

Twelfth Annual Institute on Lake Superior Geology

May 6-7, 1966



In Conjunction with the Mineralogical Society of America
and the Society of Economic Geologists

Host: Michigan Technological University
Sault Ste. Marie, Michigan

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PROGRAM

12th Annual
INSTITUTE ON LAKE SUPERIOR GEOLOGY

in conjunction with

MINERALOGICAL SOCIETY OF AMERICA
and
SOCIETY OF ECONOMIC GEOLOGISTS

Michigan Technological University
Sault Ste. Marie Branch
Sault Ste. Marie, Michigan

Wednesday, May 4, 1966

Eastern Daylight
Saving Time*

8:00 a.m.

Pre-session Field Trip, Mineralogical Society of America. Meet at Manitouwadge Hotel, Manitouwadge, Ontario, for tour of zinc-copper mines. (See Guidebook)

Thursday, May 5

8:00 a.m.

Pre-session Field Trip, Mineralogical Society of America (continued). Assemble at Marathon, Ontario, and examine road cuts en route to Sault Ste. Marie, arriving early evening.

Thursday, May 5

Eastern Standard
Time

7:00 p.m.-9:00 p.m.

Registration, Science Building, Michigan Tech. University, Sault Ste. Marie Campus.

Friday, May 6

8:00 - 9:00 a.m.

Registration (continued).

* Ontario is on Eastern Daylight Saving Time.

Friday, May 6 (continued)

PLENARY SESSION I
Science Building

Co-chairman: A. K. Snelgrove and C. Ernest Kemp

E.S.T.

- 9:00 a.m. Welcome: Vice President Kenneth J. Shouldice,
Director of Sault Ste. Marie Branch,
Michigan Technological University
- 9:05 Regional Geology
of the Sault Ste. Marie Area.....C. Ernest Kemp
- 9:25 Metallogenic Study, Lake Superior-
Chibougamau Region.....S. M. Roscoe
- 9:50 Recent Investigations of Raised Shorelines,
East Shore of Lake Superior and the Sault Ste.
Marie Area.....
.....W. M. Tovell, C. F. M. Lewis, and R. E. Deane
- 10:15 Aeromagnetic Studies of Eastern Lake Superior. William
J. Hinze, Norbert W. O'Hara, and James W. Trow
- Pause for Relaxation
- 11:15 Aeromagnetic, Gravity, and Sub-Bottom Profiling
Studies in Western Lake Superior.....
.....Richard J. Wold and Ned A. Ostenso
- 11:40 New Bathymetric Map of Lake Superior and Some
Geological Implications.....
.....W. R. Farrand, J. H. Zumberge, and J. Parker
- 12:05 p.m. Copper Deposits of the Batchawana Area,
Ontario.....P. E. Giblin

Lunch Interval

SESSION IIA

INSTITUTE ON LAKE SUPERIOR GEOLOGY
Science Building

Co-chairmen: F. S. Turneure (University of Michigan) and
P. E. Giblin (Ontario Department of Mines)

E.S.T.

- 2:00 Some Aspects of Huronian Paleogeography and
Sedimentation in the Canadian Shield. Grant M. Young
- 2:30 The Geology and Geophysics of the Moose
River Belt, Northern Ontario.....A. S. MacLaren
- 3:00 New Field Studies of the Keweenaw
Lavias of Minnesota.....John C. Green

Pause for Relaxation

Friday, May 6 (Continued)

4:00 p.m. Precambrian Stratigraphy and Structure of the
Tower, Minnesota Quadrangle....Richard W. Ojakangas
4:25 Cutting Oriented Samples.....John Q. St. Clair
4:45 Sugar Loaf Conglomerate, Marquette County,
Michigan.....Kiril Spiroff

Annual Banquet

Windsor Hotel, Sault Ste. Marie, Ontario

Eastern Daylight
Saving Time

6:45 p.m. Social Hour
7:30 Dinner
Address: "Modern Trends in Precambrian Exploration"
Dr. Duncan R. Derry

SESSION IIB

INSTITUTE ON LAKE SUPERIOR GEOLOGY
Brady Hall

Co-chairmen: D. H. Hase (State University of Iowa) and
J. S. Stevenson (McGill University)

E.S.T.

2:00 Michigan's Building Stone Resources..Joseph P. Dobell
2:30 Occurrence of Base Metals South of Dead River,
Negaunee Quadrangle, Marquette County,
Michigan.....Willard P. Puffett
3:00 Geologic Structure East and South of the
Keweenaw Fault Based on Geophysical
Evidence.....L. O. Bacon

Pause for Relaxation

4:00 A Structural Analysis of the Michigamme
Slates.....W. O. Mackasey and A. M. Johnson
4:25 Zoning of the White Pine Copper Deposit,
Ontonagon County, Michigan.....
.....Alexander C. Brown and John W. Trammell

Annual Banquet

Windsor Hotel, Sault Ste. Marie, Ontario

Friday, May 6 (Continued)

Eastern Daylight
Saving Time

6:45 p.m. Social Hour
7:30 Dinner
Address: "Modern Trends in Precambrian Exploration"
Dr. Duncan R. Derry

Saturday, May 7, 1966

SESSION IIIA

INSTITUTE ON LAKE SUPERIOR GEOLOGY
and
SOCIETY OF ECONOMIC GEOLOGISTS
Science Building

Co-chairmen: E. N. Cameron (University of Wisconsin) and
R. J. Weege (Calumet and Hecla, Inc.)

