian age (identification by E. W. Bamber). The latter were found at a single locality near Antler Cove, and pose an intriguing problem of origin. Paleocurrent evidence negates the possibility of derivation from the Sverdrup Basin, unless the basin was formerly much more extensive. Alternatively the coral-bearing pebbles may have been derived by long-range transportation from the ancestral Brooks Range geanticline.

The source of the Isachsen sands is a problem, for the local Paleozoic rocks, including the Melville Island Group, contain very little sand material of sufficient coarseness. Proterozoic sediments of Minto Uplift or the mainland, or possibly upper Paleozoic clastics from an extended Sverdrup Basin, may have been important sources. Petrographic and heavy mineral studies may provide an answer to this problem.

C. Depositional Environment - The preponderance of coarse clastic debris, the presence of lignite and the absence of any marine fauna indicate a continental origin for the Isachsen. The scarcity of silt or clay in the lower Isachsen and the absence of fining-upward cycles suggest that the unit was not formed by deltaic distributaries or high sinuosity streams, which are characterized by lateral accretion and cyclic sequences, and by minor but significant thicknesses of fine-grained overbank deposits (Visher, 1965; Allen, 1965). The lower Isachsen contains abunant superimposed large-scale planar cross-sets typically developed as sand waves and flat-topped bars within braided streams (Coleman, 1969; Williams, 1971; Smith, 1972). These streams were clearly of the bed-load type, as defined by Schumm (1968), and were probably of low sinuosity.

The upper Isachsen contains minor quantities of overbank-type strata and is generally finer grained. It may be the deposit of lower energy, more sinuous streams.

Total variance for combined data from the east flank of Northern Banks Basin (Locs. 24, 26, 29, 30 and 31) has been calculated using only data from large-scale cross-stratification (rank 5 of Miall, in prep.). The figures are as follows: n = 198, O = 003, L = 74.4, $S^2 = 2020$, $p = < 10^{-47}$ (see current rose diagram, Fig. 3). Comparison with data from modern rivers (Table 1 of Miall, in prep.) confirms a low to medium sinuosity for the lower Isachsen streams. Data were collected to show within-outcrop variance and vertical orientation changes, but have yet to be processed.

D. Tectonic Implications - The northerly flowing current system conforms only approximately to the axial direction of Northern Banks Basin and to the direction of structural strike of its margins. The present outline of the basin is thus in part the result of post-Early Albian tectonic movements, and the basin was, during the Early Cretaceous, part of a much larger and as yet undefined depositional area.

The local vectors at Baker Creek and Colquhoun River do conform to present-day structural dip, suggesting the existence of an embryonic Banks Basin, in the form of a lower-order topographic relief within the larger basinal area. Other local uplifts are suggested by the coarseness and angularity of conglomerate clasts in the lower Isachsen, near Cape Vesey Hamilton. The present-day contact between the Isachsen and Devonian strata east of Mercy Bay is at least in part fault controlled; many of these structures may have originated as fault-line erosional scarps during Isachsen times.

2. Hassel Formation

A. Thickness and Gross Lithology - The Hassel Formation appears to maintain fairly constant thickness in Northern Banks Basin, between 12 and 19 m (40 to 63 ft.). The principal lithology is sand, pale in colour, quartzose, very fine to medium grained with rare small pebbles of chert and Devonian quartz sandstone and a few minor clay laminae. Locally, ironstone nodules containing ammonites and pelecypods are present.

The sands are characterised by small-scale current structures, principally ripple-marks in solitary trains or of climbing type (kappa, lambda and mu cross-stratification of Allen 1963). Solitary troughs (theta cross-stratification) are present in a few outcrops.

The Hassel shows a gradational contact with the underlying Christopher Formation, consisting of interlaminated sand and clay. At locality 15 (lower Thomsen River) this transition is 6.5 m (21.5 ft.) in thickness and is typically lenticular bedded (in the sense of Reineck and Wunderlich, 1968). The sands contain small-scale ripples of height less than 1 cm and the shales are characteristically bioturbated.

The contact of the Hassel with the Kanguk appears to be abrupt.

B. Sediment Source and Transport Directions - Transport directions are not clearly defined by the available paleocurrent information (Fig. 4). This is partly a function of the paucity of data (58 azimuth readings

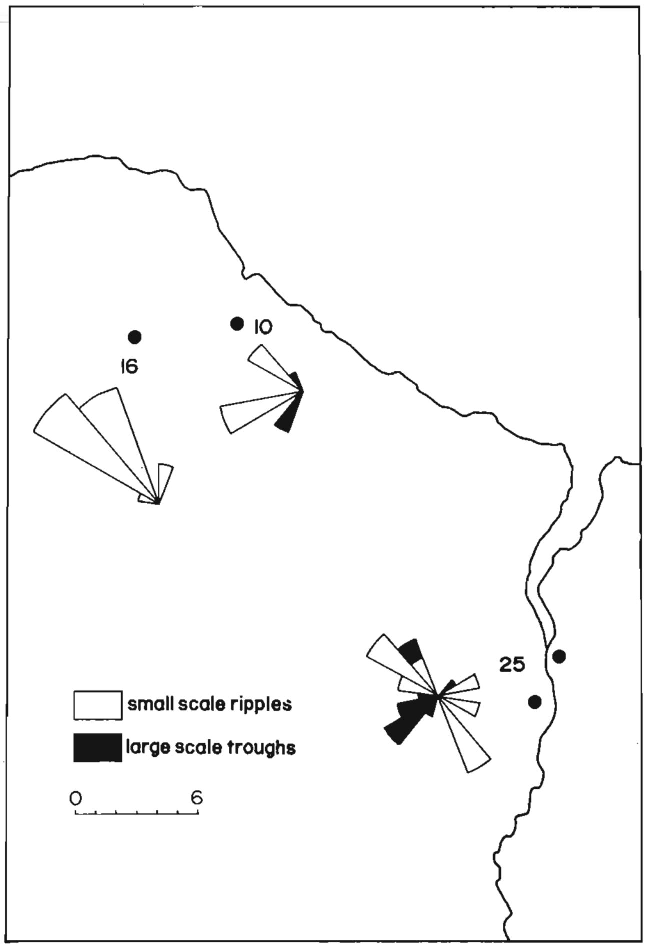

Figure 4. Paleocurrent measurements in the Hassel Formation, showing current rose diagrams plotted by number of readings, and total number of measurements per outcrop.

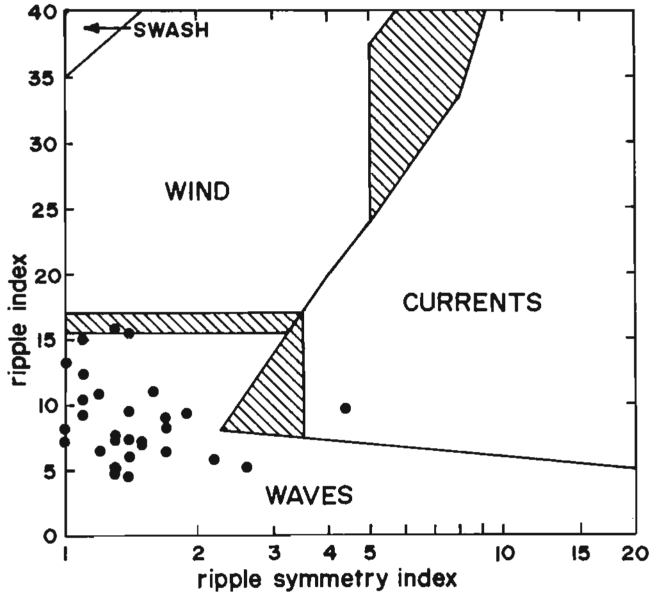

Figure 5. Measurements on 29 ripple structures in the Hassel Formation, plotted using the indices of Tanner (1967). Cross-hatched areas are regions in which index interpretation is ambiguous.

from four of the seven field stations visited) and partly due to the nature of the depositional environment. Calculated vector means were found to be not significant or barely significant at the 95 per cent confidence level.

Petrographic work is in progress in order to determine possible sediment sources for the Hassel.

C. Depositional Environment - The macrofaunal assemblage and the abundance of bioturbation indicates a marine environment for the Hassel Formation. The alternation of sand and clay beds in the Christopher-Hassel transition beds is very characteristic of deposits formed under the influence of tides (Reineck and Wunderlich, 1968). The transition upwards into predominantly sandy beds indicates a greater proximality, probably nearer shore and/or shallower water depths. A continuing marine influence is indicated by the presence of ammonites in nodules within these thick sand beds.

The depositional environment appears to have been predominantly low energy for small-scale ripples, including climbing ripples, are the most common type of internal structure.

The subtidal or intertidal environment also is indicated by a plot of ripple index and ripple symmetry index (Fig. 5). All but one of the 29 readings fall within the area interpreted by Tanner (1967) as wave-generated ripples. However, the internal structure of most of the ripples indicates that they are wave-modified current ripples. Klein (1970) has shown that polymodal or radial-elliptical paleocurrent patterns as shown in Figure 4 are characteristic of deposits formed under the influence of tides.

D. Tectonic Implications - Paleocurrent modes are sub-parallel and sub-perpendicular to the axis of Northern Banks Basin. The latter thus may have controlled the shape and orientation of the Hassel sand bars which would, presumably, parallel the coastline as do modern sand bars.

3. Eureka Sound Formation

A. Thickness and Gross Lithology - Estimates of total thickness of this unit are extremely difficult to arrive at, owing to paucity of exposure and the abundance of surficial slumping. Thorsteinsson and Tozer (1962) estimated the Eureka Sound to be approximately 1,500 feet thick, excluding beds now recognized to be Kanguk in age. Jutard and Plauchut (1973) give a figure of 4,800 feet on the basis of their own surface geological work. The present author's opinion is that a thickness figure based purely on surface information is liable to at least a 50 per cent error, and that the correct figure may be anywhere between 2,000 and 5,000 feet.

Jutard and Plauchut (1973) recognize three members within the Eureka Sound Formation. The author's own field work to date does not support a subdivision of the younger beds into their members two and three. Exposures corresponding to member one have yet to be visited.

The exposures which were visited exhibit a uniform succession of sand, shale, interlaminated sand and shale, soil zones and thin lignitic coals. The sand is generally very fine grained, quartzose, pale in colour, unconsolidated, and contains a wide range of sedimentary structures; petrified wood is abundant throughout. Bed thickness is generally in the order of a few metres, but several sand units were mapped which reached greater thicknesses, e.g., 14 m at locality 20 (Survey Lake) and 21.5 m at locality 44 (Syncline River).

Shales are soft, dark brown-grey or mottled in colour, micaceous, and contain abundant plant fragments. Sand laminae are common, and may show contorted bedding as a result of early diagenetic density flowage.

Soil zones are typically sandy and iron-stained. They contain abundant roots and rootlets, which commonly extend downwards into the underlying bed. Ironstone lenses, which are present throughout the Eureka Sound succession, may be soil zones that have been highly oxidized. Many of the ironstone nodules contain abundant root and wood impressions, which supports this interpretation.

Lignites range from lensoid bodies a few centimetres thick up to persistent seams reaching 2 m in thickness. The thicker units commonly contain thin, discontinous shale laminae.

The lithologies of the Eureka Sound Formation show a cyclic relationship in vertical section. This is discussed below.

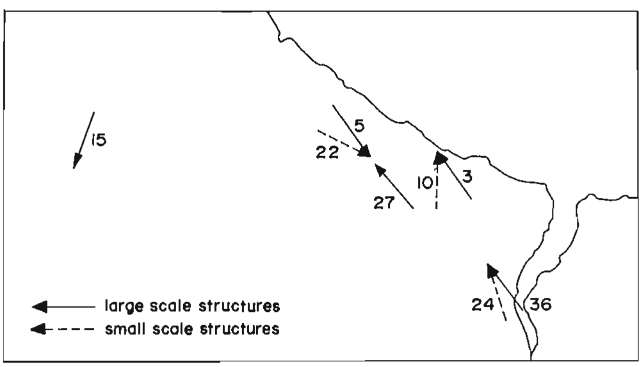

Figure 6. Paleocurrent measurements in the Eureka Sound Formation, showing outcrop vector means and number of readings.

B. Sediment Source and Transport Directions - The fine grain size of the sands would be consistent with derivation predominantly from the nearby Upper Devonian strata. Detailed petrographic work has yet to be carried out.

Paleocurrent patterns drawn up from the 145 field measurements are fairly well defined (Table 2, Fig. 6). For the most part they indicate currents flowing perpendicular to the present-day strike of Northern Banks Basin.

C. Depositional Environment - The Eureka Sound Formation is largely nonmarine throughout the Arctic Islands, and there appears no reason to doubt that this is also the case in the Banks Island area. The lithologic assemblage, particularly the presence of coal and soil zones, is typical of a deltaic environment.

The Eureka Sound deposits exhibit upward-coarsening cycles in most of the outcrops visited to date. This has been confirmed by a statistical analysis of all measured sections using a first-order Markovian embedded-chain method. The technique is summarized elsewhere (Miall, 1973). Figure 7 shows the transition paths derived by examination of the Markov difference matrix. The principal cyclic pattern or repeat-unit consists of an upward succession of shale, interbedded shale and sand, shale-free sand, and ranges from 5 to 10 m (16-33 ft.) in thickness.

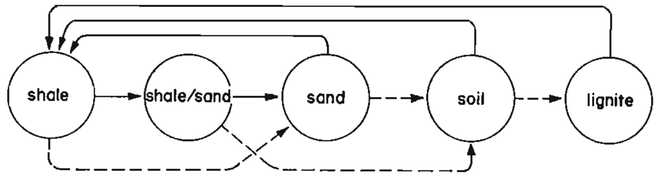

Figure 7. Lithologic transition paths in the Eureka Sound Formation, northern Banks Basin, derived from Markov analysis. Principal paths shown by solid lines, less important paths by dashed lines.

Soil zones and lignites were observed in the field to follow and be followed by several different lithologies, but statistically the most significant relationships are those shown in Figure 7. Additional field observations provide confirmatory evidence of the genetic importance of these transitions. In the case of the three-member clastic cycle the uppermost few centimetres of the sand member frequently contain large roots that are sharply truncated at the shale contact, suggesting removal of a soil by erosion before deposition of the next bed. Similarly a few soil-shale contacts, when traced laterally, exhibit small pockets of lignite preserved between the soil and the shale. The inference is, again, that erosion prior to the shale deposition removed a much more laterally persistent lignite seam.

The upward coarsening in the clastic members is thought to represent the progradation of a delta distributary or distributary system into an inter-distributary or pro-delta area. The coarsening of the sediment was accompanied by shallowing of the waters, until marsh conditions were attained and vegetation growth commenced. Abandonment of the area by the distributary as a result of channel migration or avulsion caused subsidence to exceed sedimentation rate, and the pro-delta waters returned to deposit shale and begin a new cycle. The erosional contact between pro-delta shales and the underlying beds may be either subaerial in origin or the result of wave action. This cyclic pattern is very similar to that which has been deduced for modern deltaic areas (Scruton, 1960) and for other coal-bearing cyclic deposits, particularly those of Carboniferous age in Europe and the United States (Duff and Walton, 1962; Merriam, 1970). The main difference is the absence of a marine member, commonly limestone, between the coal and the pro-delta shale.

D. Tectonic Implications - Paleocurrent evidence suggests that Northern Banks Basin was a true depositional basin in early Tertiary times, with a configuration close to that observable at the present day.

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In the 1973 field season approximately ten weeks were devoted to the gathering of additional structural stratigraphic and paleontologic control required in the production of 1:250,000 scale geological maps of the Canadian Cordillera and adjacent Interior Platform north of latitude 65° and west of longitude 132°. The writer, in addition, maintained a base camp and provided logistical support and scientific direction for field work carried out by L.D. Dyke, W.H. Fritz and R.W. Mac queen (see their respective contributions in this volume), as well as by J.A. Jeletzky and F.G. Young.

As a consequence of this work, the writer reports the occurrence of specular hematite in the Lower Cambrian on the east flank of Richardson Anticlinorium, of galena in the Lower Cambrian in the core of the anticlinorium, of copper and asbestos in Proterozoic rocks in the core of Taiga-Nahoni Fold Belt, of anthracitic coal in the Mesozoic on the northwest flank of Aklavik Arch, and of oil-saturated ironstone and sandstone in the upper Paleozoic and the Lower Cretaceous respectively, on the west flank of Richardson Anticlinorium. Because of the reconnaissance nature of the projects, the true economic significance to these occurrences could not be established. They may be of interest to the reader, however, because they identify selected areas and stratigraphic levels at which mineral potential may be localized and prospected.

In addition, some significant emendations have been made to the Correlation Chart (Table 1) summarizing the stratigraphic framework of the Cordilleran Orogenic System within the project areas. Other corrections will necessarily depend upon more office and laboratory work. Moreover, the writer re-established and augmented basic geological control in the Snake River map-area (106F), because maps and notes were almost totally lost in the Margaret Lake fire in 1970.

In conjunction with H.N. Reiser of the U.S. Geological Survey, the writer re-examined the lithostratigraphy of the Neruokpuk Formation in Romanzof Uplift on both sides of the Yukon-Alaska border, and visited the type area of the Neruokpuk in the vicinity of Lake Peters, in Mt. Michelson Quardrangle (Reiser et al., 1971) in northeastern Alaska. The coarse-grained, grey quartzites and associated grey, slaty argillites found there are noted to be very similar to lithologies observed in the Neruokpuk in Romanzof Uplift in Canada. This and other lithostratigraphic assemblages in the Neruokpuk which are recognized by U.S. geologists can be extended into Canada and mapped southeastward through the uplift to about Trail River where they are covered by Mississippian and younger sedimentary rocks. A closer study of the contact between the lower Paleozoic volcanic and limestone unit (see Table 1) and the underlying Neruokpuk would suggest that it is not angular as proposed by the writer (Norris, in press), but rather that the two rest in structural conformity with one another. Thus the Neruokpuk there is older than the late Early Cambrian but, depending on the structural and stratigraphic relations between this assemblage and that northeastward of it in the uplift, some of the Neruokpuk may be early Paleozoic in age. Indeed, a single Late Ordovician graptolite was found (Dutro et al., 1971) in dark grey, slaty argillite on the north flank of Romanzof Uplift along the International Boundary, and the occurrence of rocks coeval with part of the Road River Formation in Barn Uplift and in Richardson Anticlinorium was established.

The feldspathized, phyllitic argillites exposed on the east flank of Richardson Anticlinorium (see Norris et al., 1963) were restudied, their areal extent outlined, and their contact relations with the overlying Cambrian defined. According to W.H. Fritz (pers. comm., 1973), trilobites collected from light grey limestone approximately 115 feet stratigraphically above the phyllites are late Early Cambrian in age, and the phyllites must be correspondingly older. The whole comprises an uplifted block, bounded on both flanks by north-northwest-trending, nearly vertical faults. These limestones are particularly interesting because specular hematite (E. Ghent, University of Calgary, pers. comm., 1973) was noted in limestone breccia at one locality immediately above the phyllites. The mineral occurrence is located near the headwaters of Caribou River in Trail River map-area (106L) at Latitude 66°15.4'N, and Longitude 135°23'W. Its precise location may be found on NAPL air photograph A13754-161, at the following Cartesian co-ordinates* measured with respect to the centre of the photograph where the positive Y-axis corresponds to the north direction: X = -0.50 cm., Y = 1.58 cm. Moreover, J. Pilon of the Geological Survey reports (pers. comm., 1973) the occurrence of galena in a sink hole in this same (unnamed) limestone formation 15 miles to the southwest in Trail River map-area at Latitude 66°07.0'N, Longitude 135°48'W. Its location may be found on NAPL air photograph A14122-5 at the following co-ordinates: X = -1.53 cm., Y = -2.65 cm. The formation is exposed over an area of approximately 25 square miles in the core of the anticlinorium as well as in fault blocks on its east flank and it may warrant closer examination than that given it by the writer in the course of regional mapping.

