

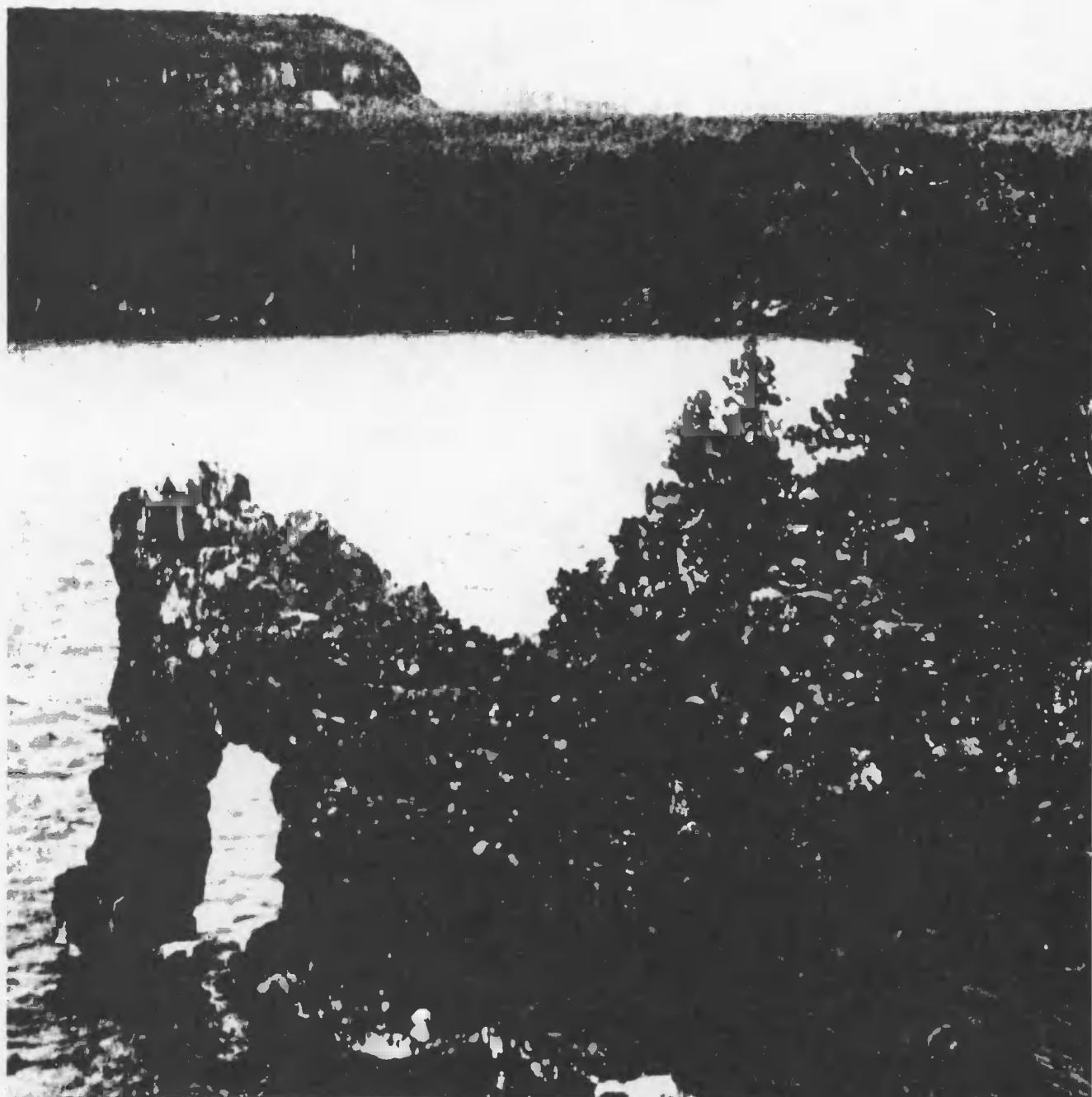
Twenty Third Annual Meeting

Thunder Bay, Ontario

Institute on Lake



Superior Geology



ABSTRACTS and PROCEEDINGS

PROCEEDINGS

TWENTY - THIRD ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY



HELD AT THE

AIRLANE MOTOR HOTEL

THUNDER BAY

ONTARIO

MAY 2 - 8, 1977

SPONSORED BY THE

ONTARIO DIVISION OF MINES

AND LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

M.M. Kehlenbeck, S.A. Kissin, R.H. Mitchell

General Editors

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GENERAL INFORMATION

23rd ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

AIRLANE MOTOR HOTEL

THUNDER BAY

MAY 2 - 8, 1977

SPONSORED BY THE

ONTARIO DIVISION OF MINES

AND LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

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Trip C - Mattabi

James M. Franklin, Geological Survey of Canada,
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Manfred M. Kehlenbeck, Department of Geology,
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Technical Program

Stephen A. Kissin, Department of Geology,
Lakehead University, Thunder Bay, Ontario.

Roger H. Mitchell, Department of Geology,
Lakehead University, Thunder Bay, Ontario.

Field Trips

Trip A - Coldwell Complex

Roger H. Mitchell, Department of Geology,
Lakehead University, Thunder Bay, Ontario.

R. Garth Platt, Department of Geology,
Lakehead University, Thunder Bay, Ontario.

Trip B - Proterozoic Rocks of the Thunder Bay Area

Kenneth G. Fenwick, Ontario Division of Mines,
Thunder Bay, Ontario.

Clarence R. Kustra, Ontario Division of Mines,
Toronto, Ontario.

William H. McIlwaine, Petrologic Ltd., Thunder Bay,
Ontario.

John F. Scott, Ontario Division of Mines,
Thunder Bay, Ontario.

Annual Banquet Guest Speaker

Dr. J. Tuzo Wilson, Department of Physics -
Geophysics Division, University of Toronto,
Toronto, Ontario

Acknowledgements

The organizing committee for the 23rd Annual Meeting of the Institute on Lake Superior Geology gratefully acknowledges the work of Wendy Bons and Cathy LeBrun for typing the final manuscripts of the field trip guidebooks and proceedings volume.

Special thanks to Sam Spivak who prepared the many figures, maps, and cover illustrations.

CALENDER OF EVENTS AND PROGRAM

MONDAY, MAY 2, 1977

1:00 p.m.- 3:30 p.m. Early Registration
Airlane Motor Hotel-Lobby

4:00 p.m. Pre-Institute field trip A-
Coldwell Complex departs from
the Airlane parking lot for
Marathon, Ontario.

8:00 p.m.-10:00 p.m. Early Registration
Airlane Motor Hotel-Lobby

TUESDAY, MAY 3, 1977

7:00 a.m.- 8:00 a.m. Early Registration
Airlane Motor Hotel-Lobby

8:00 a.m. Pre-Institute field trip B-
(part 1)-Proterozoic Rocks of the
Thunder Bay area departs from the
Airlane parking lot.

5:00 p.m. Field trip B (part 1) returns
to Airlane Motor Hotel.

WEDNESDAY, MAY 4, 1977

8:00 a.m. Pre-Institute field trip B
(part 2)-Proterozoic rocks
of the Thunder Bay area
departs Airplane parking lot.

5:00 p.m.- 9:00 p.m. Registration
Airplane Motor Hotel-Lobby

5:00 p.m. Pre-Institute field trip B
(part 2) returns to Airplane
Motor Hotel.

5:00 p.m. Pre-Institute field trip A
returns from Marathon to
Airplane Motor Hotel.

8:00 p.m. Conference Smoker (cash bar)
Tiberio Room - Airplane Motor
Hotel.

THURSDAY, MAY 5, 1977

7:30 a.m.- 9:30 a.m. Registration
Airplane Motor Hotel-Lobby

8:30 a.m.-12:00 a.m. Technical Session 1
(see page xii)

1:30 p.m.- 6:00 p.m. Technical Session 2
(see page xiii)

7:00 p.m.- 8:00 p.m. Cocktail Hour (cash bar)
Tiberio Room - Airplane Motor
Hotel.

8:00 p.m. Annual Banquet - Tiberio Room

FRIDAY, MAY 6, 1977

8:30 a.m.-12:00 noon Technical Session 3
(see page xiv)

1:30 p.m.- 5:40 p.m. Technical Session 4
(see page xv)

6:30 p.m. Post-Institute field trip C-Mattabi departs Airplane parking lot for Ignace. Trip C will return on Sunday, May 8, 1977 by 1:00 p.m. to Airplane Motor Hotel.

8:00 p.m. Northwoods Motel, Ignace
Informal discussion period
in preparation for field trip.

S E S S I O N 1

'Morning'

Thursday, May 5th, 1977 - 8:30 - 12:00 a.m.

- 8.20 Opening Remarks
- 8.30 Meineke, D.G., *Organic-rich lake sediment exploration*
 Valdis, M.K. & *geochemical survey of eastern Lake*
 Klaysmat. A.W. *Vermillion-Ely area, Northeastern*
 Minnesota.
- 8.50 Beard, R.C. *Uranium deposits of the Kenora area.*
- 9.10 Ojakangas, R.W. *Proterozoic pitchblende vein potential*
 in Minnesota: Theory and Speculation.
- 9.30 Cannon, W.F. *Two-billion-year-old sedimentary*
 phosphorite deposits in the precambrian
 of northern Michigan.

9.50 - 10.00 Coffee Break

- 10.00 Beltrame, R.J., *Preliminary manganese resource estimates*
 Holtzman, C. & *for the Cuyuna District: A statistical*
 Morey, G.B. *approach.*
- 10.20 Mudrey, M.G., *Massive sulphide deposits in Wisconsin.*
 Ostrom, M.E. &
 Reinke, G.
- 10.40 Booy, E. *Engineering problems in glacial soils*
 near the Canadian-United States border.
- 11.00 Morey, G.B. *Stratigraphic and tectonic history of*
 lower and middle precambrian rocks in
 east-central Minnesota.
- 11.20 LaBerge, G.L. *Major structural features in Central*
 Wisconsin and their implications on the
 Animike Basin.
- 11.40 Davidson, D.M. *Paleostrain analysis: What, How and Why?*

12.00 - 1.30 Lunch

'Afternoon'

Thursday, May 5th, 1977 - 1.30 - 6.00 p.m.

- | | | |
|---------------------------------|---|---|
| 1.30 | Birk, D. &
McNutt, R.H. | <i>Rb/Sr geochronology of Wabigoon Belt Granitoids, Northwestern Ontario.</i> |
| 1.50 | Chou, C.L. | <i>Rare earth element geochemistry of Archean amphibolites, tonalites, granites and paragneisses in the eastern Lac Seul area, Ontario.</i> |
| 2.10 | McLennan, S.M.,
Fryer, B.J. &
Young, G.M. | <i>An estimate of the rare earth element distribution in Post-Kenoran upper crust, north of Lake Huron.</i> |
| 2.30 | McCrae, W.E. &
Crocket, J.H. | <i>The occurrence and some noble metal concentrations in selected komatiitic ultramafic volcanic rocks from Munro Township, Ontario.</i> |
| 2.50 - 3.00 <u>Coffee Break</u> | | |
| 3.00 | Fryer, B.J. | <i>Geochemistry of early proterozoic paleosols north of Lake Huron, Ontario.</i> |
| 3.20 | Longstaffe, F.J.,
McNutt, R.H. &
Schwarcz, H.P. | <i>$^{18}O/^{16}O$ results for Archean plutonic rocks, Lake Despair area, Northwestern Ontario.</i> |
| 3.40 | Ahmad, S.N. &
Perry, E.C. Jr. | <i>Review of Oxygen isotope geochemistry of some precambrian iron formations.</i> |
| 4.00 | Mitchell, R.H. &
Platt, R.G. | <i>Mafic mineralogy of ferroaugite syenite from the Coldwell Complex, Marathon, Ontario.</i> |
| 4.20 | Weiblen, P.W. &
Cooper, R.W. | <i>Shape, size, and cooling history of troctolitic-gabbroic rocks in the Duluth complex.</i> |
| 4.40 | McMaster, G.E. &
McNutt, R.H. | <i>Archean volcanism Washeiganaga Lake area, Wabigoon Subprovince, Northwest Ontario.</i> |
| 5.00 | Blackburn, C.E. | <i>Identification of archean calc-alkaline volcanic centres in the Manitou Lakes area, Northwestern Ontario.</i> |
| 5.20 | Pilatzke, R.H.,
Karner, F.R. &
Peterson, W.M. | <i>Petrology and trend surface analysis of two lake-stage granodioritic plutons, Northern Lake of the Woods region, Ontario.</i> |
| 5.40 | Morris, W.J., &
Wilband, J.T. | <i>Geochemistry of the Yellow Dog Plains, peridotite, Marquette County, Michigan.</i> |

S E S S I O N 3

'Morning'

Friday, May 6th, 1977 - 8.30 - 12.00 a.m.

- | | | |
|------|---|--|
| 8.30 | Weber, R.E. | <i>The petrology and sedimentation of the upper precambrian sioux quartzite of Minnesota, South Dakota, and Iowa.</i> |
| 8.50 | Morey, G.B. & Schulz, K.J. | <i>Petrographic and chemical attributes of some lower and middle precambrian gray-wacke-shale sequences in northern Minnesota.</i> |
| 9.10 | Young, G.M., Long, D.G.F. & McLennan, S.M. | <i>Deltaic deposits in the upper Pecos, Espanola and Gowanda formations (Huronian).</i> |
| 9.30 | Mancuso, J.J., Seavoy, R.E. & Loughheed, M.S. | <i>Stratigraphy of the Baraga Basin meta-sediment, Michigan.</i> |

9.50 - 10.00 Coffee Break

- | | | |
|-------|---|---|
| 10.00 | Loughheed, M.S. & Mancuso, J.J. | <i>Fossil collectibles from the Gunflint formation.</i> |
| 10.20 | Shegelski, R.J. | <i>Evidence for archean turbidite and submarine fan sedimentation from the Savant Lake greenstone terrain, N.W. Ontario.</i> |
| 10:40 | Frost, B.R. | <i>Some comments on the metamorphism of iron-formations.</i> |
| 11.00 | Gower, C.F. & Clifford, P.M. | <i>Metamorphism in the English River sub-province near Kenora, Northwest Ontario.</i> |
| 11.20 | Feirn, W.C. | <i>The stratigraphy and petrology of the archean volcanic rocks at Jasper Lake, eastern Vermilion District, Cook County, Minnesota.</i> |
| 11.40 | Maas, R.S., Medaris, L.G. & VanSchmus, W.R. | <i>Penokean structures and plutonic rocks in Wisconsin.</i> |

12.00 - 1.30 Lunch

S E S S I O N 4

'Afternoon'

Friday, May 6th, 1977 - 1.30 - 5.40 p.m.