E.S.T.

9:00 New Zealand Ilmenite Sands.....M. E. Volin
9:25 Irish Strata-bound Base Metal Deposits.....
.....A. K. Snelgrove
9:45 Notes on Lake Superior Type Iron Ores at
Barsua, Orissa, India.....G. G. Suffel
10:05 The "Rock Cut", Lower St. Marys River,
Michigan.....Harold J. Lawson
10:25 Engineering Geology on New Second Lock, St.
Marys Falls Canal.....Terrence J. Smith

Pause for Relaxation

11:10 The Probability of a Single Station Being a
Representative Sample in a Magnetic
Survey..L. O. Bacon, W. A. Longacre, and A. Stevens
11:30 Results of Detailed Geochemical Prospecting in
the West-Central Part of the Negaunee
Quadrangle, Michigan.....Kenneth Segerstrom

PLENARY SESSION II
Science Building

12 noon INSTITUTE ON LAKE SUPERIOR GEOLOGY: Business Meeting.
Briefing on Field Trips.
1:30 Post-session Field Trips start.
Institute: Algoma Steel Plant
Elliot Lake, Ontario, Uranium.(See Guide-
book).
Society of Economic Geologists: Sudbury, Ontario,
Nickel-copper.(See Guidebook)

Saturday, May 7. (continued)

SESSION IIIB

MINERALOGICAL SOCIETY OF AMERICA
Brady Hall

Co-chairmen: L. G. Berry (Queen's University) and
J. A. Mandarino (Royal Ontario Museum)

E.S.T.

- 9:00 p.m. Michipicoten Scheelite Deposit near Michipicoten
Harbour, Ontario.....Louis Moyd
- 9:25 A Barite-Quartz Phase in the Firesand River
Carbonatite, Wawa, Ontario.....
.....E. Wm. Heinrich and Richard W. Vian
- 9:45 Clay Minerals in Glacial Deposits, Houghton,
Baraga, and Ontonagon Counties, Michigan.....
.....A. P. Ruotsala, G. J. Koons, and S. C. Nordeng
- 10:05 The Mn-Bearing Minerals of Champion Mine,
Champion, Michigan.....Larry L. Babcock
- 10:25 Unique Intergrowth of Calcite and Pyrite.....
.....Paul W. Zimmer
- Pause for Relaxation
- 11:10 Short-Range Chemical Variations in a Managanoan
Axinite from the Mesabi Range, Minnesota.....
.....Bevan M. French
- 11:30 Textural Relations of Hematite and Magnetite
in Some Precambrian Metamorphosed Oxide
Iron Formations.....Tsu-Ming Han

PLENARY SESSION II
Science Building

- 12 noon INSTITUTE ON LAKE SUPERIOR GEOLOGY: Business Meeting.
Briefing on Field Trips.
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Elliot Lake, Ontario, Uranium. (See
Guidebook)
Society of Economic Geologists: Sudbury, Ontario,
Nickel-copper. (See Guidebook)

THE MANGANESE-BEARING MINERALS OF CHAMPION MINE,
CHAMPION, MICHIGAN

Larry L. Babcock
Michigan Technological University
Houghton

Champion Mine is a "hard" iron ore producer on the southern limb of the Marquette synclinorium. The mine vicinity underwent staurolite-grade regional metamorphism during the post-Animikie, pre-Keweenaw interval.

Manganese-bearing quartz shear veins, generally conformable with the schistosity of the host Negaunee iron formation, are found at depths greater than 2,000 feet below the No. 7 shaft collar. These veins cut non-schistose host rock containing major percentages of spessartine and spessartine-andradite, with the former garnet zoned on the latter. Associated minerals include tabular hematite, magnetite, anhydrite, talc, manganese carbonates, diopside, actinolite, and manganooan cummingtonite - tirodite. Tourmaline, molybdenite, pyrite, and chlorite are associated with some manganese carbonates. Randomly oriented actinolite, hematite, and talc folia, and other criteria indicate that the manganese minerals are late-stage metamorphic. The presence of zoned garnets suggests that the processes of contact metasomatism acted to remobilize primary manganese in an iron-rich environment. Spessartine-andradite (spandite) has been reported from the contact metasomatic manganese ores of India, i.e., "kodurites".

Other manganese minerals under study include jacobsite, rhodonite, rhodochrosite, manganosiderite, manganankerite, kutnahorite, and several associated unknowns. Jacobsite, MnFe_2O_4 , has previously been unreported from the Western hemisphere.

Champion represents the first known occurrence of an amphibolite-grade manganese-bearing iron formation in the Western hemisphere, with mineralogical similarities to deposits in Norway, Sweden, India, and Japan. Some of the above minerals have been reported from Franklin, New Jersey.

GEOLOGICAL STRUCTURE EAST AND SOUTH OF THE
KEWEENAW FAULT BASED ON GEOPHYSICAL EVIDENCE

L. O. Bacon
Michigan Technological University
Houghton

Gravity and magnetic data indicate that a Middle Range of basalt lavas lies beneath the Jacobsville sandstone and that this is the north limb of a shallow syncline, plunging to the west at a low angle. The South Range of basalt lava is the southern limb of this syncline.