A 13,500 foot section of Proterozoic clastics and carbonates (no base) immediately east of Blackstone River (latitude 65°01', longitude 138°05') in the ex-

*For further details on this technique for precise location of points on the ground, the reader may wish to refer to Norris, 1972a.

Figure 1. View to the north of acutely folded, coal-bearing rocks of Jurassic (?) age on the northwest flank of Aklavik Arch, northern Yukon Territory. Photo DKN, 1973.

treme southeast corner of Ogilvie River map-area (116G) was restudied by L.D. Dyke, following the total loss of field notes in the 1970 fire. This examination was part of a broader study to establish the basic stratigraphic framework of the Proterozoic rocks in the project area. Noteworthy was his observation (L.D. Dyke, pers. comm., 1973) of minor copper mineralization as well as some thin veins of fibrous asbestos in the contact zones of basic igneous dykes which have intruded, and appear to be confined to, the Proterozoic succession. The latter can be subdivided there into three bulk lithostratigraphic units, a lower argillite and quartzite unit, 7,500 feet thick, a middle quartzite unit, 1,500 feet thick, and an upper orange-weathering, stromatolite-bearing unit, 4,500 feet thick. The lower argillite and quartzite would appear to correlate with Unit 1 in adjacent Dawson, Larsen Creek and Nash Creek map-areas (Green, 1972), and the remainder to Unit 2.

A second Proterozoic section was measured by Dyke still farther west near the headwaters of Tatonduk River (latitude 65°22', longitude 140°16'), with the

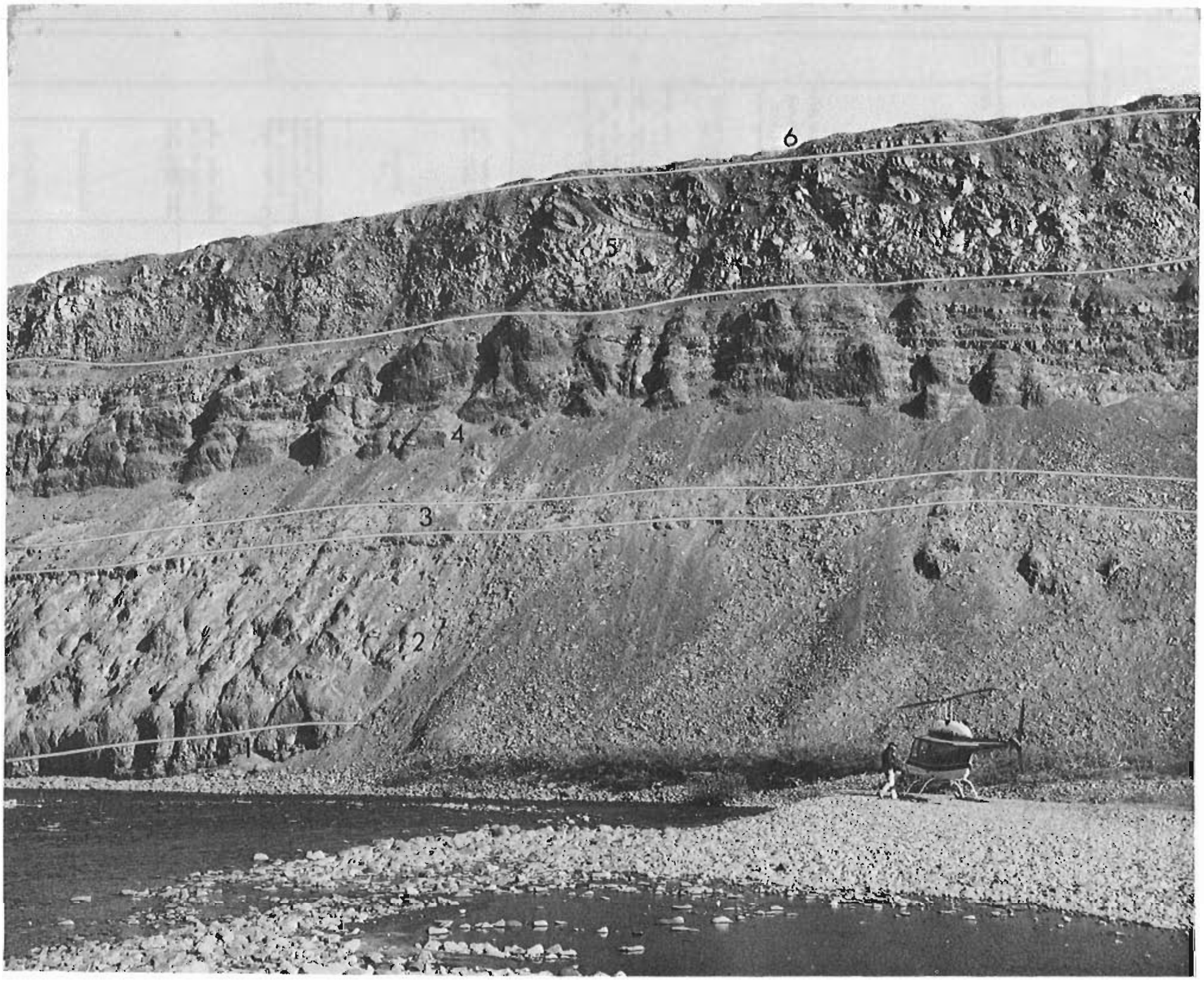


Figure 2. View to the southeast of Upper Cretaceous clastic sequence on lower Trail River in Arctic Coastal Plain, northern Yukon Territory. Photo DKN, 1973.

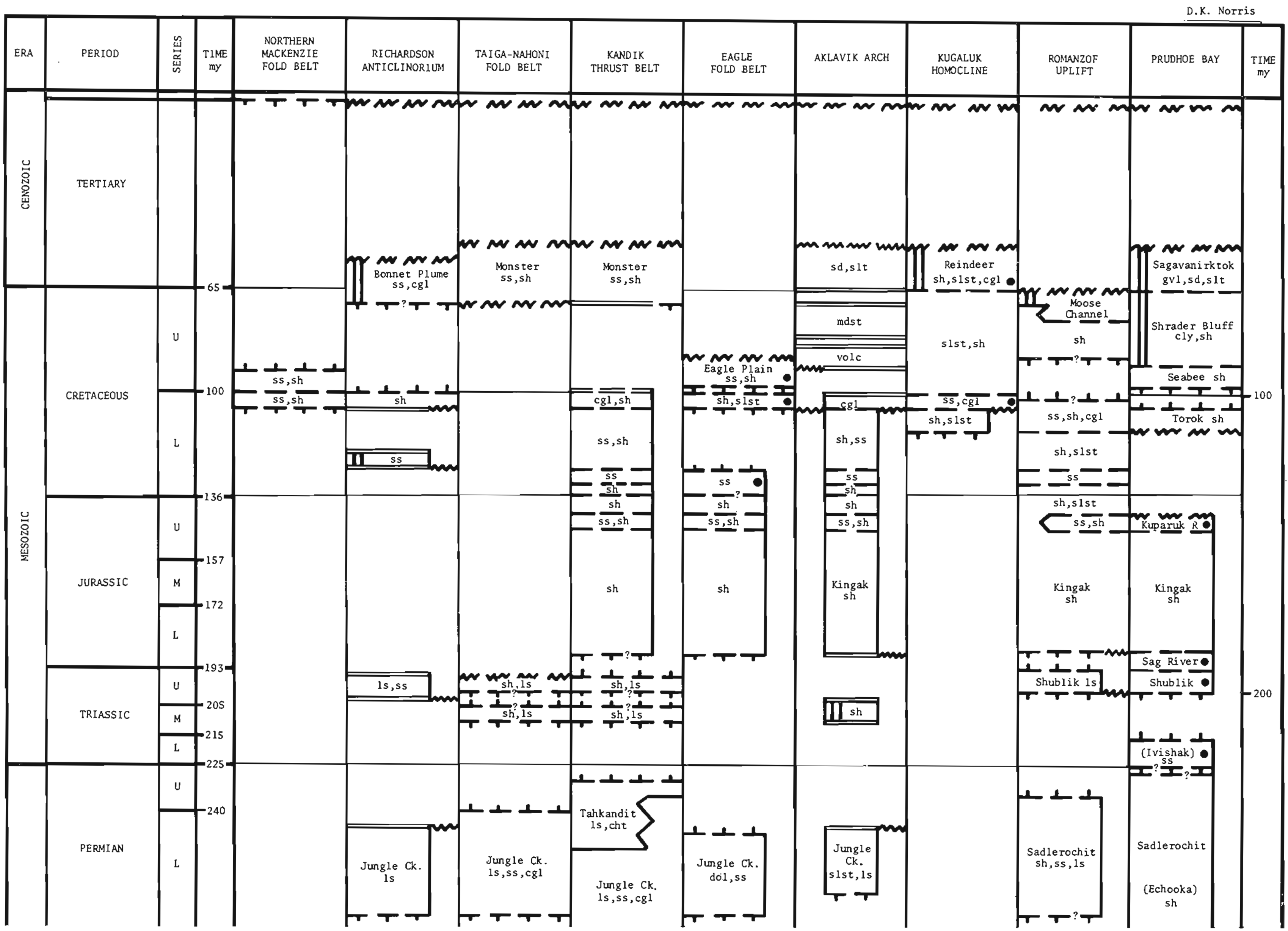
objective of correlating these rocks exposed in the cores of anticlines and uplifted blocks in Taiga-Nahoni Fold Belt with the Tindir Group along the Alaska border. In this section he observed two units, a lower quartzite unit, 900 thick, and an upper, orange-weathering dolomite, unit 775 feet thick. A spectacular anular unconformity separates the latter from the overlying Lower Cambrian carbonates. The two would appear to correspond to the upper units of the Blackstone River section, and in turn to Green's (op. cit.) Unit 2. The hematite-rich shales and quartzites reported by Cairnes (1914, p. 53) in the vicinity of Tindir Creek along the Alaska border were not recognized by Dyke in either the Blackstone or Tatonduk sections. Although precise correlations with the Tindir are not yet worked out, the the writer tentatively suggests that the stomatolite - bearing, orange-weathering dolomite and the quartzite unit underlying it may correspond to the "dolomite and shale" member (Brabb and Churkin, 1969), and the argillite and quartzite unit to the "shale" member. The latter two members comprise the basal units of the Tindir Group in the Charlie River Quadrangle (Brabb and Churkin, ibid.) in Alaska immediately adjacent to the Tatonduk section. Still younger parts of the Tindir would appear to have been removed at the sub-Cambrian unconformity.

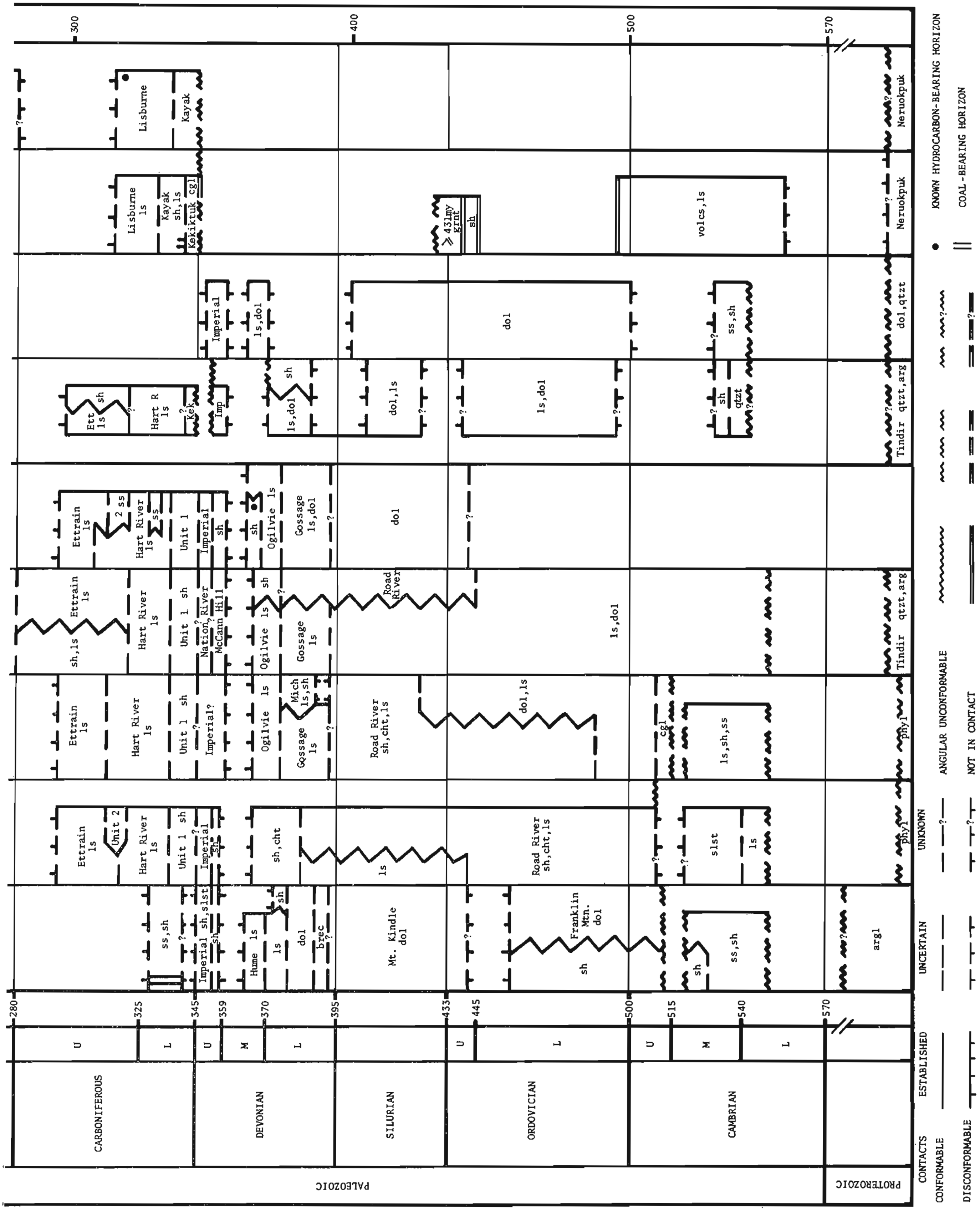
Another granitic stock was discovered in northern Yukon Territory in Old Crow map-area (116-O) a few miles north of Porcupine River and about midway between Mount Schaeffer and Driftwood River (latitude 67°35.7', longitude 139°15.0'). There the intrusion is composed of two distinct phases, a grey, relatively fresh granite which would appear to be suitable for a radiometric age determination, and a pink, rather highly altered, fluorite-rich phase. Because of poor exposure, it was not possible to establish the contact relations between the two rock types or with the Tindir Group. It seems, however, that they belong to the family of Devonian or older, discordant, acid igneous intrusions in this part of the Cordilleran Orogenic System. Their presence should not detract from the hydrocarbon po-

Table 1

CORRELATION CHART

NORTHERN YUKON TERRITORY,. NORTHWESTERN DISTRICT OF MACKENZIE AND PRUDHOE BAY





300
400
500
570
280
325
345
359
370
395
433
445
515
540
PALEOZOIC
PROTEROZOIC
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
U
L
M
Lisburne
Kayak
Neruokpuk
Lisburne ls
Kayak sh,ls
Kekiktuk cgl
≥ 431my grnt
sh
volcs,ls
Imperial
ls,dol
dol
ss,sh
dol,qtzt
Ett ls
sh
Hart R ls
Kek
Imp
ls,dol
dol,ls
qtzt
Tindir qtzt,arg
Ettrain ls
2 ss
Hart River ls
ss
Unit 1
Imperial sh
Ogilvie ls
Gossage ls,dol
sh,ls
Unit 1 sh
Nation River
McCann Hill
Gossage ls
Road River
Ogilvie
Mich ls,sh
Road River sh,cht,ls
dol,ls
Imperial?
cgl
ls,sh,ss
phyl
Unit 2
Unit 1 sh
Imperial sh
sh,cht
Road River sh,cht,ls
slst
ss,sh
Imperial sh,slst
Hume ls
brec
Mt. Kindle dol
Franklin Mtn. dol
argl
CONTACTS
CONFORMABLE
DISCONFORMABLE
ESTABLISHED
UNCERTAIN
UNKNOWN
ANGULAR UNCONFORMABLE
NOT IN CONTACT
KNOWN HYDROCARBON-BEARING HORIZON
COAL-BEARING HORIZON

tential in Mississippian and younger rocks beneath Old Crow Plain.

Bright coal, determined to be anthracite (A. Cameron, pers. comm., 1973) was discovered on the left (north) bank of a tributary of Bell River in Bell River map-area (116 P) at latitude 67°55.5', longitude 136°57'. It occurs in seams up to one foot thick as interbeds in dark grey, fine-grained sandstone deformed into tight folds (Fig. 1) with steeply south-plunging axes. Although no macrofossils were found with which to date these coal-bearing rocks, it would appear from regional mapping that they are Late Jurassic or Early Cretaceous in age. This is the third horizon at which coal is now known to be present in northern Yukon Territory, the first being anthracite in the Mississippian Kayak Formation (Norris, 1972b), on the periphery of Barn and Romanzof Uplifts, and the second being high volatile bituminous "C" coal in the Upper Cretaceous Moose Channel Formation (Norris, ibid.) on the Arctic Coastal Plain. The high rank of the Mississippian and Jurassic(?) coals clearly identifies deep burial and/or thermal metamorphism of the associated rocks and does not augur well for favorable hydrocarbon potential of stratigraphic levels below the Upper Cretaceous in this part of the orogenic system.

While mapping along the eastern margin of Eagle Plain, the writer revisited an outcrop of shale with septarian, ironstone nodules rich in fossil hash and saturated with natural hydrocarbons. The locality is in Eagle River map-area (116 I) on a tributary from the west of Eagle River. It occurs at latitude 66°26', longitude 137°00', and may be precisely located on NAPL air photograph A12133-36 at the following co-ordinates: X = 3.34 cm., Y = -4.32 cm. According to E.W. Bamber (pers. comm., 1973) the fossils would indicate that the rock is most probably late Paleozoic in age, and the writer, on the basis of its lithology, stratigraphy position and age, would assign the rock to the Mississippian Hart River Formation. Some nodules contain an abundance of saturated aromatic hydrocarbons whereas the associated shales are essentially barren (L. Snowdon, pers. comm., 1973).