- 1.30 Everson, C.I. *Drift lithology in relation to bedrock geology, Long Island Lake Quadrangle, Cook County, Minnesota.*
- 1.50 Zarth, R. *Sedimentary facies associated with late Wisconsin Glacial Lake Duluth, Wrenshall area, Minnesota.*
- 2.10 Welke, C.J.,
 Nebriga, E.L. &
 Meyer, R.P. *Surficial sediment analyses offshore of the copper-bearing province of Keweenaw Point, Upper Michigan.*
- 2.30 Green, J.C. *Environmental geology of the North Shore a coastal zone management project.*

2.50 - 3.00 Coffee Break

- 3.00 Mothersill, J.S. *Post-glacial sediment distribution in the Canadian portion of Lake Superior.*
- 3.20 Cooper, R.W. &
 Morey, G.B. *The application of linear topographic features to structural interpretation of a glaciated precambrian terraine in northeastern Minnesota.*
- 3.40 Snider, D.W.,
 Klasner, J.S.,
 Quam, S.,
 Lilienthal, R.
 Geraci, P. &
 Grosz, A. *Geophysical studies of peridotite dikes, Yellow Dog Plains, Northern Michigan.*
- 4.00 Dugan, J.P. Jr. &
 Ervin, C.P. *Geophysical study of a gabbroic intrusion, Clam Lake, Wisconsin.*
- 4.20 Klasner, J.S.,
 Hinze, W.J., Bacon,
 L.O. & O'Hara, N.W. *Bouguer gravity anomaly map of northern peninsula of Michigan, Lake Superior, and environs.*
- 4.40 Chandler, V.W.,
 Hinze, W.J. &
 Braile, L.W. *Analytical correlation of gravity and magnetic data in the North American Midcontinent.*
- 5.00 Klasner, J.S. &
 Bomke, D. *Crustal model studies of a regional gravity anomaly in northern Michigan and Wisconsin, extent of anomaly, and its relationship to near surface geology.*
- 5.20 Pesonen, L.J. &
 Halls, H.C. *Paleomagnetic and paleointensity studies of normal and reversed keweenawan rocks - implications for the polar wander path of North America.*

abstracts

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REVIEW OF OXYGEN ISOTOPE GEOCHEMISTRY
OF SOME PRECAMBRIAN IRON FORMATIONS

S.N. Ahmad

and

E.C. Perry, Jr.

ABSTRACT

A review of published values for oxygen isotope data for quartz and magnetite from the Hamersley Iron Formation and the eastern portion of the Biwabik Iron Formation indicates that consistent trend lines appear if $\delta^{18}\text{O}$ of quartz and magnetite are plotted vs Δ_{QM} . This implies that during metamorphism these iron formations behaved as closed systems on same scale and that the system as a whole records isotopic information not present in any one sample. The Hamersley and Biwabik trend lines intersect one another at a $\delta^{18}\text{O}$ for quartz of about 24.0 o/oo., a value close to that observed for pure chert horizons in the Hamersley Iron Formation and the Gunflint Iron Formation (correlative with the Biwabik).

Subject to certain assumptions, the intersection of the Hamersley and Biwabik oxygen isotope trend lines permits us to estimate that the temperature of precipitation or diagenesis of these iron formations was about 22°C. A continuing study of other iron formations of low metamorphic grade may show whether this temperature estimate is reliable. It may also permit evaluation of reactions proposed by several authors for conversion of iron carbonate to magnetite during diagenesis and metamorphism.

URANIUM DEPOSITS OF THE KENORA AREA

R. C. Beard, Ont. Div. of Mines, MNR, Kenora, Ontario

Uranium deposits were first recognized in the Kenora area in 1949 and exploration has been carried out on these occurrences during two periods, 1952-57 and 1965-67. Recent increases in the price of uranium have stimulated a new cycle of exploration in the area, and numerous programs, both detailed examinations of previously known occurrences and grassroots exploration for new deposits, are currently under way. Past work on the various properties consisted of trenching, geophysical surveys, and diamond drilling. An exception, the new Campbell Island Mining and Exploration Ltd. deposit in MacNicol Twp., has been explored by underground development on two levels.

Over thirty deposits have been documented in the Kenora-Dryden area; there is evidence to suggest that many more have been discovered which have not yet found their way into the public record. They tend to be concentrated in two general areas: a) near Vermilion Bay, 40 miles east of Kenora, associated with a narrow "greenstone" belt and, b) north of Kenora within the English River Gneiss Belt.

The uranium occurrences are (typically) associated with pegmatitic phases of anatectically-derived, rather than plutonic, granitoid rocks. Supracrustal rocks of Archean age, exhibiting remelting and assimilation features to varying degrees, are associated with almost all deposits. These are quartz-biotite paragneisses of sedimentary derivation although some deposits are associated with amphibolitized mafic volcanic rocks.

Uranium occurs as fine grains of uraninite disseminated in the granitoid rocks which are usually, but not always, pegmatitic in texture. It is frequently associated with one of the following accessory minerals: biotite, magnetite, sulphides, or apatite. Minor leaching and redeposition as uranophane along near surface fractures is common to many of the deposits. Grab sample assays from radioactive zones range from 0.5 or less to 1.5 lbs. U_3O_8 per ton, with occasional grab samples assaying over 10 lbs. per ton.

It is suggested that the uraniferous pegmatites of the area are, to a certain extent, stratigraphically controlled, having been anatectically derived from supracrustal rocks which contained anomalous amounts of uranium. Study should be directed toward the identification of these "source beds", so that exploration may then be directed to these more favorable areas. Reconnaissance mapping by the Ontario Div. of Mines (Breaks et al, 1975) suggests one such area near Umfreville Lake, north of Kenora.

PRELIMINARY MANGANESE RESOURCE ESTIMATES FOR THE CUYUNA DISTRICT: A STATISTICAL APPROACH

R.J. Beltrame, Richard C. Holtzman, and G.B. Morey, Minnesota Geological Survey,
University of Minnesota, St. Paul, Minnesota

The Cuyuna range in east-central Minnesota has produced over 105 million tons of iron ore and manganiferous-iron ore during the past 62 years. Although iron ore reserves are nearly exhausted and all mining activity has ceased, significant amounts of manganese bearing materials are presently available.

The occurrence of high-grade manganiferous material (>5 weight % Mn) is generally limited to the Emily iron-formation member of the Rabbit Lake Formation and more commonly to the Trommald Formation. In both iron-rich units the manganese is present in both the original protolithic iron-formation (10-30% Fe) and the so-called secondarily enriched "natural ores" (40-60% Fe). In the Trommald Formation of the North range, most of the manganese occurs in the transition zone between the thick-bedded (granule chert layers 1-100 cm thick) and thin-bedded (laminae <1 cm thick) facies rocks. Due to the complexity of the stratigraphic and structural relations and because of the enormous amount of available drill hole data, preliminary manganese resource estimates were statistically calculated for 69 uniquely defined deposits. A deposit was defined, for statistical reasons, as a legal land section.

The location coordinates, collar elevations, and chemical assay data for 5,045 drill holes were entered into a computerized storage and retrieval system. Statistical methods involved calculating an area of influence for each given Mn assay value for each drill hole. These areas of influence were calculated based on the spatial distribution of drill holes in each deposit and the location of the drill hole relative to the section boundaries. Computer-generated data location and drift thickness maps were produced as were grade-quantity estimates of manganese resources.

Manganese quantity resource estimates were calculated for five grade classes (1-3%, 3-5%, 5-10%, 10-15%, and >15%) for each of five depth intervals (<30, <60, <90, <120, and <150 meters below the surface) for each of the 69 deposits. Resource estimates for three deposits in the Emily district, 39 deposits in the North range, and 27 deposits in the South range accounted for 6%, 77%, and 17% of the total Cuyuna district resource estimate respectively.

A total of 22.4 billion metric tons of manganiferous material (>1% Mn) was calculated to a depth of 150 meters for the entire Cuyuna district. More realistic values are 2.3 billion metric tons at >5% Mn, and 887 million metric tons at >10% Mn, calculated to a depth of 60 meters.

Rb/Sr GEOCHRONOLOGY OF WABIGOON BELT GRANITOIDS, NORTHWESTERN ONTARIO

DIETER BIRK and ROBERT H. McNUTT
Department of Geology, McMaster University
Hamilton, Ontario L8S 4M1

Thirty-one whole rock samples from five granitoid plutons, intrusive into meta-volcanics of the Wabigoon Greenstone Belt, generate a composite Rb/Sr errorchron (MSWD = 2.34):

$$\text{Age} = 2621 \pm 42 \text{ m.y. } (2\sigma) \quad R_o = .7007 \pm 4 (2\sigma)$$

Linear regression of cogenetic samples generate Rb/Sr isochrons sensu stricto for each pluton as follows:

Pluton (No. of Samples Analysed)	Lithology	Age in m.y. ($\pm 2\sigma$)	Initial Ratio ($\pm 2\sigma$)	Location (NTS)
Burditt Lake (9)	granodiorite	2598 $\pm$ 45	.7009 $\pm$ 6	52C/13
Esox Lake (4)	quartz-feldspar porphyry	2572 $\pm$ 42	.7003 $\pm$ 5	52F/3
Flora Lake (5)	granite-monzodiorite	2636 $\pm$ 63	.7017 $\pm$ 6	52F/5
Taylor Lake (5)	granodiorite-monzonite	2640 $\pm$ 31	.7005 $\pm$ 3	52F/7E
Ryckman Lake (7)	granodiorite-monzodiorite	2609 $\pm$ 63	.7001 $\pm$ 5	52C/15
Ryckman Lake (5)		2230 $\pm$ 55	.7012 $\pm$ 2	52C/15

For the Ryckman Lake Stock, the lower age is from a "pseudoisochron" caused by the fortuitous alignment of five data points beyond that expected from known analytical error. The seven point isochron represents a wider range of rock chemistry and more meaningful age and intercept. Isochron data must be tested by several linear regression techniques to expose such "pseudoisochrons".

These Wabigoon granitoid isochrons, when compared with published isochrons from the Rainy Lake area, suggest juvenescence of granitoid plutonism from north to south. This may relate genetically to the presence of the Quetico-Wabigoon Belt interface near Rainy Lake.

The low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for all the late-kinematic granitoids implies a source region of low Rb/Sr. Partial melting of upper mantle rather than older sialic material is indicated.

IDENTIFICATION OF ARCHEAN CALC-ALKALINE VOLCANIC
CENTRES IN THE MANITOU LAKES AREA, NORTHWESTERN ONTARIO

C. E. BLACKBURN

Ontario Division of Mines, Queen's Park, Toronto

A B S T R A C T

Centres of felsic to intermediate volcanism within Archean volcanic-sedimentary belts have long remained enigmatic. In their detection reliance has frequently been made upon physical parameters in pyroclastic rocks (eg. coarsening towards vents), without special attention to overall volcanic and subvolcanic stratigraphy. In the Manitou Lakes area detailed geological mapping has pinpointed a number of vent areas, both simple and compound.

Within the study area a thick submarine basaltic flow sequence of tholeiitic affinity was built up, followed by eruption of a calc-alkaline sequence composed predominantly of dacitic to andesitic coarse pyroclastics.

The tholeiitic basalt sequence was intruded by quartz-feldspar porphyry plugs, at Sunshine Lake and at Thundercloud and Washeibemaga Lakes (McMaster and McNutt, this volume). The plug at Sunshine Lake is the subvolcanic equivalent of rhyolitic flows that occur within the pyroclastic sequence. This plug was in turn intruded by irregular lamprophyric dikes and sills that are subvolcanic equivalents of a calc-alkaline to alkaline mafic flow that terminated volcanism in this part of the area.

Southwest of Cane Lake, elongate to lenticular quartz-feldspar porphyry bodies within the pyroclastic sequence variously have subvolcanic and volcanic characteristics, suggesting the location of a felsic vent in this vicinity. A mafic sill correlatable with the late mafic phase at Sunshine Lake occurs in close spatial association with these porphyries.

None of these vents has been directly identified as supplying dacitic to andesitic pyroclastic debris. However, one vent that did supply such coarse pyroclastic material has been identified at Frenchman Island, Upper Manitou Lake, where a subvolcanic porphyritic to inequigranular plug intrudes coarse pyroclastics of comparable chemical and mineralogical composition.

ENGINEERING PROBLEMS IN GLACIAL SOILS NEAR THE
CANADIAN-UNITED STATES BORDER

Emmy Booy

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Houghton, Michigan 49931

ABSTRACT

The borderlands of the United States and Canada ranging from Lake Superior eastward to the Gulf of St. Lawrence are characterized by the presence of glacial deposits which cause problems in safe utilization of the land. At various locations, but particularly along the valley of the St. Lawrence River and its tributaries and along the southern margin of Lake Superior, slope failures have caused expensive losses in property and hazards to human life.

Because glacial clays in northern climates have been known for centuries to be prone to failure, they have been studied by engineers and geologists to determine the causes of their failures and means for controlling them. Most of these investigations have concentrated on the so-called "quick clays", glacial clays laid down in marine environments. There have been relatively few studies of fresh-water glacial deposits and their relationship, if any, to the marine and estuarine deposits.

At the present state of knowledge, there is no definitive explanation for the sudden outflows of clay which are characterized as quick clay failures. It should be noted that a variety of types of failures are observed in all the glacial deposits. Many of them appear to be a result of excess hydrostatic pressure in the coarser strata of varved deposits. These occur in both the fresh water and marine deposits. Classic slump failures have also been described in both fresh and salt-water deposits.

The only major difference in slope stability between the more easterly marine deposits of glacial soils and those deposited in the fresh water predecessors of Lake Superior, is the apparent lack of quick clay flows in the latter. These flows have been reported from Scandinavia, Alaska, and eastern Canada as occurring suddenly on slopes as low as a few degrees. The failed material has an extremely low viscosity and may require hours to regain significant shear strength. There has been a significant lack of reports in the literature of similar failures in fresh-water glacial deposits.

It appears likely that there is a significant difference in material between those soils which fail as quick clays and those which do not. It is generally agreed that there is a major rearrangement of soil fabric during quick clay failure which is held responsible for the variation in shear strength between failed and unfailed portions of a deposit. It is equally possible that the "cement" which is alleged to give quick clays their original shear strength is significantly different in marine and fresh water glacial deposits.

Two-billion-year-old sedimentary phosphorite deposits
in the Precambrian of northern Michigan 1/

by

W. F. Cannon
U. S. Geological Survey
Reston, Virginia 22092

Abstract

Phosphate-rich beds have recently been found at five localities in 2-billion-year-old metasedimentary rocks of the Marquette Range Supergroup in northern Michigan (Cannon and Klasner, 1976). All occurrences are near the unconformable base of the supergroup within 100 meters stratigraphically above older gneiss. Four occurrences are in the Michigamme Formation, part of the Baraga Group; the fifth is in the older Ajibik Quartzite, part of the Menominee Group. The phosphatic minerals occur in two ways: 1) as thin beds of apatite, mostly associated with lean carbonate iron-formation, and 2) as pebbles of apatite in conglomerate. Two thin-bedded occurrences in the Michigamme Formation, first reported by Mancuso and others (1975), have not been evaluated for grade and extent. Of the three new occurrences reported by Cannon and Klasner (1976), two are low grade and consist of scattered pebbles of apatite in basal Michigamme and Ajibik conglomerates, and a few thin beds of apatite generally less than 1 cm thick. The third contains thick conglomerate beds, including a bed about 15 m thick that averages about 15% P_2O_5 , and many thinner beds of comparable grade.