The north side of the Middle Range lavas is interpreted as a fault contact downthrown to the north. Within the graben structure between the Keweenaw fault and the Middle Range fault there appears to be a third fault. These faults appear to be cut by three to four cross faults to account for local anomalies. Maximum thickness of the Jacobsville sandstone is of the order of 10,000 feet.

THE PROBABILITY OF A SINGLE STATION
BEING A REPRESENTATIVE SAMPLE IN A MAGNETIC SURVEY

L. O. Bacon, W. A. Longacre, and A. Stevens
Michigan Technological University
Houghton

In a magnetic survey one presumes that each station reading is a representative sample of the magnetic field of the immediate area. A study of this assumption in a glaciated region indicates that, for the areas studied, variations in magnetic field around the point are randomly distributed and that the probability of a value deviating from the mean of the field in the area is essentially that to be expected from a single valued field where variations follow the Gaussian error curve.

Magnitude of the anomalies varies as a function of the type of overburden, underlying rock type, and thickness of cover over the magnetic source.

ZONING OF THE WHITE PINE COPPER DEPOSIT,
ONTONAGON CO., MICHIGAN

Alexander C. Brown
University of Michigan
Ann Arbor

John W. Trammell
Copper Range Company

As described by White (1960)* the top of the cupriferous zone at the White Pine copper deposit is characterized by an abrupt zonation of Cu-Fe sulfides. Present studies indicate that this narrow fringe occurs at only one position in any vertical section and forms a blanket-like surface between the cupriferous zone and the overlying barren pyritic shales. Although ore horizons at White Pine show strict stratigraphic control, the sulfide fringe, marking the uppermost limit of chalcocite mineralization, occurs at various stratigraphic levels near and above the ore horizons. In general this surface cross-cuts bedding at gentle angles, but locally it appears to be more irregular.

Disseminated chalcocite, native copper, and native silver are the dominant ore minerals of the cupriferous zone; pyrite and minor amounts of chalcopyrite occur in the shales above. The transition between these zones (normally measured in inches) consists of digenite, bornite, and chalcopyrite in ascending order. Textures indicate replacement of iron-rich sulfides by copper-rich minerals. Abnormal concentrations of disseminated Cd, Zn, and Pb sulfides occurs immediately above the cupriferous zone and in the "Stripey" marker bed; they have not been observed within the cupriferous zone proper.

It is suggested that the Cu-Fe transition represents the farthest advance of a copper "front", behind which syngenetic or diagenetic pyrite was replaced by chalcocite and native copper. Silver in the Nonesuch was probably associated with the copper front. Cd, Zn, and Pb were swept ahead of the front and formed anomalous concentrations immediately above the cupriferous zone. Sulfur may have been partially removed from the present cupriferous zone during copper mineralization.

* White, W. S., "The White Pine Copper Deposit:" Econ. Geol. V. 55, pp. 402-414

MICHIGAN'S BUILDING STONE RESOURCES

Joseph P. Dobell
Michigan Technological University
Houghton

An investigation of the building stone resources of the State of Michigan was undertaken in the summer of 1965. Emphasis was on undeveloped materials in the Upper Peninsula of Michigan but a number of areas in the southern part of the state were also studied.

Geologic investigation consisted of selecting and visiting the potential building stone deposits, determining the geology of the local site, sampling the deposits, and evaluating factors such as proximity of the material to transportation facilities, location of the potential quarry, and possible water and overburden problems.

In the course of the field work the most common building stone collected was of the type used as decorative aggregate surfacing for pre-cast concrete slabs. Colorful and durable materials of this category were obtained from thirty-four localities in the Precambrian terrain of Michigan's Upper Peninsula. Sandstone, limestone and dolomite suitable for dimension stone were obtained from fourteen different sites. Eight localities yielded decorative stone which could be cut into polished slabs up to four feet square. Terrazzo stone could be quarried from seven locations and five rock types are suitable for use in the lapidary arts.

The mineralogy of all specimens was determined by microscopic study of thin-sections. Standard chemical analyses were provided by the Institute of Mineral Research at Michigan Tech. The same agency also has conducted abrasion, hardness, absorption, specific gravity, compressive strength, modulus of rupture, and freeze-thaw tests on all specimens.

Funds for this investigation of the building stone resources of Michigan were provided by the Michigan Department of Economic Expansion. The project was proposed and administered by the Institute of Mineral Research at Michigan Technological University.

NEW BATHYMETRIC MAP OF LAKE SUPERIOR
AND SOME GEOLOGICAL IMPLICATIONS *

W. R. Farrand
University of Michigan

J. H. Zumberge
Grand Valley State College

J. Parker
White Pine, Michigan

Parker has compiled a new bathymetric map with a 100-foot contour interval for the eastern half of Lake Superior on the basis of recent U.S. Lake Survey soundings. This map has been completed, in connection with the University of Michigan Lake Superior Project, by the addition of the best depth data available for the western half of the basin. The strong valley-and-ridge topography of the eastern part of the basin contrasts strongly with the rest of the lake where broad, smooth-floored basins are the characteristic form. However, sub-bottom depth recorder (Sparker) surveys show that bedrock valleys similar in size to those of the eastern basin exist also in the west, where they have been completely filled with glacial and postglacial sediments so that they no longer find expression in the topography of the lake bottom. In one of these buried valleys near the Minnesota coast late Pleistocene sediments are more than 700 feet thick. In the eastern basin, on the other hand, Pleistocene sediments form, in general, only a thin veneer over a rugged bedrock topography which resembles that of the Finger Lakes area of New York.