In addition, the writer discovered an oil-saturated, porous, ridge-forming, fine-grained, quartz arenite four miles to the west of the septarian nodule occurrence in Eagle River map-area. The locality is at latitude 66°22.5', longitude 137°04', and may be located on NAPL air photograph A12133-80 at co-ordinates X = -0.7 cm., Y = 1.38 cm. It is abundantly rich in poorly preserved fossil clams and it is doubtful if a paleontological age can be ascertained. The writer, therefore, assigns the horizon to the lower part (Neocomian) of the Lower Cretaceous because of its stratigraphic position below the Upper Cretaceous Eagle Plain Formation and above the Mississippian Hart River Formation. The absence of lithic fragments, moreover, would not support the postulate that the horizon is part of the upper (Aptian-Albian) Lower Cretaceous sequence. According to L. Snowdon (pers. comm., 1973), the sandstone also contains abundant saturated and aromatic hydrocarbons and the fact that the horizon is traceable for many miles to the north and to the south of the locality examined would suggest that significant oil-sand reserves may be present there.

With H.N. Reiser, the writer also examined the relatively fresh Tertiary or Quaternary amygdaloidal basalts in the vicinity of Porcupine River, 15 miles west of the Yukon-Alaska border (Brosgé and Reiser, 1969), and compared them with the hydrothermally altered and mildly cleaved basic volcanics on Lone Mountain (latitude 67°17.5', longitude 139°37') in Old Crow map-area. It was immediately apparent that the Lone Mountain volcanics were most likely older. Their proximity to highly sheared, basic dykes trending northeast along a major, nearly vertical fault a few miles north of Porcupine River, moreover, would suggest that they may be genetically related to the dykes. From regional considerations, activity on this fault would appear to have taken place in Middle to Late Cretaceous time and it is tentatively suggested that the Lone Mountain volcanics as well as these dykes may possibly have been emplaced in the Late Cretaceous.

Because of the tecontic significance and hydrocarbon potential of Upper Cretaceous and Lower Tertiary clastic rocks beneath the Mackenzie Delta and the Tuktoyaktuk Peninsula (Norris, in press) the writer restudied a well exposed partial section of these rocks on the right bank of Trail River in Herschel Island map-area (117 D). It is located at latitude 69°02', longitude 138°32', and may be located on NAPL air photograph A13383-159 at co-ordinates X = 7.72 cm., Y = -9.37 cm. There a 155-foot sequence of interbedded sandstones, shales and conglomerates, assigned to the Moose Channel Formation, is almost completely exposed and is described below. The units in the section are identified by their respective numbers on Figure 2. Of particular interest is the Late Cretaceous (Senonian) age of Unit 3 (W.W. Brideaux, pers. comm., 1972), and the stratabound, faulted overturned folds with southwest-dipping axial surfaces in Unit 5. The succession is considered by the writer to lie at the shoreward feather edge of the coarse, Moose Channel clastics and to face a depocentre offshore near the mouth of Babbage River (see Norris, in press, Fig. 1). The section has many of the attributes of wildflysch and is interpreted to represent rapidly deposited, channelled and slumped, soft sediments in a marine environment on the flank of the northeastwardly migrating Laramide foredeep. The section is as follows:

Unit	Description	Thickness (Feet)	Height Above Base
6	Sandstone and shale: sandstone, light grey, fine grained, platy to block weathering, in beds 1 inch to 4 feet thick; interbedded with shale, dark grey, fissile, in beds ½ inch to 12 inches thick. Unit is about 60% sandstone, 40% shale. No samples at this point. Beds are essentially flat lying	6	155
5	Sandstone and shale: interbedded and acutely deformed by folding and faulting. Axial surfaces of folds commonly dip 45° south. Folds bounded and truncated by reverse faults dipping 20° to 70° south. Both folds and faults suggest differential northward transport of the unit with respect to nearly flat lying beds above and below. No samples here	34	149
4	Conglomerate, poorly sorted but with textural layering quite apparent; flat lying. Phenoclasts subangular to subrounded, comprising banded medium and dark grey chert, green chert, light and medium grey quartzite, soft, medium grey shale, medium grey quartz-chert, fine- and medium-grained sandstone, and coarse-grained biotite granite. Sparse pale yellowish brown weathering, dark grey, coarsely recrystallized limestone. Large channels up to 130 feet across and 15 feet deep (see Fig. 2)	47	215
3	Shale, dark grey, fissile, with thin pale yellowish grey and rusty brown weathering bentonitic layers up to ½ inch thick. GSC loc. C-18162 from bottom one foot of unit. GSC loc. C-18163 from top one foot of unit	11	68
2	Conglomerate, poorly sorted but with textural layering quite apparent as in Unit 4. Phenoclasts of chert and quartzite, subangular to subrounded, commonly 1 inch to 3 inches maximum observed dimension but with occasional tabular blocks of medium grey, rusty weathering, conglomeratic sandstone up to 2 feet thick and 8 feet long. Flame structure in some of the blocks suggest indigenous origin for some blocks	53	57
1	Conglomerate, very poorly sorted, with anular to subangular to subrounded clasts commonly 3 to 6 inches maximum observed dimension. Some tabular sandstone blocks measure up to 4 feet long and one foot thick. Base of exposure at river level	4	4

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TRANSPORT DIRECTIONS IN THE ISACHSEN FORMATION (LOWER CRETACEOUS) SVERDRUP ISLANDS, DISTRICT OF FRANKLIN

Project 710069

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The Isachsen Formation is a fluvio-deltaic deposit extending throughout the Sverdrup Basin. The isopach map of the Isachsen shows generally northwesterly trending contours with a thickness maximum in the vicinity of the Sverdrup Islands. There appears to be a northwesterly trending flexure zone in the vicinity of King Christian Island. The thickness increases across this flexure from 200 or 300 metres to the southwest to about 800 metres on King Christian Island to about 1, 200 metres on northern Amund Ringnes Island. The regional thickness variations in the Isachsen in part reflect regional tectonics and a tectono-sedimentologic model for the formation may allow delineation of paleotectonic features.

For prediction of facies distribution and relationships between tectonics and sedimentation it is important to determine the magnitude of the rivers that deposited the Isachsen and whether influx was via numerous relatively small short-lengthed river systems, or a few major systems. If major rivers were present their position was likely related to major tectonic features and may represent long-lived points of influx of sediment to the Sverdrup Basin. If this is the case, documentation of the Isachsen distribution pattern may be used to infer distribution of older fluvial systems. To this end, paleocurrent and other sedimentological data have been collected from the Isachsen. Preliminary analyses are presented here.

In 1972 the Isachsen Formation on Amund Ringnes Island was examined (Roy, 1973) and in 1973 work was done on Ellef Ringnes, King Christian and Cornwall Islands. The description of the Isachsen on Amund Ringnes is generally applicable to the other islands except for the lower few hundred metres on Ellef Ringnes, where, particularly in the northern part of the island, there are conglomeratic beds and pebbles to 10 cm "floating" in coarse sandstone. Conglomerate comprises less than 2 per cent of the interval and the most common sand size grade is medium with a range from very fine to very coarse. The coarser sandstones appear to be channel deposits and commonly occur as part of point bar sequences to 30 metres thick (Fig. 1). There are commonly a number of repetitions of poorly developed fining upward intervals in the channel part of the point bar sequences. Presumably these, in part, are truncated point bar sequences. The channel

Figure 1. Channel and overbank deposits in the lower part of the Isachsen Formation on the Deer River, Ellef Ringnes Island. The sandstone unit is 20 to 30 metres thick.

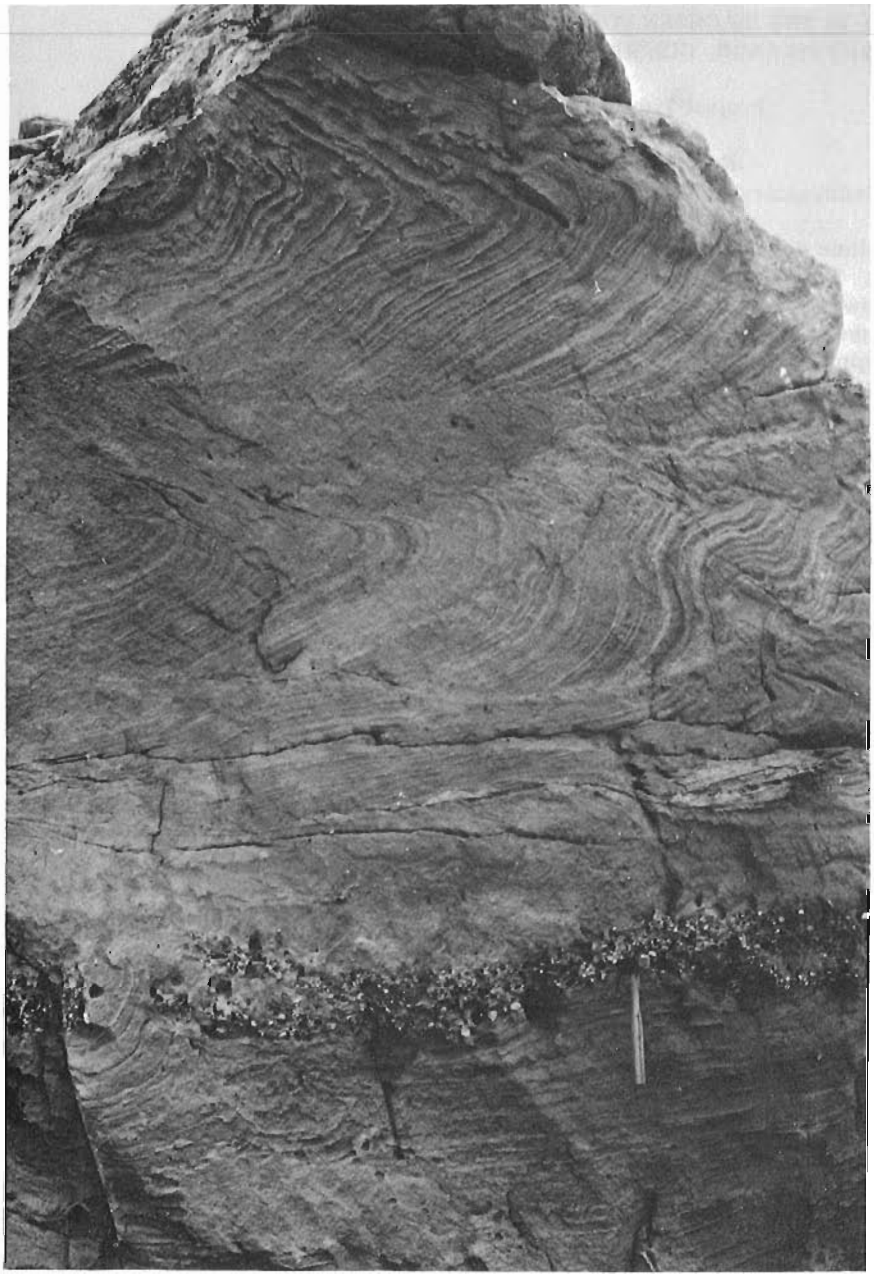

Figure 2.

Contorted cross-stratification in the lower part of the Isachsen Formation on the Deer River, Ellef Ringnes Island. Note the conglomeratic bed in the lower part of the outcrop. The hammer handle is 30 cm long.

deposits are overlain by the finer sandstones, shales and sometimes coals of the overbank deposits. The channel deposits commonly contain large-scale planar-wedge and trough-lenticular cross-stratification with sets to 2 metres thick. These sets are in part very contorted (Fig. 2) presumably in response to turbulent conditions resulting from variations in flow conditions. The size of the point bar deposits, the large scale cross-stratification, and the scattered large pebbles suggest that the streams were up to 30 metres deep at bank-full stage and had high flow velocities at least sporadically.

Preliminary analysis has been made of Isachsen Formation paleocurrent determinations (213 determinations at 56 locations). Transport directions were determined using foreset attitudes plus a few trough axes. Cross-strata used were generally in sets thicker than 0.3 metres and many were up to 1 metre or more thick. Thus, in general, the transport directions indicate movement in major channels. Figure 3 shows the distribution of transport directions, by octant groupings, for six general localities. There is insufficient data from Cornwall Island for statistical prediction.

Figure 2 presents the vector means as well as the maxima and minima of the distributions (after the method of Tanner, 1955), for the total data, and for data from the individual islands. The blacked-in octants are those for which the number of observations is more than one standard deviation larger than the average octant content in the compass rose. The blank octants contain fewer than one standard deviation less than the mean and the stippled octants have numbers

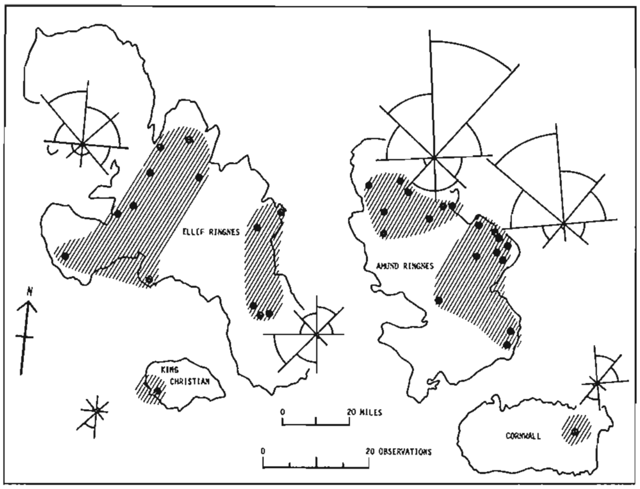

Figure 3. Isachsen Formation paleocurrent directions in the Sverdrup Islands. Data from 56 locations have been grouped into six rose diagrams. The groups of locations are indicated by the line patterns.

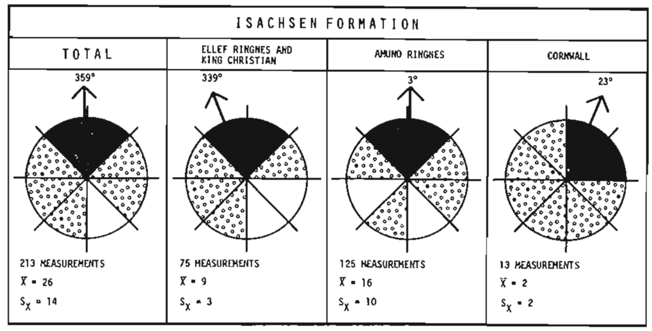

Figure 4. Compass diagram of the paleocurrent directions for the total data as well as the three island groupings. Blackened octants indicate transport directions and white octants indicate source directions (see text for discussion. X is the average number of observations per octant. Sx is the standard deviation of the distribution of observations per octant). The vector means are also given for each distribution.

of observations within one standard deviation of the mean. The maxima indicate transport direction while the minima indicate source direction.

The analyses indicate a pronounced overall northward transport direction. However, separate consideration of vector means and distribution modes in the data from Ellef and Amund Ringnes clearly show a divergence. The vector mean is northwesterly and the minima in the transport direction distribution are from the southeast on Ellef Ringnes and King Christian Islands while on Amund Ringnes the vector mean is north and the minima is from the southwest. These patterns, with the earlier presented evidence of the presence of large rivers, suggest the possibility of a major river system entering the depositional basin from the south in the vicinity of Bathurst Island and Grinnell Peninsula and forming a fan-shaped distribution system in the vicinity of the Sverdrup Islands. More data are required to substantiate this suggestion.

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120. UPPER SILURIAN AND LOWER DEVONIAN (GEDINNIAN) BIOSTRATIGRAPHY AND BRACHIOPOD FAUNAS, BAILLIE-HAMILTON, PRINCE OF WALES AND BATHURST ISLANDS, DISTRICT OF FRANKLIN

Project 730049

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Selected sections of Upper Silurian and Lower Devonian rocks were examined in detail on Baillie-Hamilton, Prince of Wales and Bathurst Islands for their faunal and lithologic content. Large collections of fossils were assembled from the sections to ensure a complete representation of faunas.

On Baillie-Hamilton Island, one section was measured on the northeast coast near Surprise Point and included 118 metres of the Cape Phillips Formation and 182 metres of shallow water, platform-type carbonate rocks that probably are equivalent to the Sutherland River Formation. Another section on the southeast coast near Washington Point included 153 metres of the Cape Phillips Formation and 500 metres of carbonate strata presumably equivalent to the Sutherland River Formation. The upper limit of this carbonate unit is not exposed in either section. The sections yielded rich collections of brachiopods as well as less numerous trilobites and graptolites.

On western Prince of Wales Island, from southern Smith Bay to northern Drake Bay, strata presumably equivalent to the Read Bay and Peel Sound formations were examined. These rocks yielded abundant brachiopods, fish, trilobites and a few graptolites. Near the northern extremity of Smith Bay a carbonate mound of probable Late Silurian age was found in a shelf type environment. It is approximately four to five metres in width and approximately seven to eight metres in height. It is composed of stromatoporoids, colonial corals and algal-like structures. The flanking rocks are composed of argillaceous limestone. On Cape John Dyer, located on the westernmost extremity of Prince of Wales Island, a single important locality was visited in order to collect faunas that are directly related to abundant fish remains. Lower Devonian strata may be in the order of one thousand metres thick in this area and consist predominantly of shallow water shelf carbonates.

On northeastern Bathurst Island, a section was measured in Cut Through Creek a few miles inland from the head of Stuart Bay. The base of the section lies two hundred and fifteen metres below the top of the Cape Phillips Formation. The section ranges through one thousand metres of the Lower Devonian Bathurst Island Formation to the top of the Lower Devonian Stuart Bay Formation, which is approximately four hundred metres thick. The lower parts of the section yielded rich graptolite faunas, of probable Late Silurian to Early Devonian age, that represent a deep water environment.

STRATIGRAPHY AND SEDIMENTOLOGY OF SILURIAN AND DEVONIAN CLASTIC FORMATIONS, CENTRAL ELLESMERE ISLAND

Project 720047

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The stratigraphy and structure of the Silurian and Devonian formations of central Ellesmere Island were established by Kerr in 1961 and 1962 (1967a, b; 1972) in the course of a far-ranging reconnaissance that included the entire pre-Carboniferous succession. The objectives of the present, areally and stratigraphically more restricted study, are to integrate the stratigraphy of northern and central Ellesmere Island and to provide additional information on the provenance and depositional environments of the Silurian and Devonian clastic sediments. These studies shed light on the last phases in the development of the Hazen Trough, which originated in the Hazen Plateau region of northern Ellesmere Island, but migrated into central Ellesmere Island in Late Silurian to Early Devonian time. They also elucidate the tectonic history of the northern regions that were the source of a large fraction of the sediments. Work in 1970 and 1972 was concerned with the Upper Ordovician to Devonian clastic succession of the Canon Fiord region, the key area for these relationships. The work in 1972, concerned with the predominantly Devonian clastic rocks farther south, was undertaken to clarify remaining problems of stratigraphic nomenclature and provenance. The sites and specific problems investigated were selected by R. Thorsteinsson, who had compiled the geological maps for this area (1972a, b, c, d). Field work from June 16 to August 5 consisted of stratigraphic sections and foot traverses from eight fly camps established by helicopter or fixed-wing aircraft with two helicopter traverses out of Eureka. In addition, several days were spend collecting specimens for age determinations from the mafic Bourne Complex and granitic intrusions in northwesternmost Ellesmere Island. Support at Eureka by D.A. Hodgson (Terrain Sciences Division) is gratefully acknowledged.