Because outcrops are very limited in the area, the grade and extent of the deposits are impossible to determine without subsurface data, but the economic potential of these deposits warrants further evaluation. The area has never been systematically explored for phosphate minerals. The five known occurrences were found by only a cursory examination of field notes and hand specimens; none of these rather cryptic deposits was identified in the field.

Precambrian sedimentary rocks have not been considered a likely host for economic phosphate deposits in the United States, and these deposits are the richest so far known in the Precambrian of this country. Because five localities have been found without a thorough field search in an area that has very sparse outcrops, a good possibility exists for undiscovered phosphate deposits in the region.

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1/ Prepared in cooperation with the Geological Survey Division, Michigan Department of Natural Resources

ANALYTICAL CORRELATION OF GRAVITY AND MAGNETIC DATA IN THE NORTH AMERICAN MIDCONTINENT

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The correlation of gravity and magnetic data is one of the most commonly used geophysical techniques in basement geological studies. This usage is especially vital in the Midcontinent area of North America where direct observation of the basement complex is essentially prohibited by a blanket of Phanerozoic strata. In the past the correlation of gravity and magnetic data has usually been carried out by purely visual methods or by restricted applications of theoretical methods such as Poisson's theorem. Visual methods are hampered by their subjective nature whereas the classical application of Poisson's theorem is often voided by necessary theoretical assumptions. Recent studies have investigated several computerized approaches to the correlation of gravity and magnetic data. One of these recently developed techniques, internal correspondence, has been investigated through model studies and has been shown to be a potentially valuable supplement to combined gravity and magnetic interpretation. The technique involves a moving window analysis of anomalies of the first vertical derivative of gravity and magnetics reduced to the pole. A least squares linear regression is conducted between the two data sets for each window position with a subsequent creation of three regression coefficient arrays over the data space. Consideration of Poisson's theorem shows that the slope coefficient array is equivalent to a continuous estimate of magnetization-density ratios for anomalous sources. The intercept coefficient array yields valuable information regarding anomaly base levels. The correlation coefficient array expresses the significance of the linear fit for each window position. Analysis of gravity and magnetic data from the Midcontinent region of North America demonstrate that the internal correspondence approach yields useful constraints in local as well as regional geophysical interpretation of the basement complex.

RARE EARTH ELEMENT GEOCHEMISTRY OF ARCHEAN AMPHIBOLITES, TONALITES,
GRANITES AND PARAGNEISSES IN THE EASTERN LAC SEUL AREA, ONTARIO

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ABSTRACT

Using neutron activation techniques twenty samples from the eastern Lac Seul area of the English River gneiss belt have been analyzed for twenty-eight major and trace elements (Al_2O_3 , total Fe, MgO , CaO , Na_2O , K_2O , TiO_2 , MnO , Sc, V, Cr, Co, Zn, Rb, Zr, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta and Th). Variations of Mn, Sc, Co and Cr are related to total Fe content, their concentrations decrease in the order of amphibolites, tonalites = paragneisses, leucosome, trondhjemite, granites, muscovite granites, and pegmatite. Distinct rare earth element (REE) patterns are found for various rock types. Two amphibolites have flat REE patterns and total REE contents about 10-12X chondritic abundances, similar to Archean basalts. A third amphibolite (T91) is enriched in La and Ce relative to other amphibolites, probably due to metamorphism. Six tonalites can be separated into two groups based on their REE patterns. Type-A tonalites (4 samples) have smooth and steep-sloped REE patterns with remarkable enrichment of light REE and depletion of heavy REE ($\text{La}_{\text{E.F.}} = 71-135$ and $\text{Yb}_{\text{E.F.}} = 3-11$). Type-B tonalites (two samples) have higher total REE contents than type-A, negative Eu anomalies and flat heavy REE abundances ($\text{La}_{\text{E.F.}} = 106-112$ and $\text{Yb}_{\text{E.F.}} = 22-39$). Type-A tonalites may have derived from garnet eclogites, with garnet as a residual phase during partial melting, whereas type-B tonalites are probably derived from dioritic source with amphibole and plagioclase as residual phases. Granites have smooth and steep-sloped REE patterns. Muscovite granites have lower light REE contents than granites and negative Eu anomalies. Both granites and muscovite granites may have originated from sedimentary rocks by crustal anatexis. The REE patterns of garnet paragneiss and biotite paragneiss are similar to type-A tonalites, suggesting that tonalitic rocks are the dominant source of meta-sediments.

THE APPLICATION OF LINEAR TOPOGRAPHIC FEATURES TO STRUCTURAL INTERPRETATION OF A GLACIATED PRECAMBRIAN TERRANE IN NORTHEASTERN MINNESOTA

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The application of linear topographic features to various kinds of structural interpretations has become increasingly popular since the advent of spacecraft and high-altitude imagery. Although many types of lineaments can be recognized in Minnesota, a major question remains as to their usefulness in structural studies, particularly in areas where glacial activity has obscured many fundamental bedrock attributes. We have analyzed in detail an area of 3600 sq. km. in parts of northern St. Louis and Cook Counties, Minnesota to determine what correlation, if any, exists between the bedrock geology and topographic lineaments.

The bedrock geology of our study area may be divided into four strato-tectonic units: (1) Lower Precambrian metavolcanic and metasedimentary rocks of the Vermilion district having a predominance of faults trending approximately N.20°E., N.33°E., N.55°-60°E., N.70°-75°E. and N.85°E.; (2) Lower Precambrian "granitic" rocks of the Vermilion massif and Giants Range batholith having faults trending N.20°-40°E.; (3) Middle Precambrian sedimentary rocks of the Animikie Group having a few northwest- and north-northeast- trending faults; and (4) various kinds of Upper Precambrian mafic rocks assignable to the Duluth Complex. In addition, the northern part of the study area is covered by thin (<6 meters), discontinuous patches of Quaternary materials, whereas a thick, more- or less continuous mantle of these materials obscures bedrock relationships in the southern part of the area.

The southern part of the study area is characterized by numerous topographic lineaments trending in a N.35°-40°E. direction; a direction parallel to movement of the Rainy lobe in this area. In contrast, lineaments in the northern part of the study area exhibit a number of diverse directions. An analysis of these lineaments indicates that bedrock structural features exerted a profound influence on present-day land forms. For example, an excellent correlation exists between N.20°E., N.35°-40°E., N.55°-60°E. and N.85°E. trending lineaments and ground-mapped faults in areas underlain by Lower Precambrian metavolcanic and metasedimentary rocks. Similarly there is a marked correspondence between N.25°-40°E. trending lineaments and ground-mapped faults in areas underlain by the Lower Precambrian Vermilion massif and Giant's Range batholith. Furthermore faulting or fracturing in a northeast direction may be much more prevalent in the "granitic" rocks than present mapping indicates because of many codirectional lineaments that are not associated with areas of known faulting.

Previous mapping has documented only a few northeast- and northwest-trending faults in the Duluth Complex. However this part of the study area is characterized by numerous northeast-trending topographic lineaments. Thus an area of approximately 20 sq. km. was mapped in detail to determine if the lineaments could be related to any structural features in the bedrock. As a result of this mapping several faults having unknown amounts of displacement were recognized that correspond to major lineament trends. Subsequently it was recognized that many topographic lineaments also coincide with northeast-trending aeromagnetic lineaments and with disrupted structural elements such as contacts between, and foliations within map units. This suggests that faulting in a northeast direction was a major tectonic process during and after intrusion of the Duluth Complex.

A few northwest-trending faults have been inferred, primarily on the basis of subsurface information, to cut the western margin of the Duluth Complex. In places these faults correspond to mapped faults in the Middle Precambrian Animikie Group, whereas in other places they correspond to well-defined northwest-trending aeromagnetic gradients. However other magnetic gradients have no known geologic expression. We infer from these data that northwest-trending faults may be more numerous than present mapping indicates.

The results of our lineament analysis suggest that any pre-glacial topographic expression of the northwest-trending faults was eliminated by the southward flow of glacial ice which at the same time enhanced the topographic expression of the northeast-trending bedrock structures. Thus although topographic lineaments are a useful adjunct to structural studies in northern Minnesota, they must be carefully interpreted in terms of the glacial history.

PALEOSTRAIN ANALYSIS: WHAT, HOW AND WHY?

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ABSTRACT

WHAT?

Several excellent techniques for quantitatively analyzing natural strain (paleostrain) in deformed rock units have appeared in the geological literature within the past decade.

HOW?

Samples are collected and slabbed along orthogonal planes or photographs taken of the unit viewing three such planes. Deformed structures within rocks, such as fossils, oolites, concretions, phenocrysts, or reduction spots, often have elliptical shapes. The major and minor axes of these ellipses may be measured along with angular relationship of the axes (ϕ) to some fundamental directional property in the rock (bedding, cleavage, foliation, lineation).

The particular method used in treating the data is dependent upon certain assumptions fundamental to the mathematical techniques employed, although virtually all methods assume that deformation involved finite, homogeneous strain. Other assumptions relate to knowledge of the initial shape of the deformed object (circular or otherwise) or knowledge of the orientation of primary planar features such as bedding within the deformed unit.

The procedures of Ramsay, Elliott, Dunnet, Hsu and Matthews and a new method currently being developed at the University of Toronto will be reviewed.

WHY?

Paleostrain techniques are powerful tools in directly analyzing strain history in rocks and shear zones, in preferentially discriminating between deformational models or in treating sedimentary fabrics. These methods warrant serious consideration by geologists working in the Lake Superior region.

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GEOPHYSICAL STUDY OF A GABBROIC INTRUSION,
CLAM LAKE, WISCONSIN

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ABSTRACT

Aeromagnetic maps recently released by the Wisconsin Geological and Natural History Survey contain a sharp, 7000 gamma magnetic anomaly near the town of Clam Lake, Ashland County, in the northwestern part of the state. The anomaly has a wavelength of only 5.5 km, suggesting a shallow source. A coincident, but less well-defined, Bouguer gravity anomaly of 15-20 mgals is also present.

Inland Steel Company drilled a 104 m hole in the center of the anomaly using a diamond drill. The lithologic log shows 29 meters of drift overlying a fresh, unaltered gabbroic sequence with zones containing up to 60% magnetite and ilmenite.

Preliminary analysis of the potential field anomalies suggests that the source is a vertical body that is circular-to-elliptical in horizontal section. Since the Mellen Gabbro Complex lies only about 8 km to the north, the Clam Lake Anomaly may be caused by an intrusive offshoot at depth.

DRIFT LITHOLOGY IN RELATION TO BEDROCK GEOLOGY,
LONG ISLAND LAKE QUADRANGLE, COOK COUNTY, MINNESOTA

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Lithologic studies in northeastern Minnesota suggest that drift prospecting is a useful tool for mapping drift-covered bedrock. A detailed study of till clasts composition in the Long Island Lake quadrangle revealed a significant relationship between drift lithology and bedrock geology.

The Long Island Lake quadrangle is a suitable area for this study for the following reasons: 1) outcrops are numerous enough to have allowed the construction of a detailed geologic map, 2) the area contains eight distinctive rock unit, 3) the local bedrock experienced glacial erosion, indicated by the existence of glacially abraded and quarried outcrops.

The distribution of glacial sediments, mainly till and outwash, were mapped, and one hundred and one samples of drift were collected along traverses parallel to ice flow (perpendicular to strike of the bedrock). Both till and outwash contain a large quantity of local bedrock clasts in the size ranges greater than 2 mm in diameter. Clasts smaller than 2 mm are mainly the mineral quartz, and therefore not so diagnostic of local bedrock. As a test, boulders greater than 1 meter in diameter were used in the field for inferring bedrock contacts. These contacts were found to be within ± 60 meters (200 ft.) of contacts placed by outcrop mapping.

Lack of local bedrock clasts in the smaller size fractions indicate either high resistance of local bedrock to crushing, or lack of opportunity for crushing because of short residence time in the glacial system (short distance transport). In either case, the fine-grained fraction therefore represents a contribution to the glacial load from more distance sources.

THE STRATIGRAPHY AND PETROLOGY OF THE ARCHEAN
VOLCANIC ROCKS AT JASPER LAKE, EASTERN VERMILION
DISTRICT, COOK COUNTY, MINNESOTA

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ABSTRACT

The Jasper Lake area, located within the eastern Vermilion district in Cook County, northeastern Minnesota, represents the basal portion of a thick metavolcanic-metasedimentary sequence. Gruner (1941) found the area to contain three dominantly igneous units: a greenstone unit, an "agglomerate-conglomerate" unit, and an "andesite intrusive" unit. These rocks were shown to have been complexly faulted and isoclinally folded. All units have been metamorphosed to greenschist facies.

The oldest unit consists of predominantly massive meta-volcanics (including basalt, diabase, andesite, and lesser dacite) and is herein referred to as the Jasper Lake greenstone. Due to the presence of pillow structures and quench textures observed at several localities, these rocks are interpreted as subaqueous flows. The unit is linear in outline, 1000-1500 meters thick (exposed), and trends east-west, and is probably continuous with the Chub Lake Volcanic Complex of Morey, Weiblen, and others (1971) to the east. The Saganaga tonalite intruded the greenstone unit along its northern margin, locally metamorphosing it to amphibolite grade along a 30-60 meter wide zone.

The "agglomerate-conglomerate", herein referred to as the Jasper Lake pyroclastic unit, and the associated "andesite intrusive" conformably overlie the greenstone. The pyroclastic unit consists mainly of volcanic breccias, tuffs, and lesser amounts of epiclastic volcanic breccias, conglomerates, and meta-graywacke. Clasts range from 0.1 mm to 1.2 meters in diameter and are composed of dominantly porphyritic andesite with very minor amounts of basalt, dacite, and tuff. Some of the basaltic clasts may have been derived from the older greenstone unit.

The Jasper Lake andesite unit (Gruner's "andesite intrusive") is composed of predominantly porphyritic augite andesite with lesser amounts of massive, porphyritic hornblende andesite-dacite. The rock is typically fine-grained to aphanitic, and vesicular to amygdaloidal, thereby representing a shallow hypabyssal intrusion which may have reached the surface locally.

These rocks are conformably overlain by a well-bedded, graded graywacke-slate unit, greater than 1.6 kilometers thick.

Detailed study in the area shows that the volcanic rocks at Jasper Lake represent the oldest portion of the regional volcanic pile. They trend west-northwest and are faulted off to the west by northeast-trending units which are clearly younger, as they contain clasts of the Saganaga tonalite, which intrudes the greenstone.