* See map, back cover

SHORT-RANGE CHEMICAL VARIATIONS IN A MANGANOAN
AXINITE FROM THE MESABI RANGE, MINNESOTA

Bevan M. French
Laboratory for Theoretical Studies
National Aeronautics and Space
Administration
Goddard Space Flight Center
Greenbelt, Maryland

A new occurrence of the calcium borosilicate axinite has been identified in a pegmatitic vein cutting metamorphosed Biwabik iron formation on the eastern Mesabi Range, Minnesota. The mineral occurs as yellow-brown, poorly-crystalline patches associated with large crystals of quartz and potassium feldspar. Two different size fractions of the crushed axinite, separated by identical heavy-liquid and magnetic methods, give different chemical compositions. Fraction 1 (- 100 + 150 mesh) gives: SiO_2 41.66, TiO_2 0.01, B_2O_3 5.96, Al_2O_3 18.00, Fe_2O_3 0.10, FeO 3.27, MnO 11.66, MgO 0.25, CaO 18.00, H_2O (-110°) 0.04, H_2O (+110°) 1.26, Na_2O 0.15, K_2O 0.02. Fraction 3 (- 150 + 200 mesh) gives, by contrast: Al_2O_3 14.23, Fe_2O_3 1.95, FeO 5.25, MnO 10.60. Similar significant differences exist in unit-cell parameters of the two fractions obtained by computer treatment of X-ray powder diffraction data. An unexpected discrepancy in the calculated unit-cell contents of Fraction 3 can be removed by substituting about 25 percent of the Mn as Mn^{+3} with aluminum, although the existence of both Mn^{+2} and Mn^{+3} in the same silicate has yet to be demonstrated. Refractive indices of the two fractions appear identical within the determinative uncertainty (± 0.003): $n_x = 1.678$, $n_y = 1.678$, $n_z = 1.692$ (Fraction 1).

Petrographic and electron microprobe studies suggest that the more iron-rich axinite (Fraction 3) has originated by fracture-controlled alteration of the original axinite during a period of more widespread secondary alteration indicated by (1) widespread sericitization of feldspar, and (2) almost complete chloritization of garnet. Relative higher PO_2 values during this latter stage are indicated by the increased $\text{Fe}^{+3}/\text{Fe}^{+2}$ in Fraction 3 and are consistent with the suggested partial conversion of Mn^{+2} to Mn^{+3} .

COPPER DEPOSITS OF THE BATCHAWANA AREA, ONTARIO

P. E. Giblin
Resident Geologist
Ontario Department of Mines
Sault Ste. Marie

Recent exploration in the Batchawana area, Ontario, located 40 miles north of Sault Ste. Marie, has led to new and significant discoveries of copper; underground development at one property; and production of copper from another.

Copper deposits are of three types:

1. Fissure-filling calcite-quartz veins, carrying chalcocite, bornite, chalcopyrite, and native copper.
2. Breccia pipe deposits, in which the mineralization consists of chalcopyrite, pyrite, molybdenite, galena, and sphalerite.
3. Disseminated chalcopyrite, pyrite, and molybdenite in altered quartz-feldspar porphyry, possibly representing a porphyry copper type of deposit.

Deposits of the first type occur in Keweenawan strata. Breccia pipe deposits are found in Archean rocks: K-A dating suggests mineralization is Keweenawan in age. The deposit of the third type may also be of Keweenawan age.

Copper deposits of the area are probably associated with magmatic activity of middle to late Keweenawan time, which in the eastern Lake Superior region appears to have been restricted to the immediate vicinity of the present lake basin.

It is suggested that the Archean terrain near the east shore of Lake Superior might warrant prospecting for breccia pipe and disseminated deposits of copper and molybdenum.

NEW FIELD STUDIES OF THE KEWEENAWAN LAVAS OF MINNESOTA

John C. Green
University of Minnesota, Duluth, and
Minnesota Geological Survey

Field work was begun in the summer of 1965 on the Keweenawan lavas and related intrusive rocks of northeastern Minnesota, with the support of the National Science Foundation and the Minnesota Geological Survey. Detailed mapping along the shore of Lake Superior in Lake and Cook counties has been concentrated on a restudy of the stratigraphic sequence, estimates of thickness, and direction of flow of the lavas. Measurements of 118 ropy structures at the tops of flows and of 38 bent pipe amygdules at the bases of flows show no clear preferred orientation and thus no uniform direction of flow or of regional slope in the area studied. Petrographic and preliminary x-ray studies show that lavas of intermediate composition are more abundant than heretofore recognized. An extensive area of flows, of both felsic and mafic composition, has been found well within the area previously mapped as Duluth Gabbro Complex northeast of Isabella. Minor intrusions, possibly connected with the Duluth Gabbro Complex at depth, show compositions that range continuously from troctolite, much of which is banded, to highly leucocratic granophyric granite. All intrusive phases contain xenoliths of anorthosite.

TEXTURAL RELATIONS OF HEMATITE AND MAGNETITE
IN SOME PRECAMBRIAN METAMORPHOSED OXIDE IRON-FORMATIONS

Tsu-Ming Han
Cleveland-Cliffs Iron Co., Ishpeming, Mich.