Upper Silurian and/or Devonian. A belt of calcareous sandstone and siltstone with minor amounts of shale and redeposited limestone west of Trold Fiord now can be assigned to the Imina Formation. The rocks were included previously in an undivided unit of Lower and Middle Devonian Clastics (map-unit D_c of Thorsteinsson, 1972b). The Imina Formation is a flysch-like succession of turbidites deposited in the Hazen Trough. The highly diachronous unit is mainly upper Middle Ordovician to Middle Silurian on the Hazen Plateau and Upper Silurian to Lower Devonian in central Ellesmere Island. At Trold Fiord, it rests on the Cape Phillips Formation, and its top is not preserved. Regional relationships (see Fig. 1, and Trettin, 1973) suggest that it was overlain by the mudstone facies of the Eids Formation. More than 2,200 paleocurrent determinations had shown that, in the Hazen Plateau and Canon Fiord (Trettin, 1971a and b) regions, the Imina Formation was deposited by turbid flows that entered the Hazen Trough from the northwest, about perpendicular to the strike, and were deflected to the southwest, about parallel with strike in the axial region of the trough. A total of 175 determinations at Trold Fiord show that

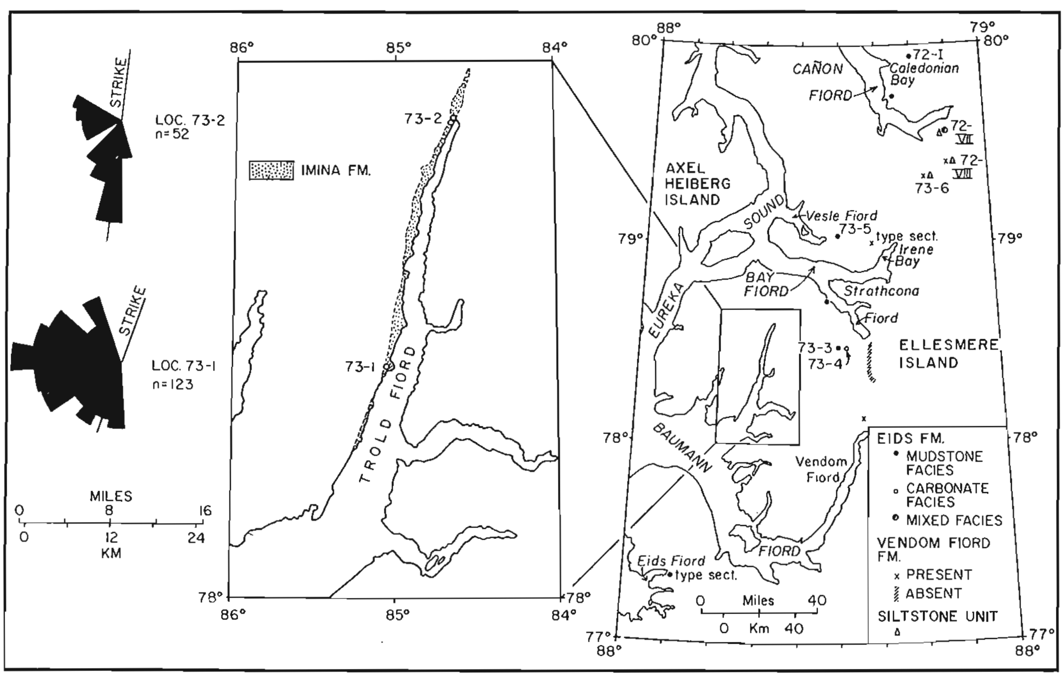

Figure 1.

Right:

Index map of central Ellesmere Island showing localities where contrasting Lower Devonian facies were examined.

Left:

Outlier of Imina Formation at Trold Fiord (after Thorsteinsson, 1972b) and histograms of paleocurrent directions using equal area projection.

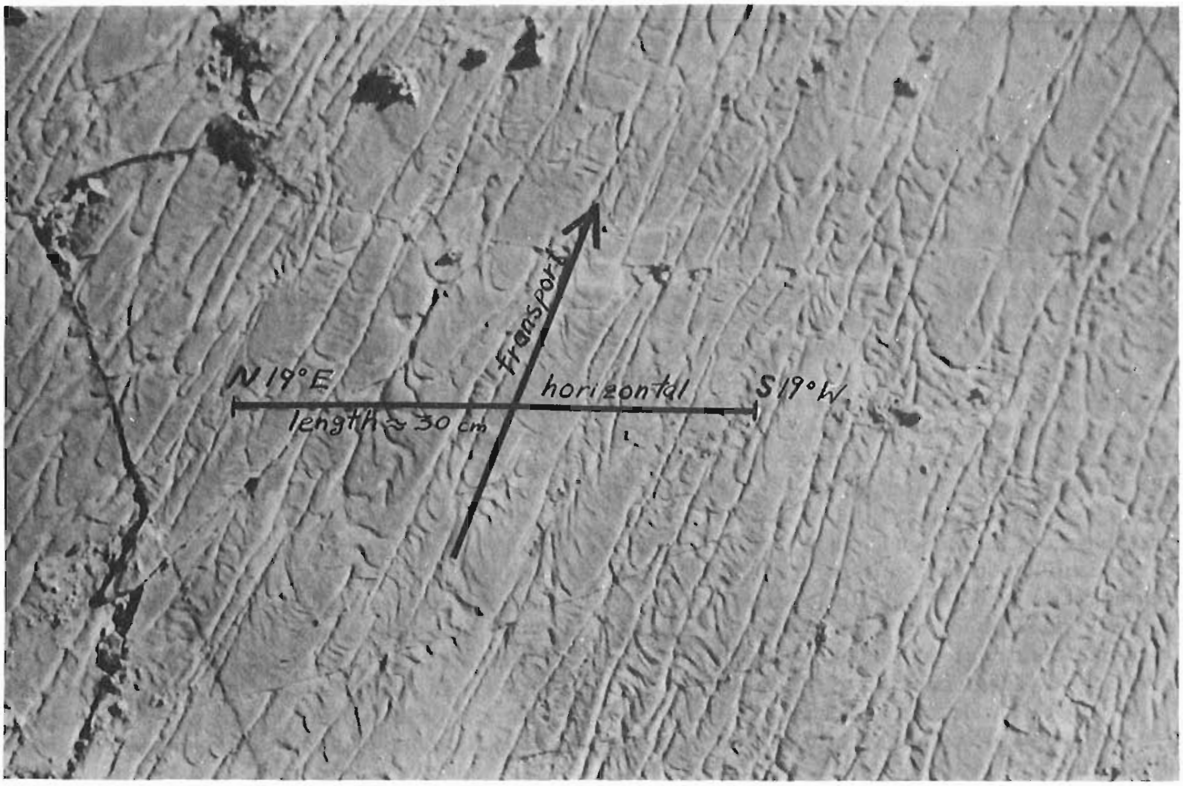

Figure 2. Flute marks at base of overturned turbidite at locality 73-1, view to ESE, perpendicular with bedding. Horizontal line (strike) was marked on rock surface with aid of level, and azimuth of strike was obtained from air photograph. Regional structural setting (see Thorsteinsson, 1972b) suggests that fold axis is about horizontal and parallel with strike. Paleocurrent indicators (comp. Dzulynski and Walton, 1965, p. 44-50) from angle of about 69^{o} with strike. Original orientation obtained by WNW-ward rotation of bed about fold axis (strike). Inferred paleocurrent direction strike SSW (199^{o} azimuth) 69^{o} 268^{o}. This direction lies within modal 15^{o}-sector of histogram, Fig. 1, left.

longitudinal transport, parallel with strike in southerly directions, persisted in this region but that transverse transport was in a westerly rather than an easterly direction (Fig. 1, histograms). The westward oriented flute casts (Fig. 2) may indicate currents that originated on the eastern, cratonic margin of the trough--perhaps as a result of an Early Devonian uplift of the Bache Peninsula Arch (see Kerr, 1967a, b)--but could also be related to essentially longitudinal flows deflected by irregularities within the trough. This problem can, perhaps, be solved by petrographic provenance studies.

Lower Devonian. Four south-trending paleogeographic belts can be outlined in the region between Bay Fiord and Baumann Fiord. They are represented by the Eids Formation, here divided into a westerly mudstone and an easterly carbonate facies; the Vendom Fiord Formation; and a belt farther to the east where equivalent units are absent because of contemporaneous nondeposition or erosion. All four belts are overlapped by the Blue Fiord Formation, a carbonate unit of probable late Emsian to Eifelian age (see Kerr, 1967a, Fig. 2).

The mudstone facies of the Eids Formation overlies the Imina and Cape Phillips formations. It consists of a monotonous succession of horizontally laminated, calcareous mudstones with minor amounts of interlaminated limestone. Fossils (including graptolites in the lower part) are very rare. The Lower Devonian mudstones at Canon Fiord (Trettin, 1973, unit 4) are now included in this unit on the basis of lithological similarities with the type section (McLaren in Fortier et al., 1963, p. 58-59) and stratigraphic setting. This unit represents the last phase in the filling of the Hazen Trough. The lower parts still were deposited in relatively deep water. This is apparent from two features: (1) At Canon Fiord, sandy and silty turbidites comparable to the Imina Formation, occur in the lower part of the section. (2) Southwest of Strathcona Fiord (Fig. 1, right, loc. 73-3) carbonate breccias and conglomerates occur in the lower part of the unit, close to the (concealed) boundary with the carbonate facies. They are comparable to mass flow deposits in the Imina and Cape Phillips formations that evidently were derived from carbonates of the Cornwallis Group and Allen Bay-Read Bay formations, and indicate that the miogeosynclinal carbonate shelf was bounded on the west and northwest by a locally unstable submarine slope. On the other hand, the mudstone facies is overlain by the Blue Fiord Formation with a gradational contact at Vesle Fiord (Fig. 1, loc. 3-5), the transition zone consisting of interbedded Eids-type mudstones and shelf-type limestones. This shows that by about Emsian time the Hazen Trough was filled to shelf level.

The provenance of the mudstones is a complex problem. Paleocurrent determinations at Canon Fiord (Trettin, 1971, Fig. 2a, loc. d) indicate that at least some silicate sediment was derived from orogenic sources to the north, whereas facies relationships in central Ellesmere Island indicate that another fraction came from the Bache Peninsula arch on the east. The carbonate mud-mainly calcite and minor dolomite, which comprise up to about one third of the rock volume—probably was derived from bordering shelves that are partly represented by the carbonate facies of the Eids Formation and by dolostones of the Vendom Fiord Formation.

A well-exposed section of the Carbonate facies of the Eids Formation at locality 73-4 is about 2,500 feet thick. It consists of a variety of rock types, mainly limestones, dolostones, and mudstones with lesser amounts of siltstone and very fine-grained sandstone, that represent a considerable range in depositional environments. Micritic limestones with abundant brachiopods and few corals, predominant in the lower part of the section, were deposited in subtidal shelf environments whereas laminated dolostones, red siltstones, and flat-pebble conglomerates in the upper part of the section were deposited in the upper part of the section were deposited in shallow marine environments. The succession as a whole represents a marine regression with some reversals. Facies relationships suggest that the terrigenous materials came from easterly, cratonic sources.

The Vendom Fiord Formation (Kerr, 1967b and 1972), which occupies a narrow belt east of the Eids Formation, consists of terrigenous carbonate and silicate sediments with gypsum-anhydrite and dolostone. The unfossiliferous unit, which includes many red beds, is of shallow marine to nonmarine origin. It unconforably overlies the Cape Phillips and Allen Bay-Read Bay formations, and its base is somewhat younger than that of the Eids although the tops are about coeval. The terrigenous carbonate clasts came from nearby Allen Bay-Read Bay sources. The silicate sediments appear to have come from easterly, cratonic sources, at least in the region east and southeast of Bay Fiord. There is, however, a marked southward decline in the content of silicate sand, which is high south of Canon Fiord (loc. 72-VIII) and low north of Vendom Fiord. It therefore remains to be clarified by provenance studies whether or not the Vendom Fiord sandstones south of Canon Fiord had a northerly source.

"Red and green siltstone unit". An as yet unnamed formation composed mainly of siltstone, but also including mudstone and sandstone, and lesser amounts of impure limestone and evaporites, underlies the Vendom Fiord in the region south of Canon Fiord (Trettin, 1973, unit 5). At locality 72-VII it is about 5,500 feet thick and overlies the Eids Formation, whereas at locality 73-6 it is only about 130 feet thick and overlies the Read Bay. This southward thinning may indicate that the silicates were derived from a northerly source, but the problem requires petrographic studies.

Upper Middle and Upper Devonian Okse Bay Formation The Okse Bay overlies the Blue Fiord Formation and is unconformably overlain by Carboniferous to lower Tertiary strata. Four stratigraphic sections measured differ in detail, but the two longest (at loc. 72-VIII and 73-4) are both divisible into a lower part, characterized by sandstones, siltstones, and mudstones that contain syngenetic carbonate minerals and probably are shallow marine in origin, and an upper part, characterized by quartz-cemented, commonly pebbly sandstone that may partly be nonmarine. Thorsteinsson and Tozer (1961) suggested that the Okse Bay Formation was derived from northwesterly sources, and this hypothesis is supported by the abundance of detrital chert, particularly in the coarse sand and conglomerate grades. Chert is common in the lower Paleozoic succession of northern Ellesmere Island where it occurs both as bedded, radiolarian deposits and as detritial material in sandstones and conglomerates, but is scarce or absent in the Precambrian terrains of southeastern Ellesmere Island and adjacent Greenland and their cratonic cover. Chert pebbles in the Okse Bay Formation reach a diameter of 5.5 cm (southeast of Strathcona Fiord). Abundant biotite appears to have been derived from metamorphic rocks of upper greenschists to amphibolite facies and perhaps also from granitic intrusions. Such terrains are limited to the north coast of Ellesmere Island and adjacent offshore region.

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122. LOWER PALEOZOIC GEOLOGY OF FOXE BASIN, NORTHEASTERN MELVILLE PENINSULA, AND PARTS OF NORTHERN AND CENTRAL BAFFIN ISLAND

Project 670018

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The field work for this project was done mainly in 1967, with the aid of a Piper Super Cub airplane, and consisted of widely spaced outcrop examinations and measurement of stratigraphic sections (Trettin, 1971). This information has been augmented, during the report interval, by detailed studies of the Rowley Island well, and by additional field work on Melville Peninsula. A final report on the entire project is in progress.

The Rowley Island well was drilled by Aquitaine Company of Canada et al., in the central part of Foxe Basin in 1971 (Monahan, 1972). It was spudded in Lower Silurian strata and cored from a depth of 505 feet to the bottom (at 1, 745 feet); Precambrian crystalline basement was entered at a depth of 1, 678 feet. This well provides a standard for the lower Paleozoic succession in the region, can be matched closely with field observations, and has been studied petrographically in some detail, using thin sections, polished sections, peels, and X-ray diffractograms. Ordovician macrofossils were identified by Norford (in Norford et al., 1973, p. 26, 27) and conodonts by C.R. Barnes of Waterloo University.

The 1973 field work involved mapping the lower Paleozoic outlier of northeastern Melville Peninsula at a publication scale of 1:250,000. This work was done in the course of a helicopter-supported reconnaissance of the Precambrian rocks in the region, directed by W.W. Heywood of the Geological Survey of Canada. The lower Paleozoic investigation was begun by B.V. Sanford and T.E. Bolton in late July and early August and completed by the writer between August 13 and 25.

Four units are recognized in the area: the upper Lower and lower Middle Ordovician Ship Point Formation, which is divisible into two members; upper Middle and Upper Ordovician dolomitic limestone, lithologically identical with both member B of the Baillarge Formation of northwestern Baffin Island, and the Bad Cache Rapids Group of the Hudson Bay region; and an Upper Ordovician or Lower Silurian (lower or middle Llandoverian) reefal unit composed of calcareous dolostone and dolomitic limestone. The unit was discovered by Heywood and studied by Heywood, Sanford and Bolton prior to my arrival. The closely spaced reefs are round to oval in outline with diameters generally between 1, 000 to 3, 000 feet. The present topographic relief, ranging from a few tens to perhaps 100 feet, gives a minimum estimate for the original height. Favositid corals occur in the core of some carbonate mounds—evidently as framework builders—and stromatolites on tops and flanks. Gentle to moderately steep dips characterize the flanks of the buildups. This unit is lithologically comparable to rocks exposed on Prince Charles[1] and Rowley Islands that have yielded Llandoverian faunas, and to the upper 450 feet of the Rowley Island well (represented by cuttings). This interval consists of dolomitic limestones and dolostones of shallow marine aspect (pellets; recrystallization features, etc.) and overlies a thick succession of subtidal dolomitic limestones, comparable to member B of the Baillarge Formation, with upper Middle Ordovician fossils in the lower part, and Upper Ordovician fossils in the upper part. Early or middle Llandoverian fossils were found at the surface in the vicinity of the well (see Trettin, 1971, p. 47). The fossil identifications from the reefs of Melville Peninsula received so far (B.S. Norford, unpub. ms.) are more indicative of a Silurian than an Ordovician age; however, comparable reefs on Southampton Island occur in the Upper Ordovician Churchill River Group (B.V. Sanford, pers. comm.). The present unit cannot be considered as promising for petroleum exploration: (1) because of an apparent lack of adequate source rocks in the entire Foxe Basin region; and (2) because it occurs high in the stratigraphic succession and probably is close to the surface wherever it may have been developed and preserved.

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[1] Current photogeological studies indicate that similar reefs are present on Prince Charles Island in an area that has yielded Llandoverian fossils.

123. PREPARATION OF COLLECTIONS OF CANADIAN ROCKS AND MINERALS FOR DISTRIBUTION TO THE PUBLIC

Project 400006

J. M. Larose
Central Laboratories and Technical Services Division

From May 15 to October 15, more than 31 tons of rocks, minerals, ores and fossils used in various collections produced by the Geological Survey of Canada have been collected from 80 localities in Newfoundland, Nova Scotia, New Brunswick, Ontario and Quebec. Over 16,000 miles have been covered. During the field season, I was ably assisted by Mr. B. Machin from the Mineral Separation Unit.

124. STUDY OF MINERAL COLLECTING AREAS OF INTEREST TO COLLECTORS AND TOURISTS

Project 640048

Ann P. Sabina
Central Laboratories and Technical Services Division

Occurrences of minerals and rocks were investigated on the Magdalen Islands, Quebec and on the Island of Newfoundland to obtain up-to-date information on collecting localities of interest to tourists, collectors and mineralogists. A guidebook containing descriptions of the localities and directions to reach them is being prepared. The occurrences are readily accessible; they include mines (active and inactive), prospects, road-cuts, and shoreline exposures. The localities furnish material suitable for mineral collections and for the lapidarist.