SOME COMMENTS ON THE METAMORPHISM OF IRON-FORMATIONS

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ABSTRACT

Preliminary work on the metamorphism of iron-formations shows that the rocks can be modeled by the system Fe-Si-O-C-H. In the typical assemblage of Fe-silicate-quartz-magnetite, the fluid composition is controlled by a reaction of the form:



When fayalite is present the oxygen fugacity is controlled by the QFM buffer and it deviates increasingly from the buffer when it is controlled by increasingly lower-temperature Fe-silicates. It is conceivable that at very low temperatures, those of the range of diagenesis, the oxygen fugacity buffered by the greenalite + quartz + Fe-oxide assemblage is high enough to make the coexisting Fe-oxide hematite.

The presence of siderite requires the consideration of carbon in the fluid phase. Fortunately, the oxygen fugacities of an Fe-silicate-quartz-magnetite rock seem to be high enough to allow CO_2 to exist as the major carbon-bearing component in the fluid instead of CH_4 . Under such conditions siderite will break down to magnetite by the reaction:



Siderite will also react to form an Fe-silicate by the reaction:



Simple topological calculations show that the assemblage siderite + magnetite + Fe-silicate + quartz will be isobarically, isothermally invariant, indicating that at fixed T and P the fugacities of O_2 , H_2O , and CO_2 will be fixed. Furthermore, the same diagrams show that the breakdown of siderite to magnetite can occur at constant f_{O_2} if there is a gradient of H_2O present.

This model can be used to explain the origin of magnetite in siderite-bearing taconite formations. If the rock originally consisted of alternating layers rich in siderite with those containing iron-silicate + quartz, each layer would be buffered to a different fluid composition. Equilibration of the fluids across the layers would cause the chemical potential of CO_2 in the siderite layer to decrease, and induce the formation of magnetite without introduction of oxygen from outside the system.

Geochemistry of Early Proterozoic Paleosols

North of Lake Huron, Ontario

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The contact between the Pre-Huronian and Huronian rocks, north of Lake Huron, Ontario, is often marked by residual weathering products or paleosols. These are characterized by extensive leaching of Na, Ca, Mg, Fe, Mn and Si in their upper parts and concentration of K, Al and Ti. Even when developed on mafic volcanics, these paleosols approach a sericite-titanium dioxide mineralogy. With increasing depth in the paleosols a very iron-rich chlorite abruptly joins the sericite and titanium oxide assemblage. This transition possibly represents the permanent paleowater table.

The behavior of the rare earth elements in these paleosols indicates that the ground waters responsible for these weathered deposits were of significantly higher pH (greater than 8) than at present. A direct consequence of this is that the high K contents of these paleosols are almost certainly original features produced during weathering and not a result of later metasomatism. This is substantiated by the behavior of Rb and Ba.

The behavior of all elements, whether major or trace, appears to be dominated by the reducing and high pH nature of the ground waters. These results suggest that element solubilities and hence concentrations during Early Proterozoic surficial processes may have been considerably different than previously assumed.

METAMORPHISM IN THE ENGLISH RIVER SUBPROVINCE NEAR KENORA, NORTHWEST ONTARIO

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Detailed petrographic investigations on 300 thin sections of gneissic and associated rocks from 200 sq.km. of the English River Subprovince near Kenora have enabled two metamorphic episodes to be defined.

M₁ metamorphism attained uppermost amphibolite facies and, using mineral assemblages together with whole rock chemistry in calcic pods, amphibolites and metasediments, it is estimated that the P-T conditions were 5.25 ± 0.75 kb and 650 ± 40 °C. Prograde reactions during this metamorphism generated garnet from hornblende and biotite in amphibolite and tonalitic gneisses respectively. The distribution of garnets can be closely correlated with (i) alkali feldspar megacryst distribution, (ii) lowest Fe₂O₃/FeO bulk composition ratios in amphibolite and tonalitic gneisses, (iii) deepest structural level. The garnets are undeformed and show no correlation with F₂ fold trends suggesting that the earliest recognizable metamorphism is late or post-F₂.

The M₂ metamorphism is retrograde and, using mineral assemblages in amphibolites and metasediments, appears to have taken place under greenschist facies conditions. P-T conditions cannot be closely defined from petrographic evidence but are estimated as 2.25 ± 1 kb and 400 ± 50 °C.

Potassium has behaved as a mobile component during both phases of metamorphism and is extensively involved in (i) as a reactant with hornblende to give biotite and epidote/clinozoisite, (ii) as a product, together with magnetite, from the oxidation of biotite, (iii) as a product from the reaction of biotite to give garnet. The presence of megacrysts in both gneisses and granitoid rocks is suggested as an expression of this mobility.

ENVIRONMENTAL GEOLOGY OF THE NORTH SHORE
A COASTAL ZONE MANAGEMENT PROJECT

by

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ABSTRACT

During the past two years the Minnesota Geological Survey, on contract from the State Planning Agency, has undertaken a study of the environmental geology of the state's Lake Superior shore as an element of the Federal Coastal Zone Management Program. Two field seasons were devoted to mapping, with sample analysis, literature research, map development, and report writing during the academic year. Besides the author, two graduate students (C. Moss and M. Jirsa) and five undergraduates (C. Baker, M. Gasser, K. Husby, and K. Peterson) were involved. The products are a set of 13 maps, covering the entire shore at a scale of 1:24,000, of each of 5 types (Bedrock geology, Surficial geology, Depth to bedrock, Landforms, and Economic Geology), plus a report which includes interpretations. Geologic processes currently active, geologic hazards, opportunities and resources offered, and land-use constraints are treated for the major surficial material types and landform units.

In this area the major geology-based land-use constraints are imposed by (a) geologic processes such as wave processes and stream erosion and flooding, (b) soil suitability related to clayey glacial lake deposits and to shallow and exposed bedrock, and (c) economic resource protection, particularly gravel in abandoned deltas of higher lake levels.

CRUSTAL MODEL STUDIES OF A REGIONAL GRAVITY ANOMALY
IN NORTHERN MICHIGAN AND WISCONSIN, EXTENT OF ANOMALY,
AND ITS RELATIONSHIP TO NEAR SURFACE GEOLOGY

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The Bouguer gravity anomaly map of northern Michigan and Wisconsin has a broad, long wavelength gravity maximum that extends in an east-west direction for about 800 km from near the eastern end of the northern peninsula of Michigan into north-central Wisconsin. This anomaly may be part of a generally continuous gravity maximum that extends along the Southern Province of the Canadian Shield, except where it is overprinted by the gravity expression of the midcontinent gravity high. It is truncated in South Dakota by a gravity maximum of similar width and amplitude that extends around the western and northern edge of the Superior province. It is truncated on the eastern end by the gravity expression of the Grenville orogenic belt.

Two dimensional gravity models were constructed over the regional anomaly in Michigan and Wisconsin. The models consider mass variations within the upper 20 km of the crust and consist of primarily two layers with a density of 2.80 gm/cc for the upper layer and 2.94 gm/cc for the lower layer. They show that the upper layer is thinnest beneath the middle Precambrian (X) basins and troughs such as the Marquette Trough and it reaches a thickness of about 16 km in central Wisconsin.

In Michigan and Wisconsin several important geologic and economic features are associated with the regional gravity anomaly. For example, middle Precambrian (X) basins and troughs, which cause relatively short (a few kilometers or less) wavelength gravity anomalies, are located over the regional anomaly. Middle Precambrian (X) volcanic accumulations are generally located along the edge of the regional anomaly or within the middle Precambrian (X) basins. The recently discovered boundary between gneiss and greenstone terrane (Sims, 1976) is located roughly near the northern edge of the regional gravity anomaly. Regional metamorphic zones are generally located near the edge of the gravity anomaly, or, where superimposed upon the anomaly, cause gravity minima within the regional anomaly. The recently discovered massive sulfide deposits in Wisconsin seem to occur along the edge of the regional gravity anomaly or along prominent gravity features that cut the regional anomaly.

The above data suggest a genetic relationship between the thinning of the uppermost (2.80 gm/cc) crustal layer and the formation of the middle Precambrian (X) basins and troughs, the accumulation of volcanic deposits, the formation of regional metamorphic zones, and possibly the accumulation of the sulfide deposits in northern Wisconsin. Perhaps the volcanic deposits, the sulfide deposits, and the igneous intrusions that supplied the heat for the formation of the metamorphic zones are all differentiates of the lower (2.94 gm/cc) crustal layer. They were intruded and extruded through fracture zones that formed in the uppermost layer during the Penokean orogeny. Sims (1976) has suggested that the middle Precambrian (X) basins were developed over, and approximately parallel to, the boundary between gneiss and greenstone terranes. The regional gravity maxima lie within the eugeosynclinal zone that Sims has postulated for this area.

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BOUGUER GRAVITY ANOMALY MAP OF
NORTHERN PENINSULA OF MICHIGAN,
LAKE SUPERIOR, AND ENVIRONS

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ABSTRACT

A prepublication version of the Bouguer gravity anomaly map of the northern peninsula of Michigan, Lake Superior, and adjacent parts of Michigan, Lake Huron and Lake Michigan, is presented for discussion purposes. The map, which is at 1:500,000 scale and has a 5-mga. contour interval, is a compilation of data collected since 1951 from several sources. Personnel from the U.S. Geological Survey tied each of the individual surveys to the 1971 base reference datum and made additional observations in areas that lacked gravity coverage. Data were reduced and compiled on digital tape by the Defense Mapping Agency, Aerospace Center, St. Louis, Missouri, using the 1967 international gravity formula, sea-level datum and a 2.67-gm/cc reduction density. Terrain corrections were applied to selected sections in the Porcupine Mountain area only. Because of high station density in the western part of northern Michigan, the Bouguer gravity data were contoured using values selected from 1-minute quadrilaterals. On most of the map, station spacing is broader than the 1-minute interval, so that all stations are represented.

Although the geologic implications of many of the individual anomalies on the map have been discussed in the literature, this map provides a comprehensive integrated view of the gravity field, which can be used in geologic and structural analysis. The geologic sources of a few of the gravity anomalies are discussed in this context. Over the Keweenaw-Lake Superior basin, a pronounced gravity low is found along the center of the lake, and gravity maxima parallel the shoreline and join together at both ends of the lake to connect the midcontinent gravity high with the mid-Michigan gravity maxima. In general the gravity maxima reflect near-surface accumulations of relatively dense mafic volcanic and plutonic rock and the gravity minima reflect thick less dense clastic rock. In northern Michigan, middle Precambrian (X) basins and troughs such as the Marquette trough have east-trending positive anomalies. Lower Precambrian (W) granitic terranes commonly have gravity minima. A broad gravity maximum extends east across the northern peninsula. It has no apparent surficial origin and is believed to be caused by deep crustal or upper mantle mass variations.

Major Structural Features in Central Wisconsin and Their Implications on the Animikie Basin

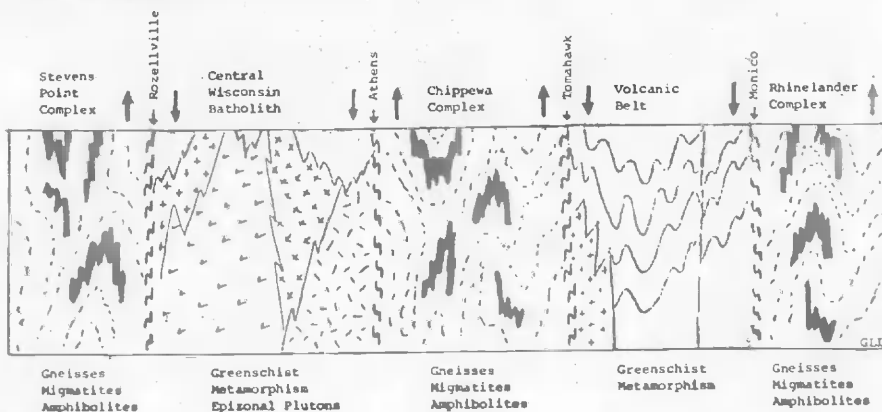
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Abstract

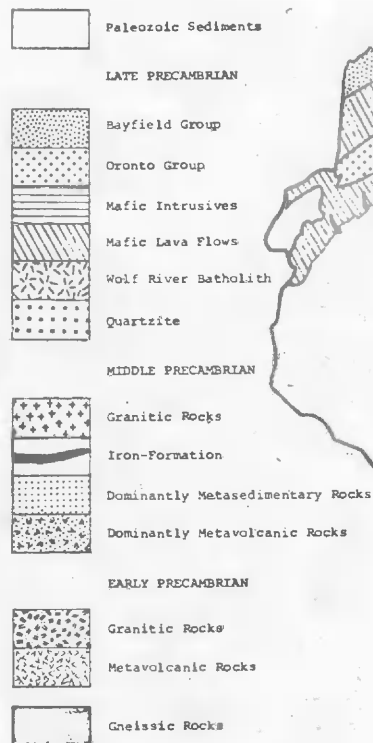
A Middle Precambrian batholith comprising numerous epizonal plutons ranging in composition from quartz diorite to granite intrusive into a complex volcanic-sedimentary pile in Central Wisconsin has been outlined by recent mapping by LaBerge and Myers. This batholith lies on the southern margin of the large east-west trending sedimentary-volcanic (Animikie) basin.

Broad steeply dipping cataclastic zones separate the composite batholith and its greenschist facies roof pendants from upper amphibolite gneisses, migmatites and amphibolites that flank the batholith on the north and south. The scale of cataclasis, presence of ultramafic bodies along the zones, and the marked difference in metamorphic grade across the shear zones indicates deformation on a crustal scale. The gneissic areas appear to be horsts, and the batholith a graben-like structure. Field relations along comparable shear zones within the batholith indicate a long and complex history of cataclasis during emplacement of the batholith, and, by inference, during the history of the Animikie Basin.

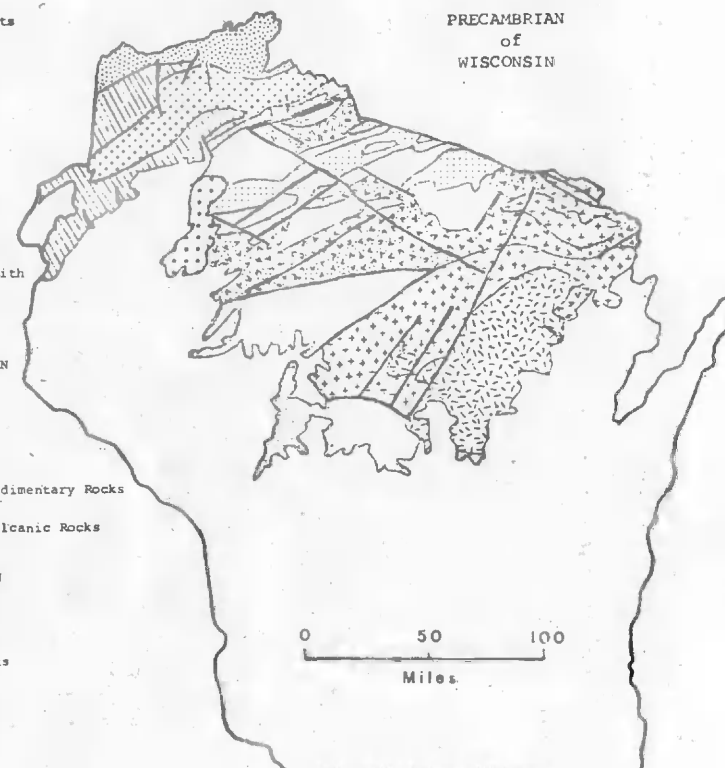
The present distribution of Precambrian rocks in Wisconsin is one of east-west trending belts of Middle Precambrian sedimentary-volcanic-plutonic rocks alternating with Early Precambrian(?) gneissic rocks. This has disrupted the basin into a series of horst-like and graben-like blocks. Field relations in Central Wisconsin indicate that at least part of this deformation occurred during the tectonic history of the basin, and is consistent with Cannon's (1973) interpretation in the Marquette District. This suggests that the Animikie Basin was characterized by vertically moving blocks, which may have provided local sediment sources within the basin and also produced local strongly reducing troughs, one of which may have resulted in the highly graphitic "Flambeau Anomaly."