Hematite-magnetite is a common ore mineral assemblage in the Precambrian oxide iron-formations. The textural relationship of the two minerals changes with the grade of metamorphism.

In the low-grade metamorphosed iron formations (ore minerals co-existing with fine-grained dusty quartz and/or sheet iron silicates), one may find hematite with magnetite rims; hematite crystal outlines reappearing in partially oxidized magnetite; magnetite veinlets in fine-grained hematite; fractures in hematite bands cross-cut by magnetite; and magnetite crystals embedded in jaspilites. These textural relations suggest that magnetite is stable whereas hematite tends to be reduced to magnetite during the metamorphism.

In iron formations of medium-grade metamorphism (ore minerals co-existing with medium-grained fairly clean quartz and/or double-chain iron silicates), specularite embedded in fine-grained magnetite; specularite containing magnetite remnants; magnetite cross-cut by specularite; and specularite bands with relicts of magnetite clusters are commonly observed. Such features suggest that during the metamorphism specularite is a stable phase whereas magnetite tends to be oxidized to specularite.

Hematite and magnetite in iron formations of high-metamorphic order are more or less simultaneously developed, and commonly associated with coarse-grained clear quartz and/or double- and single-chain iron-rich silicates. However, the cross-cutting of specularite by magnetite in some ores may suggest the earlier development of specularite.

In conclusion, reduction and oxidation do occur in iron formations during metamorphism although in general ore mineral assemblages are governed by those of the pre-metamorphic sediments. Such processes are believed to be responsible for the development, at least in part, of the magnetite-bearing jaspilite, oölitic magnetite, and specularite-magnetite ore types. The degree of such types of metamorphism tends to improve the concentrating characteristics of ores and has a direct effect on the process chosen for iron ore beneficiation.

A BARITE-QUARTZ PHASE IN THE
FIRESAND RIVER CARBONATITE, WAWA, ONTARIO

E. Wm. Heinrich and Richard W. Vian
The University of Michigan
Ann Arbor

The Firesand River alkalic complex, 4.5 miles east of Wawa, Ontario, is unusual in that it consists predominantly of carbonatite with a highly subordinate outer ring of mafic to ultramafic alkalic silicate rock. The carbonatite core is composite, with an inner core of rauhaugite encircled by sovite and silicate sovite. The ferruginous rauhaugite body, which appears to be pipe-like and vertical (in contrast to the sovite ring, which represents the accretion of a series of inward-dipping cone-sheet slices), is itself a composite of several texturally and mineralogically distinctive rocks. Among these are 1) a porphyritic phase in which calcite phenocrysts are set in a finer-grained matrix of iron-bearing carbonate; and 2) a barite-quartz-carbonate rock. This rock contains barite euhedra, quartz grain fragments deeply corroded by carbonate, and euhedral smoky quartz crystals, some as long as three inches. Most of the quartz grains appear to have been metamorphosed, showing undulatory extinction, mosaic structure, and a strong parallel alignment of "bubble train" inclusions. Against the carbonate they are locally armored by "reaction rims" of very fine-grained ferruginous feldspar.

It is concluded that this unusual rock was formed by the carbonatization of a quartzite cut by small quartz veins into which were introduced (in order): 1) barite, 2) alkali feldspar, and 3) carbonate.

AEROMAGNETIC STUDIES OF EASTERN LAKE SUPERIOR

William J. Hinze, Norbert W. O'Hara and James W. Trow
Michigan State University
East Lansing

A regional aeromagnetic survey was conducted to determine the relatively unknown basement geology and tectonics of eastern Lake Superior and the eastern half of the Northern Peninsula of Michigan. During this survey approximately 6,500 miles of flight lines spaced at six-mile intervals were recorded with a digital recording proton precession magnetometer system. The results of the survey generally supported the geological interpretation that the Lake Superior structural basin consists of thick basic volcanics overlain by clastic sediments. This basin extends southward into the Northern Peninsula of Michigan with the basic volcanics of the Keweenaw Peninsula curving southward through Stannard Rock and Grand Island. The Isle Royale fault parallels the general curvature of the Keweenaw Peninsula to the vicinity of Superior Shoal where it is terminated by a cross fault striking from Ashburton Bay to the Keweenaw Peninsula. A fault on the north side of Michipicoten Island continues to the southeast toward Gargantua Point and northward, paralleling the shoreline at a distance of 10 to 15 miles. Midway between Michipicoten Island and Pic Bay, this fault turns northwest and continues south of the Slate Islands to the volcanics outcropping on the islands of Nipigon Bay. South of Michipicoten Island the basic volcanics have been uplifted by an east-west striking fault which may be a continuation or a branch of the Keweenaw fault. On the east side of the basin, south of these basic volcanics, the volcanics appear to be discontinuous with major volcanic rock areas extending southwest from Mamainse Point and the eastern margin of the Northern Peninsula of Michigan.

THE "ROCK CUT", LOWER ST. MARYS RIVER, MICHIGAN

Harold J. Lawson
Project Engineer
U. S. Army Corps of Engineers
Sault Ste. Marie, Michigan

The "Rock Cut" is a channel nearly two miles long and 300 feet wide cut through Trenton limestone that was initially excavated in 1904. It is between Neebish Island in the St. Marys River and the mainland of the Eastern Upper Peninsula. Completion of the project permitted large navigation ships to take a more direct route downbound to Detour Passage at the northern tip of Lake Huron.