Project 490038

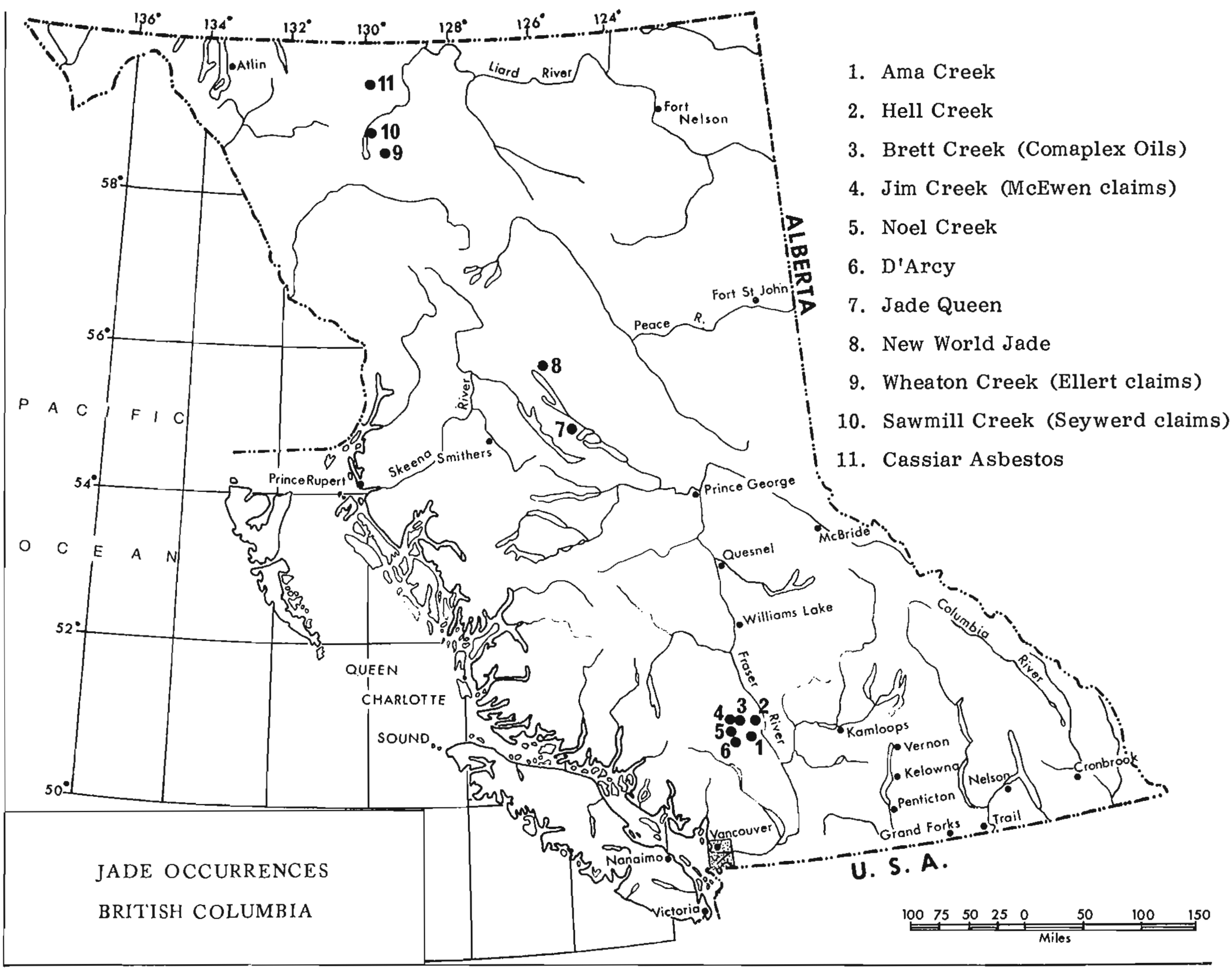
S. Leaming
Regional and Economic Geology Division, Vancouver, B.C.

During the 1973 field season about seven weeks were spent collecting data on mineral occurrences, particularly jade deposits, but also information supplemental to that contained in Geological Survey of Canada, Paper 72-53 "Rock and Mineral Collecting in British Columbia".

Two in situ occurrences of jade were visited for the first time at Wheaton Creek (Loc. 9, Fig. 1) and Jim Creek (Loc. 4). Petrified wood was collected from the Burns Lake area. Photographs of geological interest were taken along the main routes of travel. These included folds in the Rocky Mountain foothills along the Hart Highway, faults, dykes and glaciers, in the Stewart area, landslides along Peace and Tahltan rivers, erosional remnants in the François Lake area, and glacial features in various parts of central and northern British Columbia.

The Wheaton Creek jade deposit held by Mr. Walter Ellert of Terrace, B.C. is typical of the nephrite type jade found elsewhere in the province. It occurs in situ on the east side of Wheaton Creek about ¼ mile south of the confluence with Alice Shea Creek. Two east-west zones of alteration occur in serpentized peridotite. The northern zone is mainly talc but the southern zone contains some good quality jade and is up to 60 feet wide. Only a few cuts with a diamond saw have been made in this exposure. Much of the production has come from boulders, or blocks scattered about the open meadow, probably derived largely from this deposit.

The contact between the jade and the serpentinite is nowhere exposed. The jade is almost surrounded by peridotite but there is a possibility of an eastern extention along the strike direction where the deposit is concealed by overburden. There is no sign of jade



across the creek along the westerly strike direction nor is there any indication that the creek is in a fault zone. Therefore the jade zone probably plunges easterly. Although contact relationships are concealed, there is no doubt that the jade is in situ. Further study of the jade, alteration, and host rocks is continuing.

The Jim Creek occurrence of good quality jade had not been discovered at the time of the inspection. Several loose blocks were seen on the property and a weak alteration zone consisting of talcy schistose band of poor quality jade in serpentinized peridotite was noted. A later report by the owner, Mr. C. McEwen of Lillooet claims good jade had been found in place in a new location on the property.

The Dease Lake deposit held by Mr. Ben Seywerd of Chilliwack (Loc. 10) was visited again. In this deposit the jade occurs on the nose of serpentinite in fault contact with schists and ribbon cherts possibly of Late Paleozoic age. The deposit is about 8 feet wide; the strike length is perhaps 40-50 feet. Some very good quality jade has been recovered but in common with most deposits there are schistose talcose zones which must be discarded.

The jade deposit in the Cassiar asbestos mine (Loc. 11) was still covered when visited by the writer. However the stockpile of jade salvaged from the mining operation was examined. As much as 70 tons of jade or jade-bearing blocks are on hand. Mr. Clancey Hubble of Cassiar cuts this material into blocks for tourist trade. The jade sells for $2 - $3 a pound for average grade material. Cassiar jade is somewhat atypical of jade found elsewhere in British Columbia because of the higher percentage of uvarovite garnet which gives the "chrome flecks" as these are known in the lapidary trade. It also has a smoother fracture in contrast to the typical hackly fracture of most nephrite jade. The material is nevertheless true jade and much of it is of premium quality.

On the last visit to Marshall Creek area, Comaplex Oils had produced a few tons (10?) from the Brett Creek deposit (Loc. 3) optioned from Mr. R.J. Smith of Chilliwack. A wide zone of alteration with jade selvages had been opened up in the middle of the pit but no great amount of cutting had been done.

The other localities shown on the index map have been previously visited. Enough material has now been collected to allow preparation of paper on jade in British Columbia.

ADDENDUM

GEOPHYSICS

126. AIRBORNE RESISTIVITY ELECTROMAGNETIC SYSTEM

Project 680089

A. Becker
Resource Geophysics and Geochemistry Division

The current phase of the project embodies an attempt to derive synthetic variable frequency data (for a given phase angle) from an airborne electromagnetic survey performed simultaneously, at three fixed frequencies. To meet this objective specifications were drawn up and a contract has been let for a limited three frequency AEM field survey with the Scintrex TRIDEM system. The work is to be performed in the Hawkesbury and Timmins areas, where good ground control is available. It will consist of measurements of the inphase and out-of-phase components of the secondary magnetic field at 500 hz, 2,000 hz and 8,000 hz.

Only preliminary results have been obtained to date. These however already confirm the anticipated inverse variation of the secondary field phase angle with rising frequency. This was particularly well demonstrated during an overflight of a conductive clay bed in the Hawkesbury area where an increase of bed thickness resulted in a decrease of the quadrature/inphase ratio at 8,000 hz.

From the initial results we can confirm that the three-frequency survey will provide data essential to the evaluation of the proposed ARES equipment without incurring the heavy costs of a prototype model. In addition to providing information for the ARES program, the preliminary data demonstrates the usefulness of the TRIDEM system, itself, as an aid to the geological mapping of unconsolidated materials.

127. SHALLOW SEISMIC SURVEYS IN PERMAFROST, MACKENZIE VALLEY, N.W.T.

Project 730006

J.A.M. Hunter and C.P. Barry
Resource Geophysics and Geochemistry Division

During the summer field season a shallow seismic program was continued in the Mackenzie Valley to study the seismic properties of permafrost. Three test sites have been chosen: Fort Simpson (southern fringe of discontinuous permafrost), Norman Wells (discontinuous and thin permafrost), and Tuktoyaktuk (region of variable thickness of continuous permafrost and massive ground ice). A total of 650 refraction seismic records were shot in the three areas using an RS-4 12-channel seismograph. Seismic velocities and attenuation rates of first arrivals were computed. Results will be correlated with resistivity surveys done by the Electrical Methods Section and with drilling done by Terrain Sciences Division in an attempt to map the boundaries of discontinuous permafrost, to map the occurrences of ice lenses and to estimate the thickness of permafrost.

Project 730006

J. A. M. Hunter and R. L. Good
Resource Geophysics and Geochemistry Division

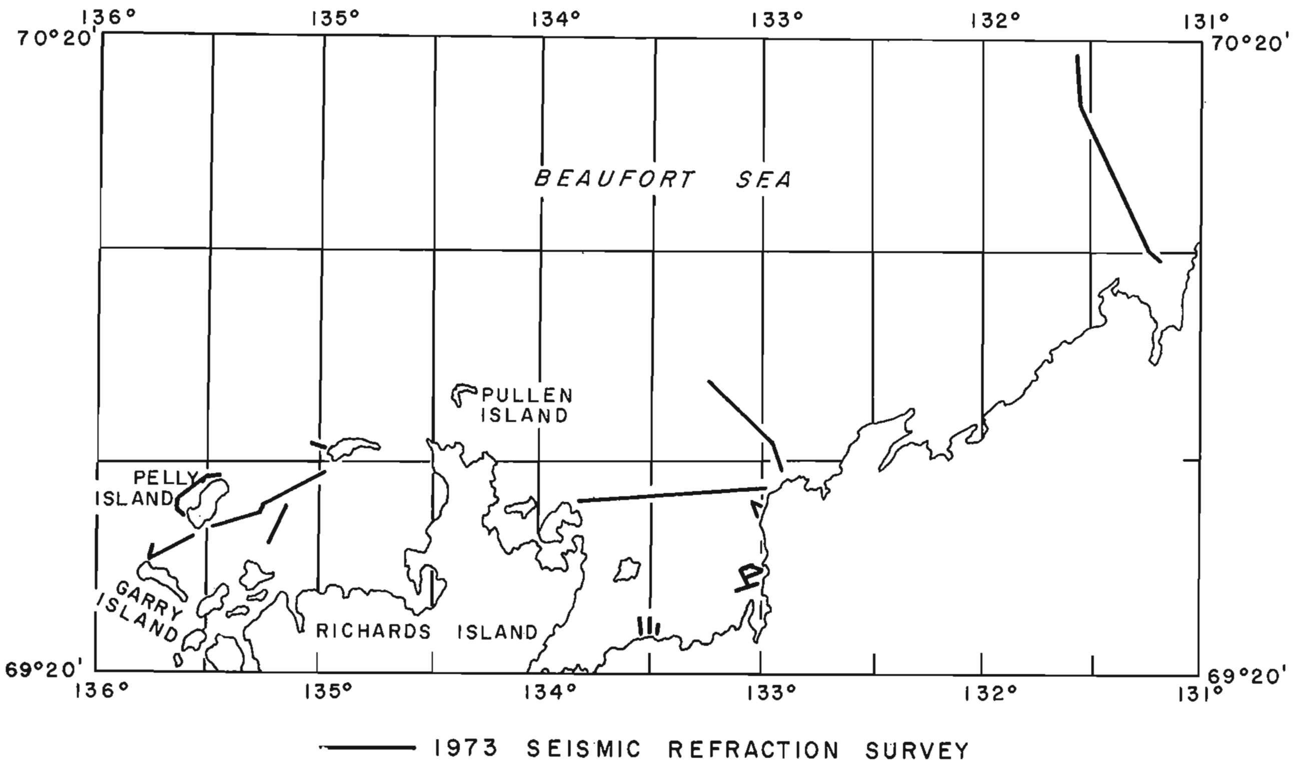
A shallow seismic refraction survey was carried out in the Mackenzie Delta region of the Beaufort Sea during the months of July and August 1973. The objectives of the survey were to test the refraction technique in the detection of sub-sea bottom permafrost and to attempt mapping the occurrence of permafrost along some selected lines both near-shore and on the "shelf" areas. The program was divided into two parts; one operation utilized a large vessel (the M.V. North Star of Herschel Island) to investigate permafrost in deep waters of the shelf; the other operation was confined to the shoreline areas where the occurrence of permafrost in relation to the shoreline was defined.

The technique used for surveying from the "North Star" consisted of a buoyed 24-channel hydrophone cable 1,200 feet long which was towed at a speed of 2½ knots. The seismic source consisted of ½ - 1 pound of high velocity dynamite detonated off the end of the cable. Seismograms were recorded using a T.I.-8,000 amplifier system, an S.I.E. PMR-20 FM tape recorder, and a S.I.E. ERC-10 Electrostatic camera monitor. Continuous coverage of single-ended profiles was achieved along each survey line. Where rapid changes in sub-sea bottom structure was apparent, shot spacings were shortened to 600 feet intervals for better definition. Navigation consisted of radar, line-of-sight on beacons, magnetic compass and doppler sonar.

For surveys along the coastline, a similar technique was used with a 600 foot 12-channel cable operating from small (20 feet) boats. Navigation was by line-of-sight from land beacons.

The survey lines completed are shown in Figure 1. High seismic velocities interpreted to be from the top of permafrost were observed on many of the lines. Due to poor ice conditions, it was not possible to complete as many lines in the shelf area as had been planned. However, much information was acquired in the Mackenzie Bay region. Two sites in the Kugmallit Bay area were examined in detail to map the occurrence of the top of permafrost in plan.

At the request of the Tuktoyaktuk Hamlet council, a marine survey was carried out in Pokiak Lake to determine the presence of permafrost below the lake bottom. This lake is under study as a possible site for land reclamation. Results of the survey indicated that the sediments beneath the north portion of the lake were unfrozen. Under the south portion of the lake high seismic velocities correlated with frozen sediments were associated with the lake bottom.



129. HAMMER SEISMIC SURVEYS, WILLOWLAKE RIVER AREA, MACKENZIE VALLEY NORTHWEST TERRITORIES

Project 680037

J. A. M. Hunter and Reginald A. Wilson
Resource Geophysics and Geochemistry Division

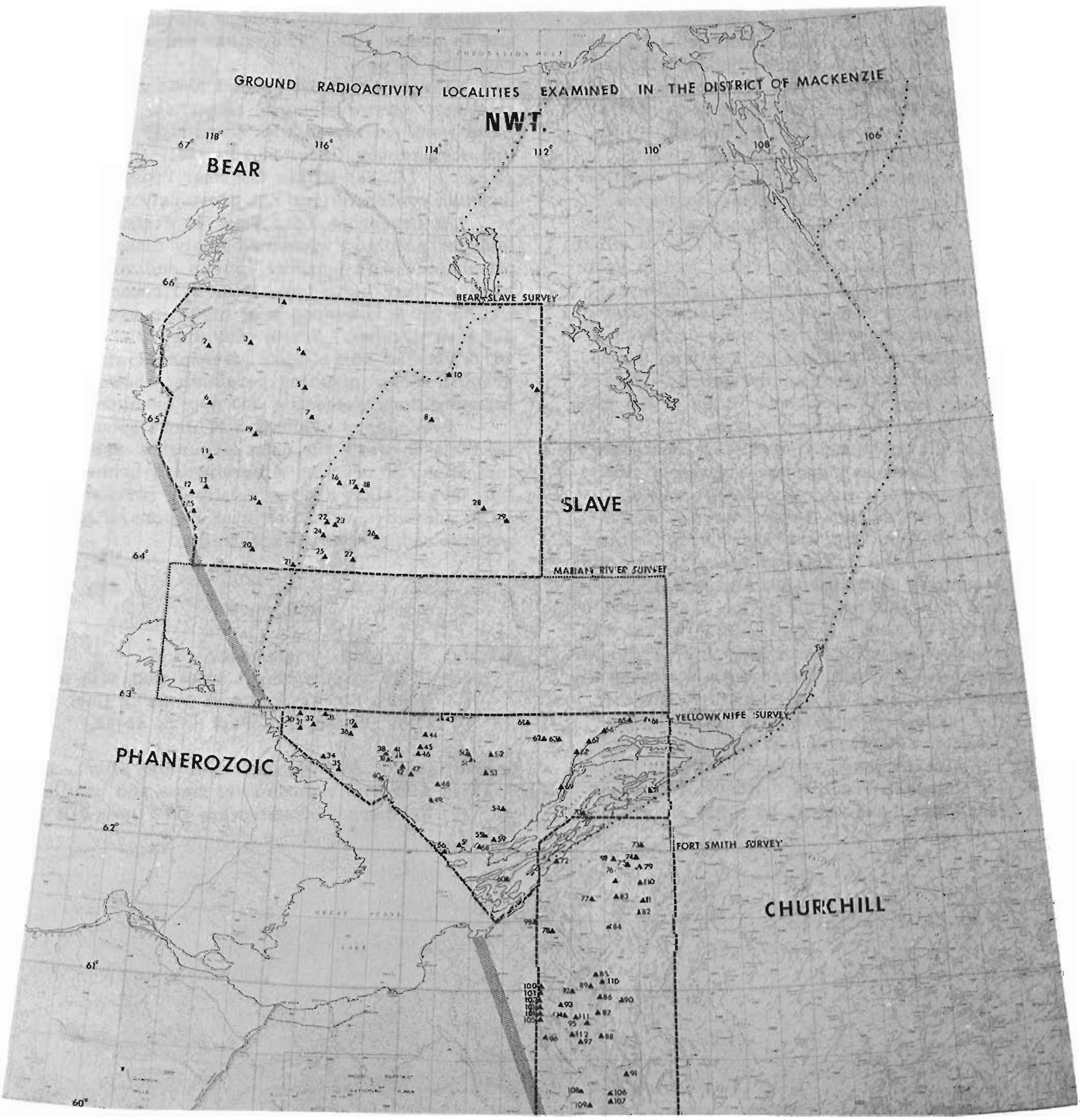
A hammer seismic survey was carried out between Willowlake River and River Between Two Mountains approximately 100 miles north of Fort Simpson in conjunction with studies by the Electrical Methods Section and Terrain Sciences Division, G. S. C. The area of interest is in the discontinuous permafrost zone and contains a 15-mile length of the proposed Mackenzie Highway where construction has begun by the Department of Public Works. A continuous section of seismic refraction profiles were shot down the centreline of the highway to determine depths to the top of permafrost and seismic velocities. Zones showing geophysical anomalies were examined in detail by grid profiling. Approximately 750 refraction profiles were obtained using the Huntec FS-3 hammer seismograph. Record quality in most of the survey area was good. On the basis of seismic velocities obtained it is possible to differentiate between frozen and unfrozen overburden (clay till) and bedrock (limestone). Confirmation of the interpretation was given by numerous D. P. W. shallow drill holes. It is planned to occupy the same stations in future years to observe possible changes in the seismic properties of the frozen overburden beneath the road bed.