EXPLANATION



PRECAMBRIAN of WISCONSIN



(Modified from Sims, 1976)

$^{18}\text{O}/^{16}\text{O}$ Results for Archean Plutonic Rocks,

Lake Despair Area, Northwestern Ontario

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and

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An oxygen isotope study of the Jackfish Lake plutonic complex and the Burditt Lake stock, (Wabigoon granite-greenstone belt), has indicated the importance of magmatic-autometasomatic fluid activity and/or hydrothermal-meteoric water interaction in their crystallization and alteration.

$\delta^{18}\text{O}$ values of the main phase of the Burditt Lake granodiorite are relatively constant across the stock (8.00 ± 0.33 ‰); microcline megacryst bearing phases, as well as late stage aplitic rocks have higher $\delta^{18}\text{O}$ values (8.95 ± 0.35 ‰). Depletion in ^{18}O occurs in the volcanoclastic country rocks as the granodiorite contact is approached (11.35 to 8.00 ‰). The movement of magmatic water upward from hotter, deeper portions of the stock through the roof zone into the country rocks can cause such isotopic variations. The high water/rock ratios required at the contact by such a model appear reasonable, as considerable chemical modifications of the country rock has occurred in the vicinity of the contact.

The Jackfish Lake Complex, as exposed in the Lake Despair area, is composed predominantly of diorite and monzodiorite, with lesser volumes of quartz diorite, microcline megacryst bearing granodiorite and soda syenite. The samples which preserve the highest and the most concordant oxygen isotopic temperatures are located within 50 meters of the contact with the mafic amphibolite country rock (which itself has been enriched in ^{18}O from 5.7 to 8.0 ‰). Apparently, the oxygen isotopes have been quenched more rapidly and more completely in the outer margins of the body. Elsewhere in the Complex, discordant oxygen isotope mineral-pair temperatures indicate varying degrees of isotopic disequilibrium. These disturbances can be largely attributed to late stage deuteric alteration and continuing subsolidus isotopic exchange. In spite of such perturbations, some primary isotopic trends are still discernible; $\delta^{18}\text{O}$ values of quartz, plagioclase, hornblende and biotite decrease gradually with increasing degree of differentiation of the rock type. This behaviour probably reflects the relative impoverishment of the remaining melt in ^{18}O as large amounts of ^{18}O -rich mineral phases begin to crystallize during the formation of the late stage small volume granodiorite. The preservation of such trends, as well as the normal $\delta^{18}\text{O}$ enrichment pattern from diorite to granodiorite observed in rock samples suggests closed system isotopic exchange in these rocks.

The southern boundary of the Jackfish Lake Complex is formed by a major fault. Granodiorite located near the shear zone is altered, showing Fe staining and large scale saussuritization of feldspars. Chemically, such samples are enriched in light rare earths, Zr, Ni, Fe, Ti, P, K and Rb, and depleted in Na, Sr and Ba. These rocks are also depleted in ^{18}O (5.41 ‰ 750 meters from the fault; 7.80 ‰ 2400 meters distant). The depleted rocks contain mineral phases which are grossly out of isotopic equilibrium and depleted in ^{18}O relative to "unaltered" granodiorites from the Complex. Such behaviour is best explained by hydrothermal-meteoric water interaction in an isotopically open system.

FOSSIL COLLECTIBLES FROM THE GUNFLINT FORMATION

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ABSTRACT

Iron-formation to be of economic value is dependent upon a succession of processes that transform the initial biogenic particulate material, produced on a gently sloping marine shelf zone into iron-rich minerals. There are five great fossil collectibles of initial material occurring in the Gunflint; they are, siliceous and carbonate shells, blue-green algae, greenaloid and bacterial framboidal pyrite. Two outstanding areas for collecting fossil materials occur at Kakabeka Falls and in the vicinity of Schreiber. Excellent specimens of ooids are found at the falls, but more remarkably, many chalcedonic chert laminae contain totally or almost completely dissolved ooids so that only the nuclei remain. The nuclei are varied in their structural pattern but commonly appear as ellipsoids, spheres, or as spheres with concentric laminae. The structures are small, generally less than thirty microns in diameter. The ellipsoid structures and probably some of the spherical structures are siliceous shells of microorganisms. Some, if not most, of the spherical nuclei are silicified shells of calcareous microorganisms. Both siliceous and calcareous shells are fairly common in organically pigmented chalcedonic chert.

Although bacterial carbonate is common in specimens from Kakabeka Falls particularly those specimens rich in pyrite, the best specimens are found in the Schreiber area, where the micron sized carbonate crystals occur in the cortex of oncolites. The carbonate bacteria produce ammonia as a by-product from their metabolism of expired algal laminae in the cortex, and carbonate is therefore precipitated in the microdomain of high alkalinity. The columnar stromatolites in the Schreiber area are noted for the fidelity of preservation of the filamentous and coccoid algae in a siliceous matrix and therefore are not associated with bacterial carbonate. We find the best specimens of bacterial carbonate produced in columnar stromatolites occurring in the Biwabic iron-formation, however good specimens may be found in the road cut at the junction of highways 590 and 17-11 near Kakabeka Falls. Greenaloid, the gel-like material composed of silica, and sapropel complexed with ferrous iron, is best collected as matrix material in laminae of ooids or as matrix material occurring with tuffball laminae at Kakabeka Falls. Many specimens show transitional steps in the oxidation of greenaloid to greenalite and/or magnetite and less commonly to hematite.

PENOKEAN STRUCTURES AND PLUTONIC ROCKS IN WISCONSIN

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ABSTRACT

Last year we reported on the occurrence of Penokean structures and plutonic rocks in early Precambrian gneiss in Portage and Wood Counties, Wisconsin. We now have completed more detailed structural and isotopic studies on these occurrences and have extended our investigations westward about 100 miles to include localities in Clark, Jackson, and Chipewa Counties.

The Early Precambrian gneiss, formed about 2.8 b.y. ago (Van Schmus and Anderson, 1977) and composed of quartzofeldspathic gneiss, amphibolite, and migmatite, contains three sets of folds: first, penetrative isoclinal folds; second, non-penetrative S- and Z-folds; and third, non-penetrative broad, open folds. The axial surfaces of the second and third fold sets are discordant to those of the first set, but the fold axes of all three are colinear. Well developed lineations, defined by the dimensional orientation of elongate minerals and trains of mineral grains, are parallel to fold axes. In all the localities examined so far, fold axes and lineations plunge steeply, from 45° to 90°.

The gneiss has been intruded by two different tonalites: an earlier medium-grained tonalite, which contains a strong foliation and lineation, and a later fine-grained tonalite, which contains a weak foliation and strong lineation. Lineations in both tonalites are colinear with those in the gneiss. The tonalites as well as the gneiss have been recrystallized under middle-grade metamorphic conditions.

Petrofabric analyses have been completed for samples along the Wisconsin River, including three samples of quartzofeldspathic gneiss, one of medium-grained tonalite, and two of fine-grained tonalite. Measurements of [0001] in quartz have given a similar pattern for all five samples: a girdle normal to the σ fabric axis. Thus, the tonalites contain structural elements in common with some of those in the gneiss, on both mesoscopic and microscopic scales.

U-Pb analyses of zircon have yielded ages of 2800 m.y. for the gneiss, 1850 ± 25 m.y. for the medium-grained tonalite, and 1800 ± 25 m.y. for the fine-grained tonalite. We believe that the zircon ages for the tonalites represent their times of emplacement and, consequently, that the structures within them and some of the structures within the gneiss were produced during the Penokean orogeny.

Further investigations of this type should give a more complete understanding of the Penokean orogeny in Wisconsin and provide a basis for comparison between gneisses of Early Precambrian age in Wisconsin and those of the Minnesota River Valley terrane.

THE OCCURENCE AND SOME NOBLE METAL CONCENTRATIONS IN SELECTED KOMATIITIC ULTRAMAFIC VOLCANIC ROCKS FROM MUNRO TOWNSHIP, ONTARIO.

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Munro township, situated in the Abitibi volcanic belt, is the location of a sequence of well documented komatiitic ultramafic volcanics. The rocks are well exposed and the area has been subjected to only very low grade metamorphism. The komatiitic volcanic rocks range from peridotitic through pyroxenitic to basaltic in composition.

Samples taken from peridotitic flows at the base of Centre Hill have been analysed for gold, platinum, palladium, and iridium by neutron activation analysis. Four lithologic units were sampled from two flows. The results of the analysis are summarized below:

Lithologic Unit (Flow)	Au	Pt	Pd	Ir	(ppb)
Chilled margins (3) *	1.6	2.5	8.9	1.1	
Spinifex zone (3)	2.1	14.3	10.7	0.8	
Foliated zone (1)	3.3	-	7.5	0.4	
Cumulate zone (4)	3.6	11.1	6.3	1.5	

*(3) Number of samples for zone.

There appears to be a slight enrichment of gold in the cumulate zone as well as iridium relative to the spinifex zone. This is probably due to the settling of immiscible sulphides as well as olivine before the formation of the spinifex. Platinum and palladium increase in the spinifex zone and were possibly enriched in the molten silicate phase. The average of the cumulate and the spinifex zone for palladium and iridium are the same as the chilled zone, while the values for gold and platinum are lower. The latter values are possibly due to seawater leaching.

The average concentration of gold (2.7 ppb) is not significantly higher in peridotitic komatiites than in other major rock types and do not appear to contain enough gold to make them a source rock for gold deposits.

Stratigraphy of the Baraga Basin Metasediments, Michigan

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ABSTRACT

The Baraga Basin is located in eastern Baraga and northern Marquette Counties, Michigan. It is 30 miles long by 8 miles wide and is filled with approximately 1400 feet of mildly deformed Middle Precambrian metasediments. Lower Precambrian basement rocks exposed around the perimeter of the basin are crystalline granites and gneisses which unconformably underly the metasediments.

The lowermost Middle Precambrian unit in the basin is a white vitreous quartzite which appears to be limited to the western and central portions of the basin. A basal quartz-pebble conglomerate is exposed at Pikes Peak in sec. 11, T. 51 N., R. 32 W. Overlying the quartzite is a chert-carbonate iron-formation and a volcanoclastic sequence. Recent phosphate discoveries occur within this unit (Mancuso, Lougheed, Shaw, 1975; Cannon and Klasner, 1976). More than 1100 feet of graphitic slates and a thick meta-arkose make up the rest of the section. Flat lying Cambrian(?) Jacobsville Sandstone unconformably overlies the Precambrian rock section.

The white basal quartzite is correlated with the Goodrich Formation while the iron-formation, volcanoclastic sequence, the black slates and the meta-arkose are correlative with the Greenwood Iron-formation Member, the Clarksburg Volcanics Member, and the Lower Slate member of the Michigamme Formation in the western part of the Marquette Basin.

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AN ESTIMATE OF THE RARE EARTH ELEMENT DISTRIBUTION
IN POST-KENORAN UPPER CRUST, NORTH OF LAKE HURON

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Rare earth analyses have been made on samples of tillite matrix from the Gowganda Formation, north of Lake Huron. A grand mean based on averages from the Cobalt, Quirke Lake and Espanola - Sudbury Areas is considered to be representative of upper crustal abundances for a large area north of Lake Huron. The three districts were given equal weight in the estimate. The overall abundances are (in ppm): La, 24; Ce, 55; Nd, 23; Sm, 4.3; Eu, 1.2; Gd, 3.8; Dy, 3.1; Er, 2.0.

These data are compatible with analyses of granitic and volcanic rocks typical of the surrounding areas. Values are also in line with estimates of Canadian Precambrian crust and post-Archean crustal abundances in Australia, though relative distributions have significant differences.

Analyses of Gowganda argillites and sandy argillites intimately associated with the tillites have similar patterns to those of the tillites. Absolute magnitudes, however, are consistently higher (by a factor of about 1.3) than the tillites. A possible explanation for this could be concentration of clay minerals in the argillites. This may suggest that other estimates of crustal abundances which are based, in part, on analyses of fine grained sedimentary rocks are systematically high by a similar proportion.

Archean Volcanism Washeibamaga Lake Area, Wabigoon Subprovince, Northwest Ontario.

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The Washeibamaga-Thundercloud Lakes area of the Wabigoon Subprovince, can be subdivided into three facies;

- 1) The Lower volcanic sequence of metabasalts (lower greenschist facies) is preserved as a steeply-dipping, north-facing homoclinal volcanic pile six kilometres thick. They show trace element (Y, Nb, Zr, Ni, Ba, Rb, Sr), geochemical similarities to modern ocean-floor tholeiitic basalts.
- 2) The Thundercloud Lake Quartz-Porphyry intrudes the lower sequence and is believed to represent a vent-plug filling a late-stage felsic volcano. Accompanying explosive volcanism produced a three kilometre thick sequence of coarse pyroclastic rocks and tuffs. Associated dacitic and autobrecciated rhyolitic flows have calc-alkaline affinities and are chemically distinct from both volcanic sequences and appear not to be a differentiated product but to have originated as a separate magma.
- 3) The Upper volcanic sequence of metabasalts is composed of tightly folded, massive to pillowed flows. The contact with the underlying epiclastic and pyroclastic rocks is at an angle of thirty degrees, implying either profound angular unconformity or a fault contact. The upper sequence is chemically distinct from the lower sequence. K, Rb, Sr, Ba, abundances suggest similarities with modern Island Arc tholeiites.

ORGANIC-RICH LAKE SEDIMENT EXPLORATION GEOCHEMICAL SURVEY
OF EASTERN LAKE VERMILION-ELY AREA, NORTHEASTERN MINNESOTA

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ABSTRACT

An organic rich (gyttja) lake sediment geochemical survey was conducted over Lower Precambrian volcanic and associated rocks in northeastern Minnesota for the purpose of determining the applicability of this method for evaluation of mineral resource potential and reconnaissance exploration. Two hundred and seventy samples were collected from 75 lakes over an area of 200 square miles (520 sq. km.).