The work consisted of constructing cofferdams upstream and downstream of the cut, 9,000 feet apart; dewatering the area; channeling and line drilling the ledge rock on the east and west channel limits; blasting and removing the rock to adjacent disposal areas; constructing an ashlar masonry guide wall at the channel limits on the ledge rock; flooding the area; and removing the cofferdams within the channel.

The blasting was done without blasting mats. The blasts were all monitored with a seismograph to maintain an Energy Ratio of 1.0 or less and to prevent excessive concussion. The largest blast was 1,800 lbs. of 60% hi-velocity gelatin. Usually the blasts were less than half this amount.

The work started in late summer 1960 and was completed in January, 1961.

A STRUCTURAL ANALYSIS OF THE MICHIGAMME SLATES

W. O. Mackasey and A. M. Johnson
Michigan Technological University
Houghton

The Animikie Michigamme slates of Michigan's Upper Peninsula represent a thick monotonous assemblage of fine-grained clastic rocks which apparently lack marker horizons suitable for interpretation by conventional field methods. For this reason, a statistical structural analysis utilizing small-scale features should be considered.

A preliminary investigation during the fall of 1965 was started in the Covington area to test the applicability of this method. Outcrops along a ten-mile stretch of highways M-28 and U.S. 141 north of the Baraga-Iron County line were examined.

Features measured within the slates included bedding, rock cleavage, axes of minor folds, and lineations produced by intersection of bedding and cleavage, etc. These data were plotted by means of an equal-area stereonet.

Two periods of deformation have been recognized and some information on the style of folding has been obtained.

Such studies may provide useful clues in determining the complex history of deformation of the Animikie rocks of the Upper Peninsula.

Further work, on a continuing basis, is planned.

THE GEOLOGY AND GEOPHYSICS OF THE MOOSE RIVER BELT, NORTHERN ONTARIO

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Geological Survey of Canada

Since 1959 the Geological Survey of Canada and the Ontario Department of Mines have cooperated in systematic aeromagnetic surveys of the Precambrian Shield of Northern Ontario.

In 1965 a major anomalous magnetic zone named the Moose River magnetic belt was recognized in these surveys. This feature extends for a distance of 160 miles south of James Bay and transects the Superior Province trends at a large angle. It coincides with granulites, gabbro, and basic dykes and is cut by a major fault along which ultramafics occur.

Detailed gravity and magnetic work indicate that the granulite and gabbro occurring in this magnetic belt can be explained by local magnetic and gravity measurements over surface material. This magnetic belt lies on the east flank of a major gravity feature, the Kapuskasing gravity anomaly.

MICHIPICOTEN SCHEELITE DEPOSIT
NEAR MICHIPICOTEN HARBOUR, ONTARIO

Louis Moyd
Curator of Minerals
National Museum of Canada

A scheelite deposit on the shore of Lake Superior about 12 miles west of Michipicoten Harbour was explored. The host rock is a nearly vertical northwest-trending septum of biotite and hornblende schist about 200 feet thick enclosed in a large body of granodiorite. Scheelite is irregularly distributed through quartz pods which form vein-like elongate swarms along the central portion of the tabular mass of schist. The mineralized zone can be seen under the lake and has been traced inland for about a mile.

The quartz pods are lenticular and vary greatly in size. Each swarm consists of pods, side by side or en echelon in both horizontal and vertical aspects, with long axes paralleling the foliation of the enclosing schist. Individual swarms may reach 30 feet in width, but are irregular and patchy, with some portions along the strike of the zone nearly free of the pods.

Individual pods are separated by septa of contorted schist from a fraction to several inches in width. Locally, adjoining portions of two or more pods have coalesced, with the intervening schist completely replaced or now represented only by strings and patches of coarsely crystallized mica and feldspar.

The scheelite is in the form of cream to buff anhedral grains and clusters from $1/8$ inch to about 12 inches in diameter. Most of the scheelite occurs near the margins of the pod, or if well within them, along the zones of coarsely crystallized mica and feldspar which represent earlier schist septa.

PRECAMBRIAN STRATIGRAPHY AND STRUCTURE OF THE TOWER,
MINNESOTA QUADRANGLE

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The Tower 7½ minute quadrangle is a strategically located area in the older Precambrian rocks of northeastern Minnesota. Rocks representing the Ely Greenstone, the Soudan Iron Formation, the Knife Lake "Group", and the Algoman granitic complex are present.

Most of the area is underlain by Knife Lake rocks, but a large nose of Ely Greenstone is present in the eastern portion of the area, entering from the adjacent Soudan quadrangle. The minor lower portion of the Knife Lake unit is comprised of conglomerates, impure quartzites, and tuffaceous rocks. These are overlain by a great thickness of alternating graywackes and "slates" (formerly mudstones). Most of the rocks have been only slightly metamorphosed, but metamorphic grade increases to the south.

Pillows in the Ely Greenstone and graded graywacke beds in the Knife Lake permit top determinations and structural interpretations. A series of tight, generally eastward-plunging folds cross the quadrangle. Overturned greenstones and graywacke-slate beds are common.

Aerial photo analysis revealed abundant lineaments in the area, generally trending about N. 35 E; one can be traced into a fault with about 1,000 feet of horizontal displacement.