Project 720071

K. A. Richardson and B. W. Charbonneau
Resource Geophysics and Geochemistry Division

Major accomplishments of the airborne gamma-ray spectrometry program in 1973 included surveys in northern Saskatchewan and Northwest Territories. In northern Saskatchewan, 7,000 line kilometres (4,400 line miles) of data were collected along east-west flight lines at 50 km line spacing. This was a co-operative

Figure 1. Location of airborne radioactivity survey blocks in the District of Mackenzie, N.W.T. and positions of ground radioactivity localities examined.



project with the Department of Northern Saskatchewan, aimed at locating any regional trends of anomalous radioelement concentration that might have high potential for economic mineral occurrence. Results of the survey are published as Open File No. 169 (Richardson et al., 1973).

In the District of Mackenzie, N.W.T., a 9,600 line km (6,000 line mile) survey covered NTS sheets 85 N, O, P and 75 M, at 5 km line spacing. Results of this work will be analyzed and prepared for Open File release early in 1974.

In addition, two cross country reconnaissance profiles were flown between Ottawa and Yellowknife, and two small areas were flown in the vicinity of Ottawa. A detailed survey of 960 line km (600 line miles) was flown over the Deloro stock on map-sheet 31 C/12, to investigate the distribution of uranium within the intrusion (Grasty and Charbonneau, 1973). 800 line km (500 line miles) of data were collected over the Pembroke map-sheet, 31 F, to complete the coverage of this map-sheet at 10 km line spacing.

High sensitivity airborne gamma-ray spectrometry data collected since 1970 in the Northwest Territories cover fifteen 1:250,000 map-sheets. The areas surveyed are outlined on Figure 1. To aid in the interpretation of the airborne data, and to evaluate the potential economic significance of different types of variations in radioelement concentrations and ratios, ground investigations were carried out in 1973. One hundred and twelve locations shown on Figure 1, were examined on the ground using a portable gamma-ray spectrometer. Some of the more interesting findings are outlined below.

Many of the locations visited were characterized by broad increases in airborne radioactivity levels, and these were generally found to relate to granitic rocks with thorium concentrations on the order of 50 - 100 ppm and uranium concentrations on the order of 20 ppm. Some of these showed evidence of secondary uranium mineralization as surface coatings of uranophane (e.g. loc. 34). Within the Bear Batholith (locs. 2, 6, 11, 12, 13, 15, 19) a wide variety of granitic rocks have high radioelement contents and they contrasted with the generally low radioelement content in the terrain to the east.

In the Slave Province activity levels in the granites between Yellowknife and Fort Rae (locs. 31 - 37) show an increase westward towards the boundary of the Bear Province. North of the east arm of Great Slave Lake (locs. 60 - 69) mainly porphyritic rocks had high uranium and thorium concentrations. Other areas with high uranium/thorium ratio values (locs. 16 - 18, 22 - 27, 54 - 58) relate to muscovite granite bodies between the East Arm and Indin Lake.

In the Fort Smith survey south of the East Arm and within the Churchill Province a belt of porphyroblastic granitic rocks was found to occupy the core of the anomalous zone. These rocks had particularly high thorium contents, with average levels of 200 ppm thorium and 15 ppm uranium along a three mile traverse at location 89.

Anomalous uranium/thorium ratio values were found in the Fort Smith belt, related to granites peripheral to the high thorium porphyroblastic zone and in places (loc. 75) uranium concentrations exceeded 50 ppm.

A number of the ground locations visited had relatively narrow airborne anomalies. Several of these were associated with previously known uranium occurrences (locs. 50, 59, 96); three locations (locs. 1, 25, 28) within the Bear Province showed uranium concentrations not previously reported.

At Greenrock Lake (loc. 1) a sheared quartz-feldspar porphyry contained finely disseminated pitchblende with hematite, pyrite and minor chalcopyrite. Near Indin Lake (loc. 25) micaceous pegmatitic zones contained spot highs in excess of 100 ppm uranium. North of Winter Lake (loc. 28) a zone of quartz-rich, uranophane-stained granitic rocks intruding paragneiss showed ground concentrations exceeding 300 ppm uranium in spots.

Preliminary evaluation of these ground investigations suggests the most favourable airborne indications of uranium mineralization in the area of this investigation are the relatively narrow U with U/Th anomalies within or near regions of high general radioelement concentration.

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131. COLOUR AERIAL PHOTOGRAPHY IN THE NORTHWEST TERRITORIES AND SOUTHEASTERN BRITISH COLUMBIA

Project 630031

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Resource Geophysics and Geochemistry Division

Three weeks in late summer were spent on two aerial colour photography projects in the Northwest Territories and across the boundaries of British Columbia and Alberta. All three areas were flown at 7,500 feet above average ground level using a Wild RC 10 camera and Kodak 2445 (colour negative) film. The film has been processed and is of reasonable to very good quality.

Both Northwest Territories surveys covered parts of the area of the 1972 Bear-Slave reconnaissance geochemical survey (Project 720063) which were selected for further detailed work in 1973.

One of these areas is centred on Beechey Lake, 250 miles east of Great Bear Lake (NTS sheet 76 G). The photography here covers an area of 900 square miles. The second area is centred about Little Crapeau Lake approximately 130 miles north-northwest of Yellowknife (NTS sheet 86 B and 86 C). The survey consists of 360 line miles of photography covering an area of 600 square miles.

The third survey was undertaken to support a study by J. Harrison (Project 720083) of the effects of opencast coal mining on the environment. 300 line miles of colour photography and 100 line miles of colour infrared photography were exposed across selected opencast coal workings in the Fernie-Sparwood and Bellevue areas of the British Columbia-Alberta border.

Flight indices and log sheets for this imagery will be placed on Open File at the Geological Survey later in the year. The negatives are held by the National Air Photo Library.

132. CONTINENTAL MARGIN OF EASTERN CANADA

Project 720111

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In May and June, 1973, geological and geophysical experiments were carried out from CSS HUDSON (Cruise 73-011). Studies were continued on the continental margin off Nova Scotia and along the southern margin of the Grand Banks. The survey within the quiet magnetic zone was also extended and now covers an area of dimensions 150 km by 150 km. As well as continuing to study these areas, data was obtained in the Newfoundland basin, over the Newfoundland fracture zone and over the continental margin east of the Grand Banks. The data collected includes seismic reflection, seismic refraction, gravity, magnetic and bathymetric measurements. Two successful heat flow stations, twelve coring stations and two bottom camera stations were also completed. Loran-C and satellite navigation provided control of the positions of the tracks to a precision of about 300 m.

The extension of the quiet magnetic zone survey has provided us with sufficient data to define the direction of magnetic lineations with more precision and to determine the magnetization of layer 2 and the presence of geomagnetic reversals with more confidence than previous results allowed. The analysis is now in progress. Survey techniques were the same as those reported for last year's survey.

Additional seismic refraction lines were run over the continental margins off Nova Scotia and along the southern margin of the Grand Banks. These show that the rifted type margin exhibits a transition zone, about 60 km wide which is occupied by 8 km or more of sediments underlain by high velocity crystalline basement (7.4 km/sec). Layer 2 is either very thin or absent beneath this area. Magnetic modelling of the slope anomaly supports the seismic refraction results (Keen et al., 1973). The refraction data south of the Grand Banks is presently being analyzed.

Preliminary surveys were made of two of the Newfoundland seamounts. These may enable us to determine paleomagnetic pole position for the seamount chain. Attempts to dredge the seamounts were unsuccessful although two camera stations indicated the presence of basaltic outcrop on their scarps.

The seismic reflection results across the margin east of the Grand Banks indicated no sedimentary ridge complex such as that observed off Nova Scotia. Reflection results across the southern margin of the Grand Banks confirmed studies completed in 1972 which showed numerous seamounts at the foot of the slope and the possibility of faulted oceanic basement structures. The data now available suggests that a magnetic slope anomaly may occur along this margin as well as along the rifted margin to the south.

We are attempting to apply the results of our studies to other continental margins, in the Labrador Sea and in Baffin Bay. Analysis of seismic refraction and magnetic data in these areas suggest that these margins exhibit properties which are similar to those of the rifted margin off Nova Scotia.

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133. GEOLOGY OF COPPER AND MOLYBDENUM DEPOSITS IN CANADA

Project 700059

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Regional and Economic Geology Division

As part of this general study, about three months were spent examining copper deposits and occurrences in various areas in Canada. Deposits were examined briefly in parts of the Appalachian, Churchill and Cordilleran provinces.

Porphyry deposits in the southern part of the Churchill Province

In considering the potential for porphyry deposits in the southern part of the Churchill province, it is important to determine if the volcanic terranes could have been parts of ancient island arc systems. The model being used is one of an analogy with modern island arcs containing porphyry deposits in temporally and genetically related volcanic sequences. Like Triassic and Jurassic porphyry deposits in British Columbia the deposits would have been preserved in the same manner as the host volcanic pile.

Amisk and "Amisk-type" calc-alkaline volcanic terranes with their abundant pillow lavas could conceivably have been portions of arc systems and as such, using this exploration model, are the most obvious areas in the southern part of the Churchill province in which to look for porphyry deposits. Although Bailes (1972) has indicated the presence of some pre-tectonic post-Amisk felsic intrusive rocks no significant volume of intrusive material genetically related to Amisk volcanism has been recognized. Near Creighton Creek east of the Hanson Lake road granitic boulders, suspiciously similar to parts of the Annabel Lake pluton, occur in the Missi conglomerate which unconformably overlies the Amisk Group. This pluton, along with many others, has been interpreted by Byers et al. (1965) to be post-Missi and syntectonic. Although it will take more petrologic, chemical and field work to establish this relationship, it is tentatively suggested that such plutons may be pre-tectonic related to Amisk volcanism and could conceivably have been associated hydrothermal activity capable of producing porphyry-type mineralization as well as the more characteristic Cu-Zn, volcanogenic massive sulphide deposits.

There are no well documented porphyry-type deposits or alteration zones in the southern part of the Churchill province; nevertheless, there are some favourable preliminary indications. The widespread vein-replacement pyrite, chalcopyrite mineralization in chloritic, sericitic and siliceous altered rocks adjacent to the main Flin Flon massive sulphide deposit, although deformed and metamorphosed, does have some characteristics of porphyry-type mineralization. It could conceivably have been part of a porphyry-type or somewhat analogous hydrothermal system, and judging from other Shield areas it would not be too surprising to find porphyry-type alteration zones in a massive sulphide district such as the one at Flin Flon.

Extensive pyritic altered zones also occur on and near Missi Island in the Amisk Lake area, Saskatchewan. These alteration zones are known to contain some Cu, Mo and Au but extensive exploration over many years, including much diamond drilling, has met with little success. Cu, Mo and Au mineralization is present in large pyritic zones near Cougal Lake in the central part of the island and on the Brain and adjacent properties on the west side of the island. Numerous highly altered, fine-grained felsic porphyries, which are probably part of a large eruptive centre (see Byers and Dalstrom, 1954), occur in the area. Deformation and greenschist facies metamorphism superimposed on the hydrothermal alteration have obliterated many of the original features of the rocks near the mineralized zones. Detailed studies of this area not only will supply much needed information on the nature of extrusive, intrusive and hydrothermal features of a very interesting central complex but may also indicate significant exploration targets.

It is too early to be certain what potential the southern part of the Churchill province has for porphyry deposits, moreover intensive deformation, metamorphism and extensive glaciation in the area will make the search difficult. Yet from preliminary examinations and modelling some potential, albeit poorly defined, seems to exist.

Gibraltar Deposit British Columbia: Pre- or Post-Metamorphic?-

Only a very brief visit was paid to this mine but one very important geological aspect of the deposit was noted. Drummond et al. (1973) described a very extensive pyritic alteration zone and have attributed its elongation in a northwesterly direction to the existence of a pre-ore regional foliation (p. 54). Certain features of the deposit, such as, "alteration minerals" being only compatible with greenschist facies metamorphism (see Drummond et al., 1973), folded mineralized quartz veins and folded, lineated and deformed masses of pyrite and chalcopyrite, marked schistosity of highly altered rocks, etc., indicate to the writer that the mineralization and related hydrothermal alteration are pre-metamorphic and that post-ore deformation is responsible for the elongation of the deposit in a northwesterly direction and not the reverse as suggested by Drummond et al. (1973). This example once again illustrates our general lack of well established criteria for the identification of deformed and metamorphosed ore deposits.

Drummond et al. (op. cit., p. 54-55) state that a centrally positioned quartz-feldspar porphyry body, which could be genetically related to the mineralization, is not foliated and is largely post-metamorphic. Although there were no exposures of this rock available for the writer to examine, it is suggested that when this body is studied in detail it will be found to possess a deformational fabric (e.g. sutured and deformed crystals) and that the reason it does not contain a prominent foliation is that it lacks abundant micaceous and mafic minerals suitable for the development of a foliation.

The practical values of determining whether or not a deposit such as Gibraltar is pre- or post-metamorphic are manifold. For example, by modelling the present geometry of the deposit and mineral and grade zones in terms of a deformational, metamorphic history the resulting reconstructions could have an important bearing on mine exploration and planning. By indicating the age of the deposit relative to various rock units in the area it could also have an important bearing on regional exploration. It is also apparent that information on metamorphism and deformation is necessary to properly evaluate such things as alteration zonation and radiometric dating of the deposit using silicate minerals. It is suggested that the Gibraltar deposit has the potential of becoming one of Canada's best examples of a deformed and metamorphosed porphyry deposit.

Sustut copper deposit

This deposit, which occurs about 120 miles northeast of Smithers, British Columbia, was discovered in 1971 by Falconbridge Nickel Mines Ltd. It consists essentially of reasonably conformable, disseminated, zoned, pyrite, chalcopyrite, bornite, chalcocite and native copper mineralization in intermediate fragmental volcanic rocks that are probably Upper Triassic or Lower Jurassic in age (company geologists report that Upper Triassic fossils have been found in a bed about 800 to 1,000 feet stratigraphically below the copper-bearing beds). This is a very significant discovery because it is the first occurrence of economically important, stratigraphically-controlled mineralization of the copper sulphide-native copper type in volcanic sequences (e.g. Keweenaw Peninsula) found in Canada. This stratigraphically-controlled mineralization belongs to a very diverse group of deposits, which are mainly minor structurally-controlled occurrences, that are very widespread in Upper Triassic and Lower Jurassic volcanic sequences of British Columbia and the Yukon (e.g. Kirkham 1970 and 1971). Most such occurrences have proved to be of little economic importance but the Sustut deposit with its prominent stratigraphic control gives encouragement that other similar important deposits will be found elsewhere in the Canadian Cordillera. Until much more work is done on these deposits and occurrences there is little firm data to guide exploration and to indicate their overall economic potential.

Minto deposits

Silver Standard-Asarco and United Keno Hill-Falconbridge-Canadian Superior have been exploring a recent copper discovery about 12 miles north-northwest of Minto in the Yukon Territory. The mineralization consists primarily of blebs and disseminations of chalcopyrite and bornite with some pyrite and magnetite in biotitic gneisses in a migmatite complex. The copper mineralization with some precious metals is, in general, approximately conformable with the layering and occurs preferentially in the gneissic rather than the massive granitic rocks. Similar deposits are known to occur in the immediate area and about 25 miles to the southeast in the Williams Creek area, although the latter have been deeply weathered. The metal and mineral assemblages, general nature and host rocks of the deposits leave their origins much in doubt. Nevertheless, the general features of the deposits indicate that the mineralization was probably pre-metamorphic and was not directly related to the migmatization that formed the granitic and gneissic host rocks or any later, superimposed hydrothermal activity. The significant gold content and potassic (biotitic) nature of the host rocks make it doubtful that these are "metasedimentary" deposits. Despite the uncertainty or origin of these deposits, like the Sustut deposit, they represent the discovery of a significant new type of copper mineralization in the Canadian Cordillera, and could become quite important as a future source of copper.

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134. GEOLOGICAL RECONNAISSANCE OF NORTHERN MELVILLE PENINSULA DISTRICT OF FRANKLIN (PARTS OF 47A, B, C, D)

Project 700073

W. W. Heywood
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The reconnaissance geological mapping of northern Melville Peninsula was commenced and completed in the 1973 field season using a Bell 47 G4A helicopter from a base camp at Hall Beach. W. L. Davison and D. N. Proudfoot assisted with the Precambrian mapping. T. E. Bolton of the Geological Survey of Canada, Ottawa, B. V. Sanford of the Atlantic Geoscience Centre, Dartmouth, and H. P. Trettin of the Institute of Sedimentary and Petroleum Geology, Calgary, spent about two weeks in August investigating problems of Paleozoic stratigraphy and structure.

Gneisses, migmatites and foliated to massive granitoid rocks underlie most of the map-area. These include some areas of metasedimentary rocks that consist of biotite-rich paragneiss, small amounts of amphibolite, and minor thin marble bands. Granulites are present in an irregular zone along the western side of Melville Peninsula. Small ultrabasic bodies occur locally but are not common.

Folded and metamorphosed sedimentary and volcanic rocks of the Prince Albert Group are the oldest recognized in the area. They outcrop at the southwest end of Hall Lake, and in a belt about 30 miles long and as much as 10 miles wide trending north to northwesterly from the mouth of Hall River. Granitic stocks and sills are common in the Hall Lake area. The Prince Albert Group is bounded by intrusive granitic rocks at the south end, and is apparently conformable with gneissic and granitoid rocks north of Hall River. Along the eastern boundary they are in fault contact with Paleozoic strata. The sedimentary rocks are mainly derived from greywacke and are metamorphosed to varying degrees. Mafic rocks derived from andesite and basalt form most of the volcanic suite. As much as 2, 000 feet of rhyolitic to dacitic rocks are interlayered. Altered ultrabasic sills were observed in scattered localities associated with the metavolcanic rocks. A similar sequence of rocks outcrop on the peninsulas and islands north and south of Richards Bay and probably represent a northern extension of the Prince Albert Group.

Discontinuous remnants of metavolcanic rock and amphibolite occur in a north- to northeasterly-trending zone from Kingora River at 83°30'W.

Iron-formation was observed in many places in the Prince Albert Group and probably forms more or less continuous layers. The maximum observed thickness of iron-formation is about 1, 500 feet, however there may be some repetition due to folding. Layers composed predominantly of magnetite are as much as 2 feet thick, and some sections contain up to 30 per cent magnetite. Iron-formation has been reported from the Garry Bay area but was not examined.

Helikian strata, gently folded and metamorphosed, outcrop in several localities on the south side of Fury and Hecla Strait from Alfred Island in the west, to the Bouviere Islands in the east. The Fury and Hecla Formation, consisting of pink and white quartzite with minor amounts of conglomerate and shale, rests unconformably on granitic and gneissic rocks. Siltstone, shale and dolomite of the Autridge Formation outcrop on islands in Fury and Hecla Strait.

Unaltered northwesterly trending diabase dykes and sills occur throughout the area. They are most abundant in the south-central region and along the north coast where they intrude the Fury and Hecla Formation.

Rusty weathering zones, some containing disseminated sulphide minerals were observed in many localities. Most are associated with metavolcanic rocks of the Prince Albert Group. A rusty zone, containing minor amounts of pyrite and pyrrhotite, extends about 15 miles north and south of the east end of Blacks Inlet. Pyrite, pyrrhotite, and minor chalcopyrite are present in metavolcanic and associated rocks north of Kingora River. Disseminated chalcopyrite occurs in peridotite plugs about 45 miles northwest of Hall Beach.