A weak aqua regia leach on unignited gyttja produced the best contrast over background. Statistical analysis of the data indicates that trace element distributions are greatly dependent upon the limnological environment of each lake; trace elements tend to be concentrated in the organic and/or inorganic fractions of the gyttja; and, of all parameters considered, LOI (loss on ignition) is the best single indicator of limnological environment.

Due to the variations in lake environments and trace element accumulation in the gyttja, parameters other than the element concentrations were considered. However, the study indicated, even though a perfect datum for comparing lakes was not possible, the element concentrations for arsenic, cobalt, copper, nickel, lead and zinc provided the best datum for comparing all 75 lakes.

Several significant anomalies were located by the survey. Anomalous copper was found in a lake near an interesting copper prospect. Copper, lead, titanium and zinc appear to reflect bedrock composition; chromium, magnesium and nickel reflect both bedrock composition and glacial dispersion.

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Plutonic Center 1 of the Coldwell alkaline complex is dominantly ferroaugite syenite associated with minor amounts of earlier hypersthene gabbro. A c. 2000 m. section of ferroaugite syenite exposed on the lake shore between Marathon and the eastern margins of the complex exhibits well defined igneous layering in the eastern portion of the sequence. The layered syenites grade into syenites with poorly defined diffuse turbulent layering and these in turn into coarse syenites containing patch and sheet pegmatites. Cryptic layering is well developed in the sequence and indicates this portion of Center 1 ferroaugite syenite is a small intrusion in which crystallization occurred simultaneously at the roof and base. Olivines range in composition from Fa_{83} to Fa_{93} . Pyroxenes initially belong to the diopside-hedenbergite series ($\text{Di}_{48}\text{Hd}_{49}\text{Ac}_3$ to $\text{Di}_{10}\text{Hd}_{85}\text{Ac}_5$) and grade into members of the aegirine-hedenbergite series ($\text{Di}_{10}\text{Hd}_{85}\text{Ac}_5$ - $\text{Di}_{5}\text{Hd}_{45}\text{Ac}_{50}$). Pyroxene compositional trends are similar to those observed in peralkaline igneous rocks and in particular to those of the undersaturated Ilimaussaq intrusion. Five groups of amphiboles are present; 1 - ferroedenite-hastingsite; 2 - sub-aluminous-ferroedenite; 3 - aluminous ferrorichterite - ferrorichterite; 4 - arfvedsonite; 5 - ferroactinolite. Amphibole compositional trends parallel those of the pyroxene in showing decreasing Al and Ca with increasing Na and extreme iron enrichment. Oxide minerals in the earliest stages of crystallization were Fe-Ti oxides and baddeleyite, these were replaced as liquidus phase by aenigmatite and zircon respectively as the magma evolved. Residual liquids as represented by the pegmatites crystallized ferrorichterite, feldspar, zircon and quartz. The ferroaugite syenite magma evolved along an oversaturated peralkaline trend characterized by extreme iron enrichment under conditions of low oxygen fugacity at high silica activity.

STRATIGRAPHIC AND TECTONIC HISTORY OF LOWER AND MIDDLE PRECAMBRIAN ROCKS IN EAST-CENTRAL MINNESOTA

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It has been recognized for nearly 70 years that a great diversity of Precambrian rock types crop out in east-central Minnesota. However the rocks are poorly exposed and an understanding of their geologic history has been hampered by a lack of definitive geologic data from which age and spatial relationships can be deduced. Nonetheless, recent geologic studies utilizing conventional mapping techniques in conjunction with subsurface, magnetic, and recently acquired gravity data have more precisely defined the spatial relationships of various rock units and have led to a more complete understanding of their stratigraphic and tectonic histories.

The Lower and Middle Precambrian rocks in east-central Minnesota are divisible into three distinct terranes: (1) a diverse Lower Precambrian terrane; (2) overlain on the north by a thick sequence of folded and metamorphosed Middle Precambrian stratified rocks; and (3) intruded on the south by a variety of Middle Precambrian plutonic rocks. All of these rocks are overlain by generally flat-lying sedimentary rocks of Late Precambrian, Cambrian and Cretaceous age.

Two presumably high-angle, east-trending faults of Early Precambrian age divide the Lower Precambrian terrane into three lithotectonic segments. The southernmost segment consists dominantly of quartzofeldspathic gneisses metamorphosed to the upper amphibolite or granulite grade. Granite and lesser amounts of metasedimentary and metavolcanic rocks assignable to the greenstone-granite belts of northern Minnesota comprise the northernmost segment. Substantive data bearing on the lithic attributes in the middle segment are lacking. The segment may consist of either cataclasized gneissic rocks or metagraywacke and slate similar to that in northernmost segment. However, regardless of their original age and character, the rocks in the middle segment form a discrete zone separating two considerably different Lower Precambrian lithotectonic units.

The Middle Precambrian stratified rocks occur within an intracratonic basin centered over and approximately parallel to the boundary zone between the Lower Precambrian gneissic and greenstone-granite segments. The stratified rocks are divisible into two groups separated by an unconformity. The older group consists dominantly of quartzose rocks of clastic and perhaps volcanogenic origin. Mappable units of metabasalt, mafic tuff, oxide- to carbonate-facies iron-formation and carbonaceous mudstone are abundant near the base, whereas carbonate rocks occur as mappable beds near the top of the group. The younger group is similar to, and correlative with, the well-known Animikie Group of northern Minnesota and Ontario.

Sedimentation was either terminated or closely followed by a period of regional deformation and metamorphism assignable to the Penokean orogeny. The dominant Penokean structure is an eastward-plunging synclinorium bounded on the north, west, and south by Lower Precambrian rocks. However the extent to which the rocks were deformed varies from place to place within the synclinorium and the style of deformation is attributable to the tectonic behavior of contrasting kinds of Lower Precambrian rocks. Where they overlie granitic basement rocks, the stratified rocks dip gently southward and the basal contact is relatively undisturbed. In contrast, where they overlie gneissic or metasedimentary basement rocks, the stratified rocks are complexly infolded into a number of large anticlines and synclines having numerous coaxial, second- and third-order folds on their limbs.

The metamorphic grade of the stratified rocks increases from north to south. To the north, argillaceous rocks contain minerals indicative of high-grade diagenesis or zeolite-facies metamorphism, whereas to the south they contain minerals indicative of the lower amphibolite facies. Metamorphic mineral isograds conform in a general way to the fold geometry, but in detail they transect fold axes implying that deformation and metamorphism were discrete events.

Tectonic instability during the Penokean orogeny was manifested principally by vertical uplift of the gneissic basement rocks and the development of a mantled gneiss dome along the south edge of the Penokean synclinorium. The virtual coincidence of bedding in the stratified rocks that surround the gneiss dome with cataclastic foliations within the gneiss dome suggests that folding and uplift occurred contemporaneously. In addition, the spatial coincidence of high-grade metamorphic rocks along the flanks of the gneiss dome suggests that the gneissic terrane was characterized by relatively high heat flow during deformation.

The Middle Precambrian plutonic rocks are confined to that part of east-central Minnesota underlain by gneissic rocks. Most of the plutonic rocks are post-tectonic in age as evidenced by cross-cutting relationships with the mantled gneiss dome, and by their relatively homogeneous and undeformed nature. Igneous activity of calc-alkaline affinity began with the emplacement of dike-like bodies of quartz diorite. This was followed by the emplacement of small to large plutons of granodiorite and quartz monzonite, which in turn was followed by the emplacement of various sized plutons of granite. Quartz monzonitic rocks having rapakivi-like textures occur locally as border phases to some of the granite plutons.

Erosion, following uplift along major northwest-trending faults, exposed the gneissic and plutonic rocks prior to the deposition of Upper Precambrian sedimentary rocks.

PETROGRAPHIC AND CHEMICAL ATTRIBUTES OF SOME LOWER AND MIDDLE PRECAMBRIAN GRAYWACKE-SHALE SEQUENCES IN NORTHERN MINNESOTA

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Graywacke-shale sequences comprise a significant proportion of the Lower and Middle Precambrian rock record in northern Minnesota. Although the petrographic character of these rocks has been evaluated in detail, little use has been made of their bulk chemical compositions, particularly in classification and provenance studies. We suggest however that the chemical data, when used with petrographic data, provide useful new insights regarding the sedimentological history of these rocks.

According to the classification scheme of Crook (1974), which considers only the framework grains, the Lower Precambrian graywackes are quartz-poor to quartz-intermediate in composition and are indicative of a tectonically active island-arc environment. They contain 25-50 percent dacitic to rhyodacitic rock fragments, 10-36 percent sodic plagioclase, trace amounts to 12 percent volcanic quartz, and as much as 22 percent labile components such as hornblende. In contrast, the Middle Precambrian graywackes are quartz-intermediate to quartz-rich in composition and are indicative of deposition under tectonically stable conditions. They contain 15-90 percent plutonic quartz, 1-36 percent feldspar, and as much as 7 percent rock fragments of mostly granitic composition.

The bulk chemistry of the two sequences emphasizes the fact that they are different chemical entities. The Middle Precambrian graywackes contain more silica ($\bar{X}$ = 75% vs. 62%) and less K_2O ($\bar{X}$ = 1.43% vs. 1.90%) and Na_2O ($\bar{X}$ = 2.42% vs. 4.06) than do the Lower Precambrian graywackes. The former also exhibit a narrower range of Na_2O/K_2O values (1:2 to 2:1) than do the latter (1:1 to 13:1). These differences can be related to the mineralogy of the framework grains. Quartz is the dominant mineralogic variable in the Middle Precambrian graywackes, and its abundance exerts a major influence on the amount of SiO_2 in the analyzed samples. In contrast, dacitic to rhyodacitic rock fragments dominate the framework grains of the Lower Precambrian graywackes and exert a strong influence on the Na_2O/K_2O ratios.

Very little is known about the petrography of intercalated shale units in either sequence. However the bulk chemical data suggest that the Lower Precambrian shales are fine-grained equivalents of the graywackes, whereas the Middle Precambrian shales are discrete chemical entities not related to graywackes simply by the relative abundances of framework grains.

The bulk chemistry of the Lower Precambrian graywackes suggests that they were derived from a dacitic to rhyodacitic source with little attendant chemical alteration. Thus these rocks were not markedly affected by post-depositional processes; the framework grains reflect the composition of the source area. However, neither the Middle Precambrian graywackes nor their intercalated shales can be derived chemically from a simple granitic source; chemical-mixing calculations indicate a complex source of consisting of quartz monzonitic, rhyodacitic, and basaltic rocks. The mixing calculations also imply that the Middle Precambrian sediments were derived from a considerably weathered terrane and subjected to post-depositional processes which considerably modified the original framework mineralogy.

GEOCHEMISTRY OF THE YELLOW DOG PLAINS PERIDOTITE,
MARQUETTE COUNTY, MICHIGAN

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A relatively fresh, previously undescribed, peridotite body outcrops in an area locally known as the Yellow Dog Plains, adjacent to county road AAA in the Champion quadrangle, Marquette County, Michigan. A small exposure south of the road and a roughly oval shaped "plug", 120 meters wide by 190 meters long, intrude the Precambrian X Michigamme Slate which underlies most of the Yellow Dog Plains. The larger outcrop stands 15 meters above the plain at its highest point. Recent paleomagnetic data indicate the intrusive is of lower Keweenawan (Precambrian Y) age (K. Books, U.S.G.S., personal communication, 1977). The fact that the Yellow Dog Plains peridotite is located in an extensive east-west trending magnetic belt suggests it may be genetically related to the exposed east-west trending Keweenawan diabase dikes to the south which have been sampled and analyzed for comparisons.

The peridotite contains up to 50 percent olivine, as much as 30 percent pyroxene (both clino- and orthopyroxene), approximately 10 percent plagioclase, and less than 10 percent opaque minerals. A dark red pleochroic biotite (<1 percent) is common in most specimens. Preliminary microprobe analysis of unserpentinized olivine and plagioclase give Fo_{80} and An_{58-65} , respectively. The sulfide minerals pyrite, pyrrhotite, chalcopyrite, cubanite (?), pentlandite, and bornite are present in small amounts mostly associated with magnetite.

Major oxides, Cu, Ni, Cr, Zn, Co, and several rare earth elements were analyzed from 22 specimens. The average values for the oxides are as follows: $SiO_2 = 42.46\%$, $Al_2O_3 = 4.24\%$, $Fe_2O_3 = 5.65\%$, $FeO = 8.71\%$, $MgO = 26.19\%$, $CaO = 4.40\%$, $Na_2O = 0.49\%$, $K_2O = 0.24\%$, $H_2O = 6.72\%$, $TiO_2 = 0.71\%$, $P_2O_5 = 0.10\%$, $MnO = 0.18\%$. Samples from a 30 meter vertical drill core in the large exposure show a continuous increase in Ni with depth. MgO, FeO, and Cr have the same trend as Ni. A break in the alkali values, which otherwise consistently decrease with depth, suggests the intrusion may be layered. Layering has not been confirmed by modal data.

Post-Glacial Sediment Distribution in the Canadian Portion of Lake Superior

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The Canadian portion of Lake Superior covers an area of approximately 29,882 km² of a total lake area of 82,375 km². The drainage area of the Canadian portion of the lake, excluding the lake and the Lake Nipigon drainage basin, is approximately 72,000 km². The drainage basin which was covered by a virgin forest up until a century ago, is still mainly covered by boreal forest. Based on radiocarbon dating of the lake-sediments, glacial retreat from the northern part of Lake Superior occurred about 11,600 yrs. B.P. Since the time of glacial retreat, approximately $12,545 \times 10^6$ m³ of sediment have been deposited in the lake proper and adjacent bay areas. The post-glacial sediments tend to have been deposited in topographic basins with the thickest sequences occurring in Thunder Bay, Nipigon Bay and Black Bay where up to 12 m, 12 m and 14 m respectively have been deposited in topographic basins. In the lake proper, the maximum thickness of post-glacial sediments is only in the order of 5 m. The average rate of sediment reaching the lake since glacial retreat has been about 1.08×10^6 m³/yr. The sediments consist of quartzarenite to arkosic sands which occur adjacent to the shore and the islands and a silty clay sequence that occurs in the topographic basins. The bulk of the sediments (>99% percent) are formed of silty clay which is comprised of major amounts of quartz, K-feldspar and plagioclase, subordinate amounts of chlorite, illite and kaolin and minor amounts of amphibole and an interbedding of vermiculite and smectite. The average sediment yield from the drainage basin was about 15 m³/km²/yr. or a total of 174,000 m³/km² since glacial retreat.

MASSIVE SULFIDE DEPOSITS IN WISCONSIN

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ABSTRACT

Since 1968 with the discovery near Ladysmith in Rusk County of a massive sulfide ore body, over three dozen mining companies have at one time or another explored for non-ferrous massive sulfide deposits in the Precambrian of northern Wisconsin. The most significant find to date is by the Exxon Company, U. S. A., of a 60-million ton deposit of zinc and copper south of Crandon in Forest County. Exploration activity has precipitated numerous studies by the state, including geological, geophysical and hydrological surveys, review of legislation, and social and economic impact analysis.