Work is continuing in this area under auspices of the Minnesota Geological Survey. Major objectives are the solution of the regional structure (several workers are involved) and the sedimentary history of the Knife Lake rocks.

OCCURRENCES OF BASE METALS SOUTH OF DEAD RIVER,
NEGAUNEE QUADRANGLE, MARQUETTE COUNTY, MICHIGAN*

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In the south half of the Negaunee quadrangle, Marquette County, Michigan, rocks of early Precambrian age are bounded on the northwest and on the south by metasedimentary rocks of the Animikie Series of middle Precambrian age. The lower Precambrian rocks include massive and layered greenstones of the Mona Schist, pyroclastic rocks of the Kitchi Schist, and a syenite-diorite-granodiorite pluton that intrudes the Mona Schist. The metasedimentary rocks to the northwest, in the Dead River Basin, rest on an erosional surface cut on the pluton. The metasedimentary rocks in the southern part of the area are on the north limb of the Marquette syncline and are separated from the lower Precambrian rocks by a profound unconformity.

Small and widely separated deposits of base-metal sulfides have been found in the lower Precambrian rocks. The most common type is chalcopyrite with sparse pyrite in steeply-dipping quartz-carbonate veins. These veins have been found in both massive greenstone and coarsely crystalline granodiorite. They range in thickness from a few inches to more than 5 feet, and some can be traced along strike for several hundred feet. The sulfides make up only a small part of the veins and commonly are most concentrated near the footwall. Assays of selected specimens of vein material indicate that gold and silver are not present in measurable quantities.

Small amounts of chalcopyrite and copper carbonates occur in a shear zone in greenstone that has been carbonatized and sericitized. Tests for heavy metals in this shear zone indicate a rather broad mineralized area in which both copper and zinc occur in anomalous amounts. No zinc minerals have been identified.

In one locality, galena has been found with chalcopyrite in a quartz vein in granodiorite near its contact with greenstone. Elsewhere chalcopyrite has been found in joints in the granodiorite; no other vein material is exposed.

Some of the veins occur in topographic lineaments that are conspicuous on aerial photographs. Areas containing sulfide-bearing veins also coincide with magnetic lows shown on aeromagnetic maps of the region. Commonly the aeromagnetic lows occur above diabasic intrusions, suggesting a possible genetic relationship between the sulfide-bearing veins and diabase.

* Publication authorized by the Director, U. S. Geological Survey. Work done in cooperation with the Geological Survey Division of the Michigan Department of Conservation.

METALLOGENIC STUDY, LAKE SUPERIOR-CHIBOUGAMAU REGION*

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Geological Survey of Canada

Mineral deposits in the region are associated with rocks are tectonic activities of five different ages:

Early Archaean (-3.1 to 2.7×10^9 yrs.) iron formations, Zn and Cu - bearing iron sulphide deposits, Ni, Cr, asbestos, Cu-Ni, Cu, and Au deposits in volcanic, sedimentary, and associated ultrabasic, basic, and acidic intrusive rocks.

Late Archaean (-2.7 to 2.4×10^9 yrs.) Mo, Li, and Be in Kenoran pegmatites; minor Pb-Zn veins; Au and Cu-Mo deposits associated with late Archaean alkalic volcanic and intrusive rocks; remobilized early Archaean deposits.

Early Aphebian (-2.4 to 2.0×10^9 yrs.) conglomeratic U-Th deposits in Huronian rocks; veins containing native silver, Cu, Pb-Zn, Au, or U associated with Nipissing diabase and correlative intrusives.

Late Aphebian (-2.0 to 1.6×10^9 yrs.) iron formations in Animikean strata; Zn-Pb-Cu - bearing pyritic deposits in White-water strata in the Sudbury basin; Ni-Cu deposits associated with the Sudbury irruptive.

Neoheikian (-1.3 to 0.9×10^9 yrs.) native copper and other Cu deposits in Keweenawan strata; Ag deposits associated with basic intrusives; Pb-Zn and pitchblende veins; disseminated Cu deposits in breccia and in acidic intrusives; Nb and Cu deposits in alkalic syenite complexes.

Analyses of minor element contents of sulphide minerals and lead isotope analyses aid in classification of deposits and interpretation of their histories with respect to associated rocks dated by K-Ar and Rb-Sr methods. Many deposits contain radiogenic lead presumably generated during inter-orogenic periods. It is not clear in every case whether this was added at the time of formation or at a time of metamorphism of the deposit.

* See map, inside back cover

CLAY MINERALS IN GLACIAL DEPOSITS, HOUGHTON, BARAGA, AND ONTONOGAN
COUNTIES, MICHIGAN

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The clay-sized fractions from surficial glacial tills, outwash, and lacustrine deposits from 13 Baraga, Houghton, and Ontonogan County localities have been examined by x-ray diffraction. Results show that the clay fraction of most recent deposits consist of illite (clay-mica) and chlorite approximately in equal amounts. Clay fractions from older glacial deposits contain substantial amounts of expandable mixed-layer clay minerals in addition to illite-chlorite. Basal reflections of expandable clays typically consist of single broad $12.6 \text{ \AA}$ peaks or double $11.2 \text{ \AA} - 12.6 \text{ \AA}$ peaks which expand to $17 \text{ \AA}$ upon treatment with ethylene glycol.