Soapstone occurs at the southwestern end of Hall Lake and north of the Kingora River at 68°39'N, 84°16'W. Soapstone at the latter locality is derived from an altered peridotite dyke that is more than 125 feet wide and is exposed for at least 2, 000 feet. It is medium to light grey coloured, relatively free from impurities, and could be quarried in large blocks.

GEOLOGY OF THE CALDER RIVER MAP-AREA (86F), DISTRICT OF MACKENZIE

Project 730041

J.C. McGlynn
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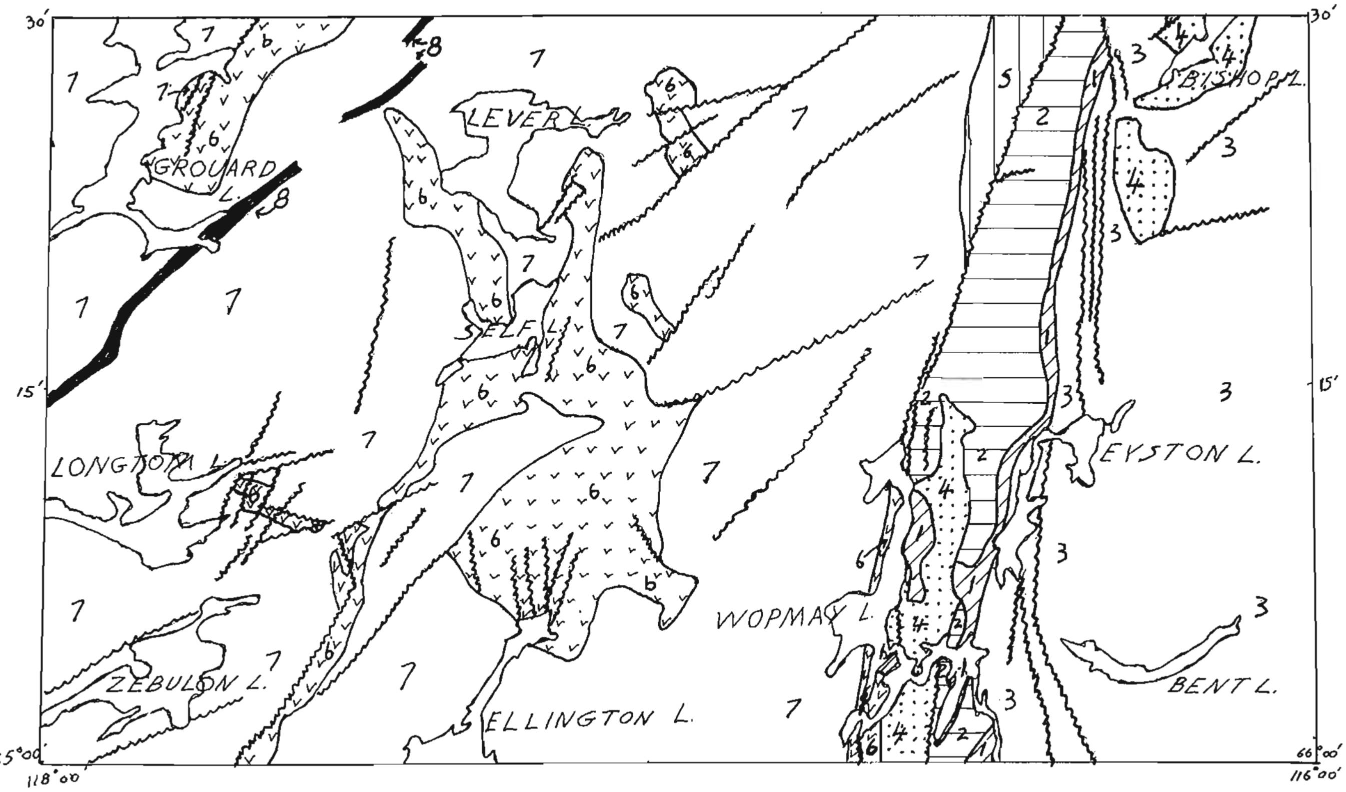
During the first summer of field work for this project a map of the south half of the Calder River area was completed. However, in succeeding summers further work will be required in the area to refine parts of the mapping and to better document some of the relationships established during the past field season. The objectives of the study include the definition of the stratigraphic and relative age relations of Aphebian supercrustal rocks and associated plutonic rocks; the determination of the nature and environment of the volcanogenic-plutonic complex in the western part of the Bear Structural Province; and a more precise definition of the various tectonic environments present in the Bear Structural Province. These aims lead to the ultimate objective of providing a more refined assessment of the resource potential of the area, an improved map and additional data as a basis for further mineral exploration in the region.

The south half of the Calder River map area spans two major tectonic divisions of Stockwell's Wopmay Belt (Stockwell, 1970) which has been also called the Wopmay Orogen by Fraser et al. (1972). These divisions are known as the Great Bear batholith and the Hepburn metamorphic-plutonic belt and their mutual boundary is defined by the Wopmay fault (Fraser et al., 1972).

The oldest rocks in the area (units 1 and 2, Fig. 1) occur just east of the Wopmay fault and comprise a conformable sequence of siltstones and shales overlain by dolomite which in turn is overlain by basic volcanic rocks. These rocks were assigned to the Snare Group by Lord and Parsons (1952) and later by McGlynn (1964). This correlation remains a reasonable one. The thickness of the lowest siltstone and shale formation cannot be known as it is everywhere cut by granite but within the area some hundreds of feet are exposed.



1. Snare siltstone-shales and dolomite;
2. Snare basic volcanic rocks;
3. Migmatites, mixed gneisses, veined gneisses, granitic gneisses;
4. massive, porphyritic granodiorite;
5. shales, siltstone, ash flow tuff;
6. ash-flow tuff, ash-fall tuff, lithic sandstone, felsitic porphyry intrusions;
7. granodiorite and quartz monzonite;
8. diabase dyke.

Figure 1. Geological sketch map of the south half of the Calder River map-area.

The dolomite formation where exposed is very thin varying between 5 and 50 feet in thickness. In some sections it is not present but its true distribution is difficult to determine as it outcrops poorly. The top of the volcanic unit is not exposed but as much as two thousand feet are present in the sequence. The bulk of the volcanic sequence consists of massive thick flows of probable basaltic composition. A few thin pillowed flows occur locally near the base of the sequence and northeast of Wopmay Lake, and facies comprising thin (up to 6 feet) basic flows with scoriaceous tops occur. Two small areas of interrelated basic and intermediate to acidic flows and tuffs were found in the upper part of the sequence. The rocks are metamorphosed to low greenschist facies except near granitic intrusions. The sequence is gently folded about axes that trend about northeast. The lower shale unit is intensely cleaved so that in most outcrops bedding is all but destroyed. The Snare rocks appear to be tectonically preserved between the Wopmay fault and the complex fault zone that marks their eastern boundary.

East of the belt of Snare rocks, gneisses (unit 3) of the Hepburn metamorphic-plutonic belt comprise migmatites (with Snare type sediments), veined gneisses, biotite gneisses and granitic gneisses. The structure of the gneisses is complex and more detailed work is needed to define their structural style but they appear to be doubly folded with first fold axes trending northeast to east. These folds are open to isoclinal and overturned so as to be almost recumbent. They, in turn, are refolded about northerly or west of north trending axes. The regional grade of metamorphism is amphibolite of low pressure high temperature type.

The granitoid gneisses and less deformed Snare rocks are cut by high level, massive, coarsely porphyritic granodiorites to quartz monzonites. Within the Snare rocks these intrusions are bounded by narrow metamorphic zones in which rocks reach amphibolite grades of metamorphism and they modify preexisting regional structures.

The transition from moderately to gently deformed and metamorphosed Snare strata to highly deformed gneisses containing highly metamorphosed Snare rocks is sharp but the nature of the transition is obscured by intense faulting that produces wide zones of mylonite and crushed and brecciated rocks. The late massive granodiorites are also affected by this faulting. It seems likely that somewhat deeper level gneisses and higher level moderately deformed Snare strata were brought into juxtaposition along this complex fault zone.

The western boundary of the Snare rocks and granitic rocks that intrude them is the Wopmay fault. Rocks of the Great Bear batholith are found west of this northerly to northeasterly striking fault. Supercrustal rocks of the Great Bear batholith include a sequence of sediments (unit 5) just west of the Wopmay fault and volcanic rocks (unit 6) that occur between Ellington and Lever lakes and around Grouard Lake. Granodiorites and quartz monzonites (unit 7) are the other components of the Great Bear batholith. The supercrustal rocks within the area have been assigned to Snare, Cameron Bay and Echo Bay Groups by previous workers (Lord and Parsons, 1952). They are not part of the Snare Group and the nomenclature of the Cameron and Echo Bay Group is so confused that it seems best for the present to consider the rocks as Cameron and Echo Bay type. As work progresses a new nomenclature will have to be devised or the old one refined.

The sedimentary strata along the Wopmay fault comprise a sequence of shales, silty shales with local fine siliceous beds and bands of ash-flow tuffs. The rocks have an intense cleavage that strikes east of north and dips nearly vertically. In all but a few outcrops bedding is destroyed. Where present it strikes about parallel to the cleavage but dips at lower angles. However, too few observations were made to determine the fold pattern of these sedimentary rocks. The cleavage is paralled to the Wopmay fault and may be related to it.

Cameron Bay, Echo Bay type rocks (unit 6) at Wopmay Lake consist of ash flow tuffs with some red conglomerate lithic sandstones near the top of the sequence. The units here were not sheared, strike northeast to east and dip gently north. Ash flow tuffs are found resting unconformably on sheared or crushed porphyritic granodiorites that cut the Snare strata. These volcanic rocks, therefore, are younger than the Snare rocks and the granitic rocks of the Hepburn plutonic and metamorphic complex and probably younger that the faulting that affected those rocks and produced in the granitoid rocks extensive mylonite and crush zones. The rocks are older than the Wopmay fault as they are cut by the fault and sheared along the fault zone.

The most extensive areas of volcanic rocks of Echo, Cameron Bay type north of Ellington Lake and around Grouard Lake comprise a thick sequence of massive ash flow tuffs with interbedded ash fall and waterlain tuffs, volcanogenic sedimentary rocks, and dykes and sills of intrusive felsitic porphyries. At Grouard Lake the sequence contains a few andesite flows. In various sections in the sequence as much as 15, 000 feet of these rocks are exposed but the cumulative thickness is much greater.

Just north of Ellington Lake the sequence consists of at least four cycles composed of a thin unit of delicately, persistently banded rocks that are probably ash-fall and waterlain tuffs and more crudely banded crystal tuffs overlain by massive crystal and less commonly lithic ash flow tuffs. Within the banded rocks are thin lensy bands of crossbedded coarse grained lithic sandstones. The grains are of locally derived volcanic rocks. The massive tuff is moderately to densely welded. The composition appears to be dominantly intermediate possibly dacite or quartz latite with some rhyolitic phases. These rocks give way to the north to a succession of massive ash flow tuffs with no intercalated banded tuffs or sedimentary strata. Felsitic porphyry dykes, sills and stocks occur within the volcanic sequence and are most abundant around Self and Lever lakes. The volcanic rocks strike easterly to southeasterly and have a regional dip or tilt to the north. The amount of dip ranges from horizontal to about forty degrees. Dips are steep and strikes more variable near granitic rocks.

The volcanic rocks are everywhere cut by granitic intrusions (unit 7) of the Great Bear batholith. Narrow metamorphic zones occur around the granitic intrusions and the volcanic rocks tend to be tilted at steeper angles along the margins of the granitic rocks. The felsitic porphyry intrusions cut the volcanic sequence but both intrude and are intruded by granitic rocks. They probably are therefore about the same age as the granitic rocks.

The granitic rocks are massive granodiorite to quartz monzonites with local quartz diorite phases. Of the three units defined (but not shown on Fig. 1) two are porphyritic with phenocrysts ranging, in length, from ½ to 3 inches. These rocks are in sharp contact with the volcanic strata, have chilled or finer grained marginal phases, are bounded by narrow metamorphic zones, have dyked older rocks about their margins, tend to disrupt regional structure only locally and are therefore considered to be very high level intrusions. The volcanic rocks may well be their extrusive equivalents or skins and the felsitic intrusions their somewhat higher level equivalents. The range of composition of the intrusive and extrusive rocks appears to be about the same.

The youngest rocks are diabase dykes most of which strike northeast. All rocks of the Great Bear batholith are cut by northeasterly trending vertically dipping faults along which quartz stockworks or "giant quartz veins" locally occur. These faults seem to die out before reaching the Wopmay fault.

The sequence of events determined in the Calder River area, then, includes deposition and extrusion of the Snare rocks in the Coronation Geosyncline (Hoffman et al., 1970); burial of these rocks; folding, metamorphism and formation of granitic gneisses and migmatites; late or post tectonic intrusion of massive porphyritic granodiorites followed by rather deep level faulting that produced broad mylonite zones and brought gneisses containing highly metamorphosed Snare rocks and less deformed and metamorphosed Snare strata into juxtaposition. After erosion exposed at least the high level granitic rocks in the Snare sequence, Cameron - Echo Bay type volcanism occurred and a thick sequence of ash flow tuffs was deposited while granodiorite and quartz monzonites were being formed at depth and intruding their own extrusive equivalents. Late in this process the Wopmay fault formed along the boundary of the Great Bear batholith. Later northeast-trending faults cut the Great Bear batholith. Some of the volcanic rocks were tectonically preserved along these faults. The last event was intrusion of diabase dykes.

There is little evidence of mineralization in either Snare rocks or the younger ash-flow tuffs. Sparsely disseminated sulphides occur along parts of some northeast trending faults in the Great Bear batholith especially near quartz stockworks.

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136. SOME OBSERVATIONS ON ICE IN THE ACTIVE LAYER AND IN MASSIVE ICE BODIES, TUKTOYAKTUK COAST, N.W.T. (107 C)

Project 680047

A. Gell[1]
Terrain Sciences Division

Ground ice along the Beaufort Sea coast near Tuktoyaktuk has been studied both from cliff exposures and core samples. The principal method has been by petrofabric analysis, the aim being to determine the growth modes of the exposed ice types, and to establish a petrologic classification for recognition of ice type from limited samples where exposure is lacking.

Ice at the base of the active layer

Ice growth above the previous season's base of thaw was examined in several exposures. Ice content varied from dispersed ice particles to 0.5 m thick accumulations where standing water had frozen in a depression. Refreezing of the active layer occurs from both above and below as indicated by distinct bubble patterns associated with the separate freezing fronts.

The ice is characterized by its inclusions. Although little sediment is present vegetational remains and some live roots may be incorporated. Bubbles are abundant and their patterns and characteristics are significant of freezing directions. In this ice type much of the freezing occurs from below. Abrupt changes in bubble content from low to high indicate nucleation of bubbles throughout the body.

Where ice growth occurred from a curved surface, bubble trains begin orthogonal to the surface then curve into the general heat flow direction. Crystal size varies from less than 0.1 mm diameter on the surface of first growth to long axis dimensions of over 3 cm in crystals favourably oriented to heat flow and water supply. Crystal shape is lath in the zone of competitive growth, giving way to serrated boundaries characteristic of freezing of bulk water. The ice type is recognizable in the field by its bubble patterns and its lower boundary which may be on frozen sediment, peat or ice, corresponding to a previous depth of thaw.

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Massive ice

A large massive ice body containing well defined alternating bands of clear ice, bubbly ice and sediment-rich ice was examined in cliff exposures and by core samples. Characteristically the ice is overlain by stony clay and underlain by sand. Structures in the ice are broad gentle anticlines and pressure-release joints.

Ice-crystal-size is affected by sediment content. In sediment bands showing a dimensional preferred orientation at right angles to the compositional foliation crystals are less than 1 mm in diameter, but reach 3 cm in clear ice. Ice crystal shape varies with size. Large crystals are anhedral to subhedral, boundaries showing single curvature. Small crystals tend to be euhedral. Where curved boundaries occur, these embay large crystals. Boundary triple points tend to subtend 120° angles.

Lattice preferred orientations are approximately orthogonal to bedding. This relationship is disturbed where dirt bands are offset by subvertical microfaults. Both normal and reversed faults occur, and are associated with ice wedges. The faults have clear ice infills, up to 0.8 cm wide, with narrow sediment and bubble trains in the centre. Crystals which grew in the fault plane have strong preferred dimensional orientations parallel to that plane, but random lattice orientations.

Several bubble types occur. Cylindrical bubbles up to 1.2 cm long trend upwards from sediment bands into clear ice. Away from sediment bands, spherical, ellipsoidal and flattened bubbles occur. Flattened bubbles have planar faces which are parallel in a given crystal. Maximum bubble dimension is 2 mm. Spherical shapes are rare; ellipsoidal are more common and are up to 3 mm in diameter.

The above two ice types differ petrographically from each other and from many other ice types in adjacent exposures. A petrographic classification is being developed for future field recognition of ice type from limited samples.

137. SEISMIC SHOT HOLES AND GROUND TEMPERATURES, MACKENZIE DELTA AREA, NORTHWEST TERRITORIES

Project 680047

J. Ross Mackay[1]
Terrain Sciences Division

Introduction

Ground temperature measurements are often required for permafrost areas in which geophysical surveys are now being carried out or where future development might take place. Seismic shot holes have been used for many years to obtain such ground temperature measurements. The usual procedure is to place a multiconductor thermistor cable in an air filled shot hole, sealed at the top. At least 100 such cables have been installed along the Western Arctic Coast to depths ranging from 50 to 200 feet.

The temperature measurements are usually carried out in order to obtain an estimate of the mean annual ground surface temperature. The short term (eg. 10 year) mean annual ground surface temperature corresponds closely to that at the depth of zero annual temperature change, which will vary from site to site. The 50-foot depth is often used as that of the zero annual temperature change, and it has been so used in the Mackenzie Delta area. The advantage of using a 50-foot-deep temperature measurement is considerable, because only a single temperature measurement is required to provide a good estimate of the mean annual ground surface temperature which would otherwise take a year of surface observations. This report deals with some uses of seismic shot holes in estimating ground surface temperatures.

Open Shot Holes

Through the co-operation of Gulf Oil Canada, Ltd., temperature measurements in shot holes were carried out on Eglinton Island, N.W.T., in May 1972, in order to determine the rapidity with which the temperature in an air filled hole stabilized. Two holes were air drilled in shale to a depth of 100 feet. Thermistor cables were then lowered into each hole, to depths of 40 and 80 feet. Temperatures were read immediately after completion of the drilling and then continued for a week. Figure 1 shows that the temperatures stabilized within a day.

The question may be raised as to whether the temperature measured in an air filled shot hole, plugged at the top, accurately reflects the surrounding ground temperature. In at least one series of tests, temperature measurements in small diameter air filled holes, plugged at the top, were shown to be as good or better than holes backfilled with soil or filled with a liquid (Dr. F.E. Are, Institute for Permafrost Study, Yakutsk, U.S.S.R., pers. comm., 1973). Furthermore, the temperatures measured for holes 1 and 2 (Fig. 1) agree well with those in the -13°C to -14.5°C range recorded for nearby islands (Judge, 1973). After the tests at Eglinton Island showed that temperatures in an air drilled shot hole stabilized rapidly, further tests were carried out successfully at six sites in the Mackenzie Delta area. The method then seems suitable for field use in measuring temperatures a day or so after drilling.