Exploration has been concentrated in a 100-km wide band from Ladysmith in the west, through the Rhinelander-Crandon area to the Pembine area in the east, a distance of 350 kilometers. Available outcrop data, gravity compilations, and state-acquired aeromagnetic data, coupled with isotopic studies by the U. S. Geological Survey and the University of Kansas, suggest that this terrane is a middle Precambrian volcanic belt surrounded by early Precambrian gneisses.

Detailed geology is known only for the Ladysmith deposit. This deposit, owned by the Kennecott Copper Corporation, is essentially a vertically-oriented, lens-shaped pod 15 m wide, 720 m long, and 240 m deep. Country rock consists of intermediate to felsic volcanic rocks of andalusite metamorphic grade. Economic minerals found within a pyritized quartz-sericite schist are a supergene enriched blanket of chalcocite and bornite of pre-Late Cambrian age, overlying primary chalcopyrite. The 6-million ton body averages three and one-half to four percent copper. Favorable terrane was identified by an INPUT survey in 1967, and follow-up drilling in 1969-1970.

In 1974, Noranda Exploration, Inc. announced the discovery of a small zinc-copper body on the Pelican River east of Rhinelander in Oneida County. The deposit consists of three zones. The total deposit consists of 2.3 million tons at an average grade of one percent copper and four and one-half percent zinc. The deposit is 300 m long, 15 m wide and 200 m deep. It was identified by combined geologic and INPUT surveys. The generally small size and uncertain mine development climate, preclude the immediate development of the property. Noranda is continuing exploration activities in the area.

In May 1976, the Exxon Company, U. S. A., announced the discovery of a zinc-copper body south of Crandon. The body appears to be slightly less than 2 km long, at least 480 m deep, and about 60 m wide. Preliminary drilling suggests 60-million tons of ore averaging six and one-half percent zinc and one percent copper, making this one of the five largest massive

sulfide ore bodies in North America.

Wisconsin environmental laws are administered by the state Department of Natural Resources. Present regulations require an environmental impact assessment of all proposed mining operations. Experience has shown that for significant new mines this assessment will invariably result in preparation of an Environmental Impact Statement by the Department. New mines are also required to obtain a mining permit which includes a reclamation plan approved by the Department. Mine operators are required to post a bond to cover the cost of reclamation. Mining companies must also obtain other permits required by the Department for the protection of the environment.

Several pieces of legislation that were introduced in the spring 1977 legislative session would: (1) replace present mineral taxes with a graduated severance tax on net proceeds; (2) require the registration of exploration companies in Wisconsin with the additional requirement that some kinds of company-acquired geologic data be turned over to the state after exploration; (3) require the registration of severed mineral rights and ultimate acquisition of orphan mineral rights; (4) set limits on the duration of mineral exploration leases; (5) set a cooling-off period during which an exploration lease could be broken; and (6) eliminate the mineral depletion allowance.

It is reasonable to expect that more deposits of massive sulfide ore will be identified in future years in Wisconsin. Whether or not the deposits are developed depends on costs, metal prices, environmental constraints at each individual prospect, the tax climate, and the mineral policy of the state.

PROTEROZOIC PITCHBLENDE VEIN POTENTIAL IN MINNESOTA: THEORY AND SPECULATION

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ABSTRACT

Several major Proterozoic unconformities are present within the rock column of Minnesota. (1) The MP6 Animikian formations (the Pokegama Quartzite and older units) rest upon LP6 granitic and volcanic rocks. (2) The UP6 Sioux Quartzite overlies LP6 rocks in southwestern Minnesota and adjacent South Dakota and Iowa. (3) The UP6 Puckwunge Formation overlies the MP6 Rove Formation in northeastern Minnesota, and in adjacent Ontario the correlative Sibley Formation overlies the Rove and older units. (4) The UP6 "Nopeming Quartzite" overlies the MP6 Thomson Formation near Duluth. (5) The UP6 Fond du Lac Formation rests upon the MP6 Thomson Formation in east-central Minnesota. In addition, Upper Cambrian rocks of southeastern Minnesota unconformably overlie LP6, MP6, and UP6 units and Cretaceous deposits overlie LP6, MP6 and UP6 rock units over the western half of the state.

Two localities which have abnormal total radioactivity may be related to nearby unconformities. One is in the LP6 McGrath Gneiss, nearly adjacent to moderately dipping unnamed MP6 rock units. The second is in a probable shear zone in the MP6 Thomson Formation, a few miles from the UP6 Fond du Lac Formation.

At Beaverlodge, Northern Saskatchewan, the MP6 Martin Formation overlies crystalline basement rocks; pitchblende veins in the area may be related to this unconformity (e.g., Langford, 1977). Further south, the UP6 Athabasca Sandstone unconformably overlies a similar basement and uranium mineralization appears to be related to the unconformity. Discoveries in northern Australia are of a similar nature.

No promising uranium shows have as yet been discovered in Minnesota. However, the stratigraphic-structural relationships, coupled with the supergene pitchblende vein model, calls for detailed exploration along the cited unconformities.

Reference

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PALEOMAGNETIC AND PALEOINTENSITY STUDIES OF NORMAL AND REVERSED KEWEENAWAN ROCKS -
IMPLICATIONS FOR THE POLAR WANDER PATH OF NORTH AMERICA

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A B S T R A C T

Paleomagnetic studies on Keweenawan rocks (1200 - 1000 my) have revealed a well-defined magnetic stratigraphy composed of units with both normal and reversed polarity. There are at least two polarity changes in the Keweenawan sequence of which the younger one (from reversed to normal polarity) has been detected throughout the Lake Superior region. A characteristic feature of this reversal is its asymmetry: the reversed magnetization always has a much steeper (upward) inclination than the normal (downward) one, resulting in a difference of 30° in their paleopoles. Of particular concern in the interpretation of Keweenawan paleomagnetism is whether this asymmetry in reversal is caused by a secondary remagnetization component or whether it is the signature of apparent polar wander during Keweenawan igneous activity.

Detailed thermal and alternating field demagnetization studies on both igneous and baked Keweenawan rocks do not, however, reveal any systematic secondary component but rather the difference in inclination between reversed and normal rocks remains throughout the blocking temperature and coercivity spectra. A possibility still exists that these demagnetization techniques are unable to detect the secondary component. If a 'non-removable' secondary component indeed is present in all Keweenawan rock units, it would result in a lower Thellier-type paleointensity determination for the reversed rocks compared to that predicted for the normal ones. On the other hand, if the apparent polar wander interpretation is correct, and the Earth's magnetic field was dipolar during the Keweenawan, an enhanced paleo-field value would be obtained for the reversed rocks because they have a significantly higher paleolatitude than do the normal ones. In order to test the credibility of the above models, we have conducted about 100 Thellier-Thellier paleointensity measurements on Keweenawan intrusives of both polarities, and adjacent baked contact rocks from the Sibley and Rove formations. These results suggest a higher paleo-field for the reversed epoch compared to that for the normal one. Moreover if the paleofield data are reduced to the paleoequator, this difference in paleointensity between reversed and normal rocks disappears. Both paleomagnetic and paleointensity data therefore cast doubt on the hypothesis that a secondary component has caused the Keweenawan asymmetric reversal. The results, however, are consistent with apparent polar wander during Keweenawan time.

PETROLOGY AND TREND SURFACE ANALYSIS OF TWO LATE-STAGE GRANODIORITIC PLUTONS,
NORTHERN LAKE OF THE WOODS REGION, ONTARIO

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Trend Surface analysis of modal data for two small plutons in the Kenora block of the Superior Province show similar concentric patterns of mineral abundance. Alkali feldspar is concentrated at the margins of the plutons and oligoclase in the cores.

The Indian Reserve pluton outcrops about one km northeast of Kejick at the north end of Shoal Lake at latitude $49^{\circ}38'N$ and longitude $95^{\circ}04'W$. The area of exposure is about 6 km^2 and has an elliptical shape about 4.0 km by 1.6 km with the major axis trending E-W. Field study at 60 locations and point-count analysis of 30 thin sections shows that the rock is typically a pink, medium-grained, hypidiomorphic granular granodiorite with minor oligoclase phenocrysts and scattered, small, greenstone xenoliths. The average composition is 50% oligoclase, 26% quartz, 13% slightly perthitic microcline, 4% biotite, 3% sericite, 2% epidote and minor opaque minerals, sphene and apatite. The oligoclase typically contains two or three, thin, euhedral to subhedral, internal alteration zones marked by a concentration of fine-grained sericite and epidote.

The Dogtooth pluton outcrops about 16 km east of Kenora at latitude $49^{\circ}14'N$ and longitude $94^{\circ}13'W$. The area studied is 4 km^2 and is irregular in shape with its long axis oriented NE-SW. It appears to be a texturally distinct lobe of a larger granodioritic pluton to the east. Field study at 115 locations and point-count analysis of 86 thin sections indicates that the rock is typically a pink, medium-grained, hypidiomorphic granular granodiorite characterized by polycrystalline quartz aggregates, protoclastically deformed oligoclase, and very low total mafic mineral content. The average composition is 47% oligoclase, 26% quartz, 20% slightly perthitic microcline, 1% biotite and 4% epidote, sericite, chlorite, opaque minerals and accessories.

In these rocks oligoclase typically varies from 40% to 60% and microcline from 5% to 25%. Trend surface analysis of mineral distributions shows similar NE-SW trends for first and second-order surfaces for oligoclase and alkali feldspar with oligoclase increasing to the SE and inward and alkali feldspar increasing to the NW and outward. Higher degree surfaces show increasingly complex, concentric patterns. Quartz surfaces show more irregular patterns with higher order surfaces showing marginal, alternating highs and lows. Biotite surfaces for the Indian Reserve pluton follow the pattern of alkali feldspar surfaces.

We interpret the striking concentric patterns of the feldspar distributions to be related to the cooling and crystallization histories of the plutons. The linear trends for lower order surfaces and the axes of elongation of the concentric patterns reflect regional structural trends. The southeastward increase of oligoclase and the northwestward increase of alkali feldspar shown on lower order surfaces may reflect a fundamental asymmetry of the plutons or their regional tectonic framework relative to the present erosional surface. Both plutons may be on the southern limb of major synclinal features.

EVIDENCE FOR ARCHEAN TURBIDITE AND SUBMARINE FAN SEDIMENTATION
FROM THE SAVANT LAKE GREENSTONE TERRAIN, N.W. ONTARIO

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Results from an investigation of vertically dipping Archean metasediments in the Savant area have outlined the presence of four basic sedimentary facies:

1. Graded-stratified conglomerates of submarine fan association.
2. Graded greywacke-siltstone beds of turbidite association.
3. Stratified-laminated mudstones of pelitic association.
4. Laminated oxide iron formation of chemical association.

The graded-stratified conglomerates are commonly associated with graded greywacke-siltstone beds and form a coarse-grained 1.-2. facies group. The oxide iron formation and mudstones are also associated with greywacke-siltstone sequences and form a finer-grained 2.-3.-4. facies group. The sequence of deposition of metasediments in the north arm of Savant Lake is that of coarse-grained 1.-2. facies group overlain by the finer grained 2.-3.-4. facies group, thereby forming a mega-fining upward cycle.

Facies Group 1.-2.

Detailed field mapping of this conglomerate-rich group reveals major fining-upward cycles within the group. Such features may be indicative of fan-channel abandonment. A predominance of well-rounded clasts within the conglomerate suggest efficient abrasion of clasts in a shallow-water, high-energy environment, prior to final deposition, via turbid flow, in a deep-water environment. The 1.-2. facies group is therefore considered to represent a portion of a submarine fan system composed of residimented conglomerates and interlayered turbidites.

Facies Group 2.-3.-4.

Detailed mapping indicates that the overlying greywacke-siltstone and mudstone facies contain several sedimentary structures and textures of the deep-water turbidite association. The presence of interlayered iron-rich mudstones and chemical iron formation indicate extremely quiet periods between turbidite deposition. This facies group is therefore considered to represent clastic and chemical accumulation in a portion of a restricted, deep-water turbidite basin.

The interpretation that the clastic metasediments are coexisting proximal coarse-grained submarine fan facies and distal finer-grained turbidite basin facies requires a deep-water environment for the accumulation of oxide iron formation as well. This interpretation sheds doubt upon the common belief that Archean oxide facies iron formations are products of shallow water deposition.

GEOPHYSICAL STUDIES OF PERIDOTITE DIKES,
YELLOW DOG PLAINS, NORTHERN MICHIGAN

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ABSTRACT

Very low frequency electromagnetic, gravity, and ground magnetic studies indicate that peridotite exposed in two outcrops within the Pleistocene outwash of the Yellow Dog Plains is part of a dike swarm that extends in a west-northwest direction for about 20 km beneath the Pleistocene drift cover. Rocks at the two outcrops contain small quantities of copper- and nickel-bearing sulfide minerals and have slightly anomalous copper content. Paleomagnetic studies by Kenneth Books of the U.S. Geological Survey show that the peridotite has a remnant pole position typical of lower Keweenawan rocks from throughout the region.

Analyses of the three types of geophysical data in sec. 11 and 12, T. 50 N., R. 29 W., where the peridotite crops out, indicate that several dikes are present. The dikes are intruded into middle Precambrian (X) metasedimentary rocks within a structural trough in lower Precambrian (W) rocks. Gravity data suggest that a steep, west-trending fault with the downdropped side to the south lies beneath the southernmost dike in secs. 11 and 12. The fault offsets the contact between lower and middle Precambrian rocks and may have been a channelway for intrusion of the dikes. Northwest-trending faults offset both the dikes and the west-trending fault.

Filtered VLF-EM data combined with ground magnetic data suggest the presence of two different types of dikes. Negative VLF-EM anomalies and associated large-magnitude positive magnetic anomalies occur at the peridotite outcrops. In addition, positive VLF-EM anomalies cannot be attributed to near-surface conductors or fault zones, and therefore suggest the presence of subsurface conductors. Gravity studies indicate the presence of dikes in the NW $\frac{1}{4}$ sec. 12 and NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 11, T. 50 N., R. 29 W. but no magnetic anomalies were found. Two positive VLF-EM anomalies were also found there. We believe that these are attractive exploration targets for sulfide mineralization and warrant further study.

THE PETROLOGY AND SEDIMENTATION OF THE UPPER PRECAMBRIAN
SIOUX QUARTZITE OF MINNESOTA, SOUTH DAKOTA, AND IOWA

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ABSTRACT

The Upper Precambrian Sioux Quartzite is exposed at several locations along an east-west trend 175 miles long and 30 miles wide between Mitchell, South Dakota and New Ulm, Minnesota. It rests unconformably on Lower Precambrian rocks and is overlain by Cretaceous sediments and Pleistocene drift. The formation consists of over 1600 meters of orthoquartzite sandstone with minor interbedded conglomerates and mudstones. The conglomerates are present in the lower two-thirds of the section and minor thin mudstones occur in the upper third. The pebbles of the conglomerates consist of vein quartz, hematitic chert, iron formation and quartzite. A coarse basal conglomerate is exposed at New Ulm, Minnesota where it crops out 110 meters from the underlying granite.