Backfilled Shot Holes

Through the co-operation of Imperial Oil Ltd., tests were carried out on temperature measurements in backfilled shot holes at Garry Island, N.W.T., in April 1973. All of the holes were drilled to a depth of 105 feet. The holes were then loaded, with the top of the charge at a depth of 85 feet. Cuttings from the hole were then added to fill the hole to a depth of 50 feet. A 50-foot thermistor cable was then lowered into the hole. The upper 50 feet was then infilled. When the charge was set off, there appeared to be no damage to the probe or shifts in the probe position. Temperatures were then read at intervals of 24 hours, 48 hours, 72 hours, and 4 months. The temperature measurements show that the backfilling disturbed the ground (i.e., hole) temperature for at least three days afterwards. However, all of the temperatures seemed stable at the end of 4 months, and they showed excellent

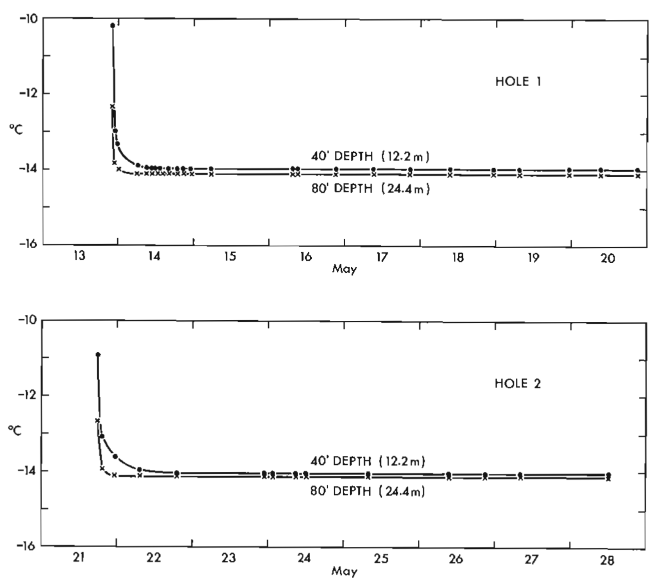

Figure 1. Stabilization of ground temperatures in shot holes, after drilling. Eglinton Island, N.W.T.

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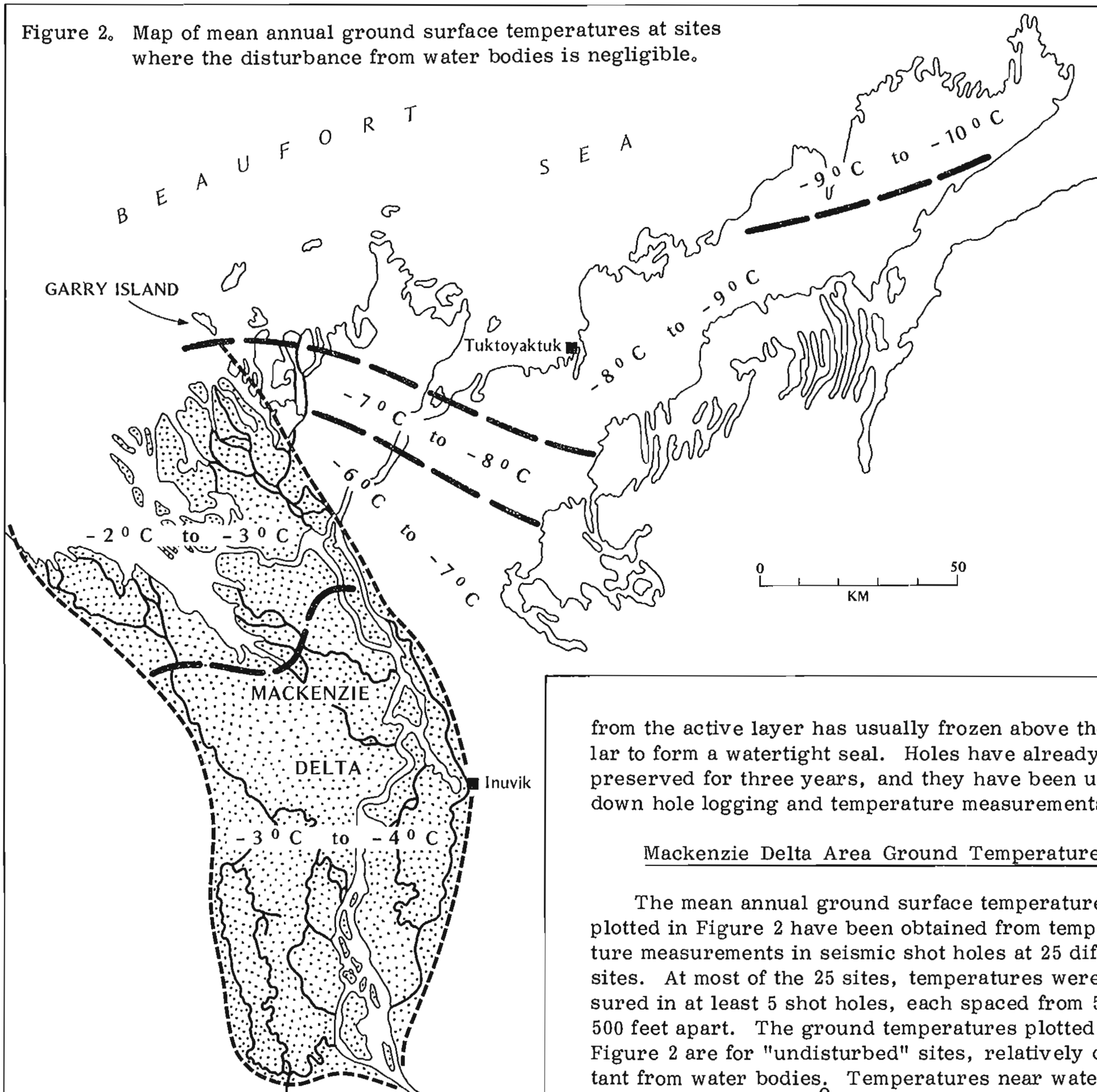

Figure 2. Map of mean annual ground surface temperatures at sites where the disturbance from water bodies is negligible.

agreement with nearby long term (3 year) ground temperature measurements.

Preservation of Shot Holes

Field tests have shown that shot holes in well drained sites can be preserved as "open holes". The procedure has been to insert a rigid PVC tube, capped at one end, well down into permafrost. In the Tuktoyaktuk, N.W.T. area, 6- to 9-foot tubes have been used. In order to provide a water seal, collars slightly larger than the hole diameter have been welded onto the tubes. When the collars lie within permafrost, water from the active layer has usually frozen above the collar to form a watertight seal. Holes have already been preserved for three years, and they have been used for down hole logging and temperature measurements.

Mackenzie Delta Area Ground Temperatures

The mean annual ground surface temperatures, plotted in Figure 2 have been obtained from temperature measurements in seismic shot holes at 25 different sites. At most of the 25 sites, temperatures were measured in at least 5 shot holes, each spaced from 50 to 500 feet apart. The ground temperatures plotted in Figure 2 are for "undisturbed" sites, relatively distant from water bodies. Temperatures near water bodies can approach 0°C close to lakes and rivers in the Mackenzie Delta, and they may be several degrees warmer than undisturbed sites elsewhere.

Acknowledgments

The writer would like to thank Gulf Oil Canada Ltd., Imperial Oil Ltd., and Shell Canada Ltd. for their help in the temperature measurements.

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THE RAPIDITY OF TUNDRA POLYGON GROWTH AND DESTRUCTION, TUKTOYAKTUK PENINSULA–RICHARDS ISLAND AREA, N.W.T.

Project 680047

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Terrain Sciences Division

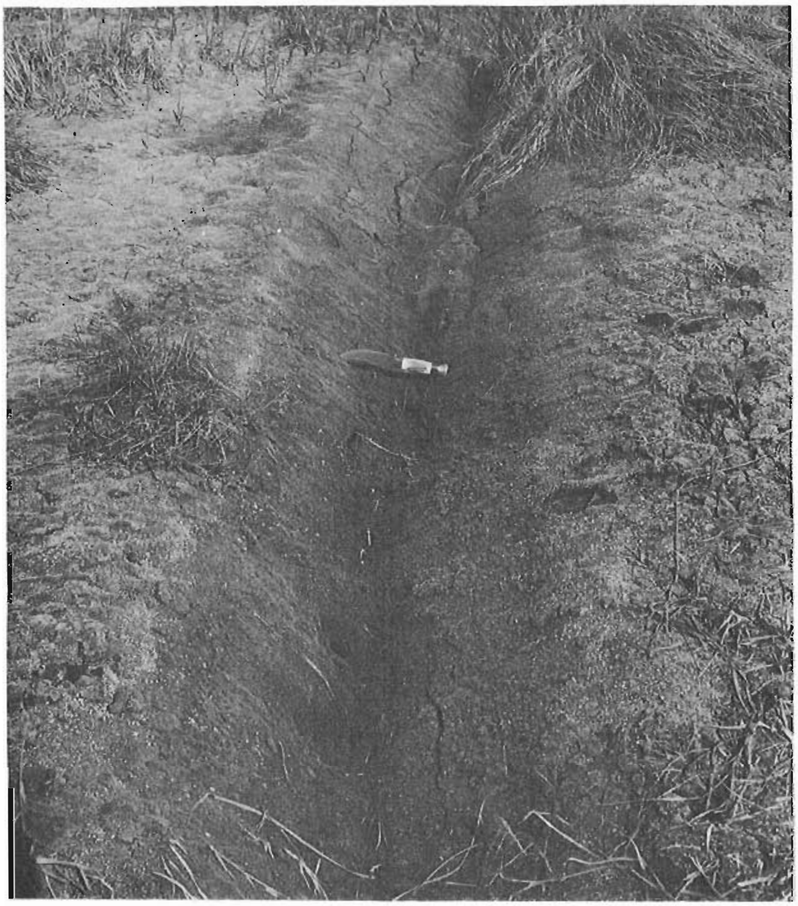

Figure 1. A polygon trough which has developed since 1964 on the bottom of a drained lake. The ice wedge, below, is only a few millimetres wide.

Tundra (ice-wedge) polygons are constantly used as a diagnostic indicator for the presence of permafrost, and in fossil form, as proof of the past existence of permafrost. This report deals with some field evidence which shows that the polygonal forms can grow, and be destroyed, quite rapidly. The region involved is the Tuktoyaktuk Peninsula and Richards Island area, N.W.T., to the north and northeast of Inuvik, N.W.T.

The Rapidity of Tundra Polygon Growth

The rapidity of tundra polygon growth has been determined for numerous sites by field studies of drained lake bottoms where drainage and exposure to air temperatures has initiated polygon growth. Field observations show that polygonal patterns can develop in well drained sandy sites within 10 years. In poorly drained sites, polygonal patterns may not be visible even 100 years after drainage.

Two examples of the rapidity of polygon growth can be cited. The first example is on Richards Island, 30 km northeast of Tununuk, N.W.T., where a lake drained in 1964. Figure 1 shows a polygon trough 65 cm wide and 20 to 25 cm deep. Such troughs outline excellent polygons on the drained lake floor. The second example is 25 km south of Atkinson Point, N.W.T., (on Tuktoyaktuk Peninsula) where a group of interconnected lakes drained within a year or two of 1958. Much of the exposed lake bottom is composed of sands in which large polygons, 10 to 20 m in diameter, have grown. The larger troughs are 60 to 70 cm wide, and 15 to 25 cm deep. Excavations across the troughs show that vertical sand wedges extend downwards below each trough. The volume of sand in each wedge corresponds closely with the void in the trough above it. However, the widths of the ice wedges, which have been exposed by digging, measure no more than a couple of millimetres.

Ice Wedge Destruction

Most of the lakes in the Tuktoyaktuk Peninsula and Richards Island area that have drained since 1945, have been drained by thermal erosion of ice wedges at their outlets.

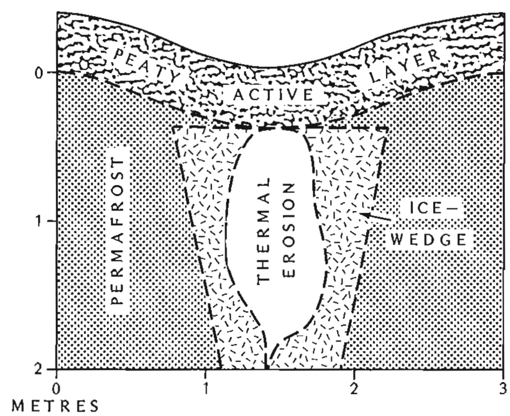

Figure 2. Cross section of ice wedge at Garry Island, N.W.T., showing thermal erosion which occurred by channel flow in August, 1973.

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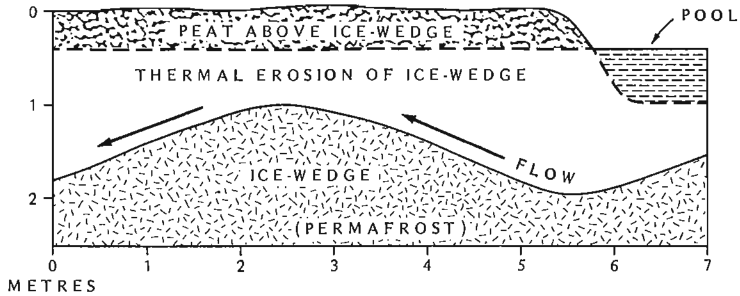

Figure 3. Transverse section of ice wedge shown in Figure 2.

The thermal erosion has usually been through the troughs of high centred polygons. In some instances, erosion has followed spring snowmelt; in others, heavy or prolonged summer rains.

An illustration of thermal erosion which was accomplished by sustained flow in several weeks is given in Figures 2 and 3, for a site at Garry Island, N.W.T., 150 km northwest of Inuvik, N.W.T. In August 1973 persistent drizzles kept the ground saturated, and there was continuous flow out of a small basin, 150 m in radius, by way of several polygon troughs at the outlet ent of the basin. The flow became channeled through one trough, and thermal erosion resulted (Figs. 2 and 3). As soon as the flow ceased, inward freezing commenced, and water in the channel will probably freeze in the winter of 1973-74.

Conclusions

1) Large polygon troughs in recently drained lakes should not be taken as indicators of correspondingly large ice wedges below. This constrasts with low and high centred polygons where the widths of the troughs tend to reflect the widths of the underlying ice wedges.

2) Interception and channeling of runoff, from a relatively small drainage area, can cause rapid thermal erosion of ice wedges. This is a factor to be considered where construction induces interception and channeling of flow through an ice wedge area.

139. STRATIGRAPHY, FACIES AND PALAEOGEOGRAPHY OF JURASSIC AND CRETACEOUS ROCKS OF NORTHERN YUKON AND DISTRICT OF MACKENZIE, (NTS-116I, 116J, 116L, 116O, 116P, 117A)

Project 550004

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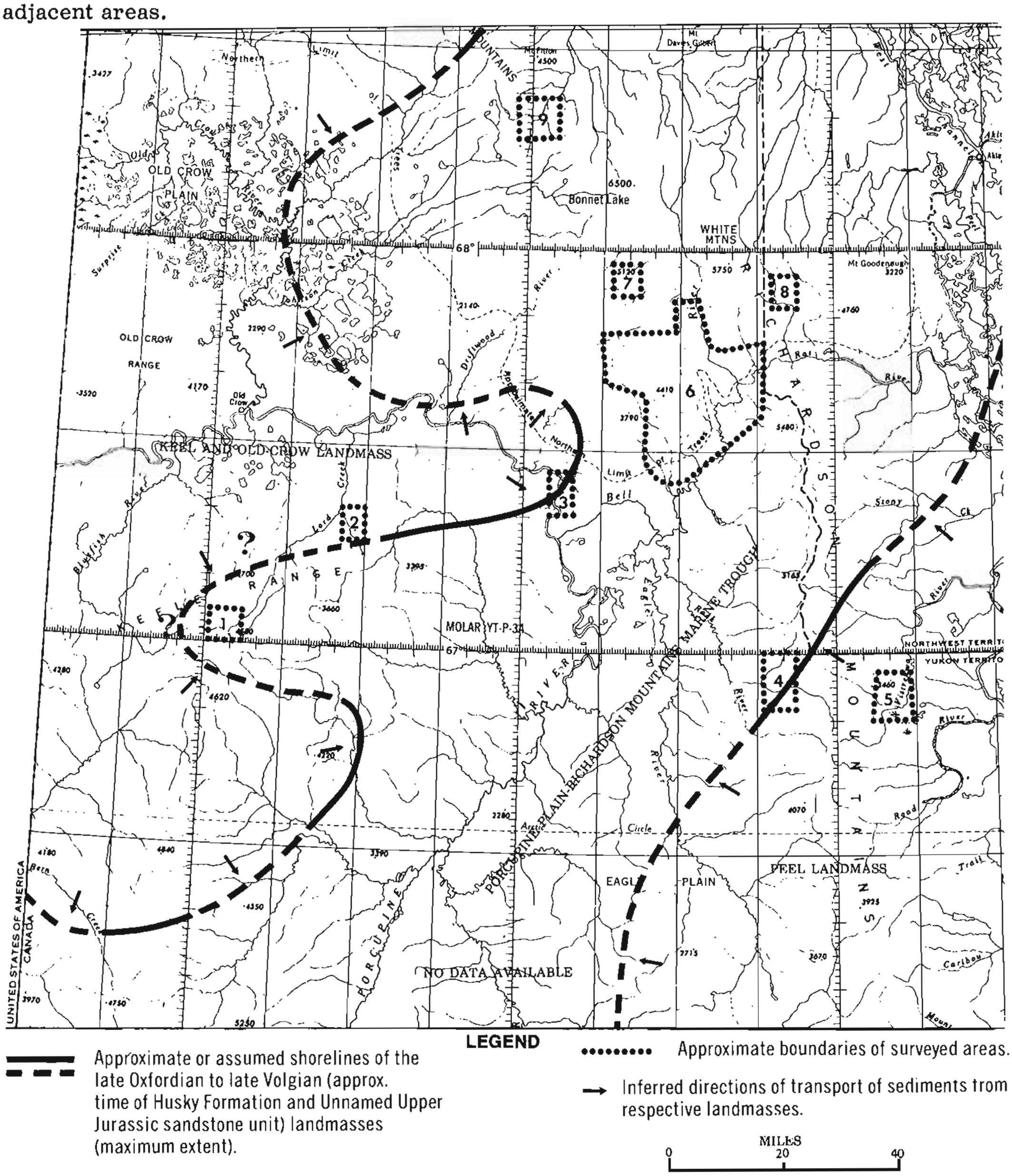
In June and July 1973, about five weeks were spent in a stratigraphical-paleontological study of the Jurassic and Cretaceous (mainly Berriasian to Aptian) rocks of the northern Yukon and the District of Mackenzie and in supporting the field work of D. K. Norris (Project 690005) and F. G. Young (Project 700068) in these and adjacent areas.

The approximate boundaries of the principal areas surveyed in 1973 are indicated in Figure 1 where they are numbered from 1-10 inclusive. Detailed supporting text with full documentation is being placed on the Geological Survey Open File for general consultation.



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