The mature orthoquartzite is composed almost exclusively of well rounded, moderately sorted, monocrystalline quartz. Detrital chert and jasper are common in some samples. Grains are coated with a thin film of iron oxide and cemented by quartz overgrowths that are locally partially replaced by secondary diasporite and sericite. Rounded zircon and tourmaline are the only common nonopaque detrital heavy minerals.

Measurements of 856 cross-beds and 491 ripple marks show paleocurrent directions to the south and southeast; no major vertical or lateral changes in trends were observed. Paleocurrent patterns are unimodal throughout most of the unit but some bimodal patterns occur in the upper part of the section. The crossbedding consists predominantly of narrow troughs 60 to 140 cm wide and 15 to 30 cm thick. Asymmetric current ripple marks are common, but both small- and large-scale symmetrical ripple marks are also present.

The abundance of crossbedding and current ripple marks indicates vigorous current action. Mudcracks and mudchip conglomerates suggest periodic exposure and fluctuating current strength. These structures may suggest in part a fluvial origin but herring-bone cross-beds and reactivation surfaces, structures commonly associated with tidal deposits, are present in a few areas in the upper third of the section.

The Sioux Quartzite is gently folded. It is intruded by diabase at Corson, South Dakota. A rhyolite interbedded with the quartzite in a well at Hull, Iowa has been dated at 1470 ± 50 m.y. (Lidiak, 1971).

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SHAPE, SIZE, AND COOLING HISTORY OF TROCTOLITIC-GABBROIC ROCKS IN THE DULUTH COMPLEX

by P.W. Weiblen and R.W. Cooper

Data on mineral proportions and chemistry have been obtained on randomly oriented thin sections of troctolitic-gabbroic rocks along a 10 km traverse normal to the contact in the central part of the Duluth Complex in N.E. Minnesota. The data provide new insights into the shape, size, and cooling history of individual intrusions.

The spread in data at any locality on olivine (fig. 1), plagioclase, and to a lesser extent clinopyroxene may be correlated with degree of layering in the rocks. The data suggest a regular increase in mineral layering away from the contact.

Data on biotite (fig. 2) sulfides, iron oxides and orthopyroxene show an exponential decrease away from the contact. These data suggest a diffusion controlled equilibration of basaltic magma with pelitic country rocks and introduction of K, H₂O, and S into the magma.

The above data combined with geological and geophysical data on textural relations, faulting, and aeromagnetic anomalies suggest the shape and size of individual troctolitic-gabbroic intrusions as shown in fig. 3. These intrusions are distinctly asymmetric and show a continuous variation between flow (region A fig. 2) and gravity (region B, fig. 2) layered rocks.

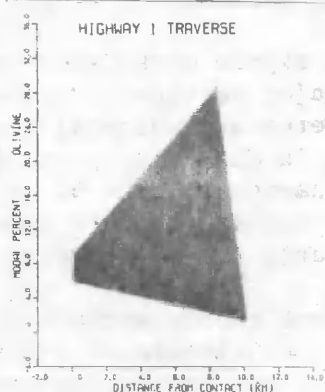


Fig. 1. Olivine vs distance.

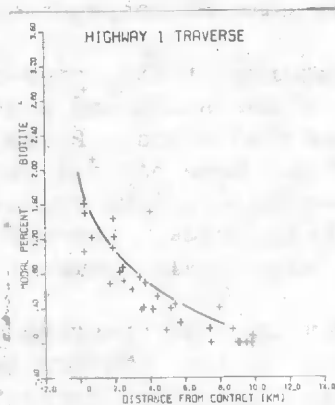
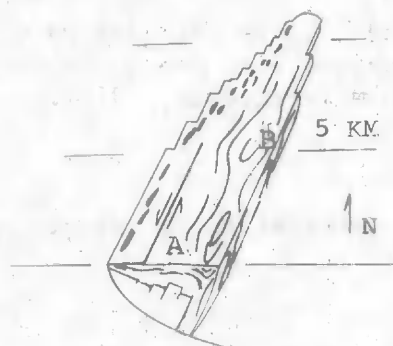


Fig. 2. Biotite vs distance.



Black areas - Inclusions
Curved lines - Flow pattern
Fault shown is normal to the probable transform fault direction in the Midcontinent Rift.

Fig. 3. Three dimensional view of proposed magma chamber for troctolitic-gabbroic intrusions in the Duluth Complex.

Surficial Sediment Analyses Offshore of the Copper-Bearing Province of Keweenaw Point, Upper Michigan

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Surficial bottom samples collected in 1974 and 1975 around Keweenaw Point were analyzed for selected trace elements and textural parameters as indicators of depositional processes following the methods of Moore and Welkie (1976). The distribution of the concentrations of Cu, Zn, Ni, Co, Mn and Fe were compared for Five Mile Point (north of the peninsula) and Bete Grise bay (south). The test of log-normality was applied (Ahrens, 1954) and the number of statistical geochemical populations for each element determined. For Cu, three statistical populations were found in both sites. Regression curves were drawn for all possible pairs of trace elements and a least-squares fit determined. The slopes of the regression lines support the contention of Smith and Moore (1972) that the sediments north of the Keweenaw represent a separate grouping of populations from those to the south.

The contours of copper distribution off Five Mile Point generally parallel the shore, with three areas of high concentration (295 to 175 ppm) which are uncorrelated to bathymetry. In Bete Grise, six samples containing anomalous values were found (145 to 175 ppm) and these clustered in two areas, both occurring in an elongate bathymetric low corresponding to a postulated ancient channel of the Montreal River which drains copper-bearing rocks (Goodden, 1974). Thus, the samples are anomalous according to the criteria established by Bolviken (1971), i.e., values exceeding two standard deviations from the arithmetic mean over all samples.

After correlation of copper content with all other variables, multiple linear-regression analysis showed 91% of the variation in Cu at Five Mile Point could be explained by the variables Zn, Ni, Fe, Mn, by percent 3.5 ϕ , percent 4.0 ϕ and percent 4.5 ϕ grain size, and by bathymetry. At Bete Grise, only 72% of the variation in the copper concentrations could be explained by these variables; either the relationships between these parameters are nonlinear, or other variables as yet undetermined enter into the linear model.

3.5 Kc seismic profiles and towed electrical resistivity profiling and sounding failed to correlate with the areal extent of the placer deposits as determined from physical sampling in Bete Grise, implying that the anomalous values do not continue to depth or that these geophysical techniques as applied had insufficient resolution.

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DELTAIC DEPOSITS IN THE UPPER PECORS, ESPANOLA AND GOWGANDA
FORMATIONS (HURONIAN)

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The cyclical repetition of mixtite, siltstone, sandstone is the hall-mark of much of the Huronian succession. Little attention has been given to the finer grained units (Pecors, Espanola and upper Gowganda Formations). This report deals mainly with the upper parts of these units in the southern part of the Huronian outcrop belt.

The upper parts of the Pecors and Gowganda Formations constitute complex coarsening upward sequences with many of the attributes of the classical prograding deltaic sequence. Both units are composed mainly of muddy and silty argillite. The prodelta deposits consist of laminated, in some cases graded siltstone-mudstone couplets, some of which may be varves. The delta slope is represented by finely interbedded mudstones and wavy, laminated and cross laminated siltstones. Slope instability is evidenced by the presence of abundant asymmetrical flame, and ball and pillow structures. Thin-to-thick massive units of siltstone-fine sandstone with rip-up clasts and erosive bases are considered to have been resedimented by downslope mass movement. Clastic dykes are present in the Pecors Formation. The delta slope deposits pass rapidly upwards into fluvial(?) sandstones of the Mississagi and Lorrain Formations which appear to have been derived predominantly from the northwest.

The upper Espanola Formation differs from the other two units in containing much more sandstone, and carbonate-rich units. In some areas the upper Espanola Formation contains abundant fining upward sequences (one to several metres thick) like those of both fluvial and tidal channel deposits. The latter interpretation is favoured because of the presence of bimodal-bipolar (NW-SE oriented) cross bedding distributions in some units. This interpretation is important because it implies a tide-dominated and therefore marine environment in the upper Espanola Formation. This unit passes upward into the fluvial (part eolian?) sandstones of the Serpent Formation.

The Pecors and upper Gowganda Formations are interpreted as prograding muddy delta deposits whereas the upper Espanola appears to have accumulated in a higher energy, tide-dominated delta platform. The reasons for this difference are not understood, but might have been caused by greater rates of subsidence or fluvial advance in the Pecors and Gowganda than in the case of the Espanola Formation.

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SEDIMENTARY FACIES ASSOCIATED WITH LATE WISCONSIN
GLACIAL LAKE DULUTH, WRENSHALL AREA, MINNESOTA.

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ABSTRACT

Study of late Wisconsin glacial deposits southwest of Duluth suggests a revised model for the late- and postglacial history of the area. Two major sedimentary environments are distinguished: (1) an ice-disintegration environment and (2) a glaciolacustrine environment associated with Glacial Lake Duluth.

Sediments produced by ice-disintegration are stratified, moderately- to poorly-sorted sand and gravel, with clasts predominately of Precambrian sandstone, volcanics, granite, and slate; and minor bodies of laminated silt and clay. Topographically, these sediments comprise a wide belt of kettles, kames, disintegration ridges, and outwash plains that are dissected locally by meltwater channels and tunnel valleys, some of which contain eskers.

The lacustrine environment contains the following facies: (1) thick, flat-bedded sands, (2) cross-bedded sands, (3) parallel laminated silt and clay, (4) massive clay, and (5) massive and stratified drop stone deposits. In the nearshore environment are found moderately-sorted and well-rounded sand grains (0.25 mm) with boulders at the shoreline. At 305 to 314 meters in elevation, the sand grades rather abruptly to massive clay. The sand facies overlies the silts and clays indicating progradation into Glacial Lake Duluth by nearshore currents.

The highest strandline features occur at elevations near 335 meters. They are expressed primarily as beach scarps and other well-developed shoreline features, such as several spits and a delta. A prominent linear, northeast trending scarp between 305 and 314 meters previously considered to be a strandline, is here interpreted to be the depositional front of a coarse-grained shelf deposited into Glacial Lake Duluth as it stood near its highest stage (335 meters). This indicates what was previously considered to be two stages: Glacial Lake Nemadji and Glacial Lake Duluth is actually a single stage of Glacial Lake Duluth.

The following late- and early postglacial history is indicated: (1) Ice from the last advance of the Superior Lobe stagnated along the margin of the Lake Superior Basin, resulting in the development of an ice-disintegration complex and stratified glacial deposits. (2) Meltwater from the disintegrating ice, the retreating Superior Lobe in the basin, and from more distant upland sources, along with runoff from the hydrologic cycle, were ponded in front of the retreating ice to form Glacial Lake Duluth. (3) A lake level rise to 335 meters is represented by a transgressive sequence of sediments. (4) The lake stabilized long enough to develop strong beach features. Sediment supplied to the lake at this stage appears to have been mainly derived from the ice-disintegration complex with minor contributions from ice rafting. (5) Progradation of the shallow water facies over the deep water facies was the result of sediment laden streams, meltwater, and other runoff entering the lake. (6) The lack of a regressive facies indicates a rapid drop in the lake level as a lower outlet was uncovered by the retreating ice front.

field trips

Copies of the guidebooks may be obtained from:

Department of Geology
Lakehead University
Thunder Bay, Ontario
P7B 5E1

Price \$5.00 Canadian. Make checks payable to Lake Superior Institute.

FIELD TRIP A

COLDWELL COMPLEX

LEADERS: R.H. Mitchell and R.G. Platt

DATE: May 2 - 4, 1977.

The Coldwell Complex is a large Proterozoic alkaline igneous complex containing saturated, oversaturated, and under-saturated syenites. Visits will be made to exposures of all the major rock types found within the complex and to areas which illustrate the relationships between the magma types and the mechanisms of intrusion of the complex.

1. Depart Thunder Bay on Monday May 2 at 4:00 p.m.
Return Thunder Bay Wednesday May 4 by 5:00 p.m.

All day Tuesday May 3 and the morning of Wednesday May 4 will be spent examining the complex.

2. The cost is \$70.00 and includes:

- a) 2 nights accomodation (double) at Marathon.
- b) Transportation to and from Thunder Bay and during the excursion.
- c) Guidebook.

Cost does not include meals. Maximum costs for meals in Marathon are about \$12.00 per day.

3. Accomodation will be in motels in Marathon (with restaurants). Costs are based upon double occupancy of motel units. Persons requiring single occupancy must notify the organizers in advance and be prepared to pay \$10.00 extra.
4. Limited to a maximum of 45 persons.

FIELD TRIP B

PROTEROZOIC ROCKS OF THE THUNDER BAY AREA

LEADERS: K.G. Fenwick, C.R. Kustra, W.H. McIlwaine,
J.F. Scott.

DATE: May 3 and 4, 1977.

A two day field trip will cover the Proterozoic (Middle to Lake Precambrian) rocks of the Thunder Bay area. Day one will cover selected stratigraphic units of lower and upper members of the Gunflint Formation and the overlying Rove Formation. On the second day, outcrops of the Sibley Group will be examined. The stops are designed to illustrate the stratigraphic relationships of the three fold division of the Sibley Group into formations. Side trips to Ouimet Canyon and the Thunder Bay Amethyst Mine are also planned.

1. Field Trip B will leave the Airplane Motor Hotel, Thunder Bay, on Tuesday May 3rd and on Wednesday May 4th at 8:00 a.m. The bus will return each day by late afternoon.
2. The costs for participants is \$40.00 per person. This fee includes bus transportation, lunch each day, literature, and guide to field stops. It does not include lodging.
3. Limited to a maximum of 45 persons.

FIELD TRIP C

STURGEON LAKE

LEADERS: W. Gibb, P. Severin, A. Tamman, H. Poulsen,
J. Franklin.

DATE: May 6 - 8, 1977.

A one day field trip to the Sturgeon Lake area will include the examination of two open-pit mines (Mattabi and Sturgeon Lake Mines Ltd.) and outcrops representative of the volcanic stratigraphy of the lower portion of the pile. The Mattabi and Sturgeon Lake Mines are typical volcanogenic massive sulphide deposits. Tour stops within the mines will include an examination of both massive and stringer ore and various types of alteration associated with the footwall stringer sulphides. The regional stops will examine a variety of felsic and mafic pyroclastic, flow, and epiclastic rocks, and two subvolcanic intrusive bodies.

1. Participants will depart by bus from Thunder Bay at approximately 6:30 p.m. on Friday, May 6. A discussion period, will be held in Ignace that evening. As the tour will be rather lengthy, participants will stay in Ignace the evening of Saturday, May 7. Buses will reach Thunder Bay and Dryden on Sunday, May 8 in order to connect with mid-day planes.
2. A fee of \$75.00 will include transportation, accomodation, meals, and guidebook.
3. Limited to a maximum of 45 persons.