The difference in clay mineralogy with depth may represent a weathering sequence in the local area and suggests the possibility of correlation of glacial deposits on the basis of clay mineralogy.

ORIENTED CHANNEL SAMPLES

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Channel samples of rock outcrops may be easily taken and oriented in the field by using a specially-equipped, lightweight Homelite gasoline motor unit operating two parallel, diamond-impregnated sawing blades spaced about one inch apart on the high-speed drive spindle.

The same unit may be used to trim the specimens to required dimensions, a convenient size being 1" by 1" in cross-section and 6" in length.

Water collant may be supplied by a standard portable pressure tank.

Orientation of the channel samples is accomplished by using a simple goniometer device in conjunction with an ordinary Brunton compass.

RESULTS OF DETAILED GEOCHEMICAL PROSPECTING IN THE WEST-CENTRAL
PART OF THE NEGAUNEE QUADRANGLE, MICHIGAN*

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Surficial materials in Marquette County were sampled and analyzed for lead, copper, and zinc during 1963-64 (Segerstrom, 1965).** Five areas where anomalously high concentrations of base metals were found in the soil were sampled in greater detail in 1965. The 1965 localities and their microtopographic setting were mapped at a scale of 1 inch = 200 feet. Where anomalies were especially high, small portions of the larger mapped area were resampled and remapped at 1 inch = 50 feet. Four of the five major areas are in T. 49 N., R. 27 W., as follows: NE $\frac{1}{4}$ sec. 30, NW $\frac{1}{4}$ sec. 35, N $\frac{1}{2}$ sec. 36, and vicinity of corner secs. 8, 9, 16, 17. The fifth area is in W $\frac{1}{2}$ sec. 7, T. 49 N., R. 27 W., and adjacent NE $\frac{1}{4}$ sec. 12, T. 49 N., R. 28 W.

Analytical results from the entire 1963-65 mapping program indicate that anomalous concentrations of lead, copper, and zinc in soils of the region are in large part post-glacial and reflect a local source. Results from the 1965 work have made it possible to delineate within each of the five areas relatively small targets for further exploration. Their geologic setting indicates that most of the targets in the first, fourth, and fifth areas may reflect sulfide mineralization along crosscutting (north-striking) faults or shears. The mineralization indicated by targets in the second and third areas appears to be largely related to bedding-plane (east-striking) shears.

* Work done in cooperation with the Geological Survey Division of the Michigan Department of Conservation.

** Segerstrom, Kenneth, 1965, "Preliminary Results of Geochemical Prospecting North of the Marquette Iron Range, Michigan (abs.): in 11th Ann. Inst. on Lake Superior Geology, St. Paul, Minn., p. 30.

ENGINEERING GEOLOGY ON NEW SECOND LOCK, ST. MARYS FALLS CANAL
SAULT STE. MARIE, MICHIGAN

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As part of navigation improvement between Lake Huron and Lake Superior, the U. S. Army Corps of Engineers is replacing an obsolete lock with a new lock 1,200 feet long, 110 feet wide and 32 feet deep.

Construction is on Cambrian sandstone and shaly sandstone which dips three degrees west. The sandstone is massive, and hard to very hard, with soft shaly seams. The shaly sandstone is hard with soft seams, slakes readily, and deforms and rebounds when unloaded. Good-quality rock was required for maximum stability. Consequently, more than 7,000 linear feet of 6-inch diameter core were drilled and examined.

Construction requirements are unique because the lock is in a trench excavated 80 feet below river level on an island of rock separated from land by adjacent locks. Adjacent structures and rock are protected against blast damage by pre-splitting or close-line drilling and broaching, and blasts are monitored with a seismograph. Dangerous hydrostatic forces are controlled during construction with cofferdams and by dewatering adjacent locks. A foundation grout curtain, drain and weep holes, and lateral drains in the lock floor, metal waterstops between lock wall monoliths, and a strutted lock floor will protect the structure against hydrostatic forces after construction.

Approximately 950,000 cubic yards of rock, old lock masonry and overburden, will be removed, and 350,000 cubic yards of concrete will be placed during excavation and construction. The lock will be completed in August 1967 at a cost of \$40 million.

IRISH STRATA-BOUND BASE METAL DEPOSITS

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In the Central Plain of Eire two important stratiform zinc-lead deposits, Nenagh and Tynagh, are about to come into production. A disseminated zinc-lead deposit, Riofinex, and a disseminated copper deposit, Gortdrum, are being explored.

These deposits occur in Lower Carboniferous limestones, some as massive sulphides, other as disseminations; some conformable with limestone bedding, others evidently remobilized and forming replacements and veinlets. Association with or near Waulsortian Reef Limestone muds is common but not necessarily genetic. The paleophysiography is fairly well established, and provides a broad guide in ore search. Tuffs may indicate volcanic exhalative contribution of metals, including relatively high silver values, thus differentiating these deposits from the Mississippi Valley type.

The deposits occur near normally faulted inliers, and Armorican (late Carboniferous) movements may account for their diplogenic character as well preservation of gossans. Mantle fissures have been invoked as regional controls of mineralization.

Geochemical dispersion as determined at Tynagh was predominately mechanical and syngenetic with till. Cu, Zn, Pb, and Hg dispersion trains are detectable in stream sediments and are related to soil/till anomalies rather than bedrock source in areas of glacial overburden. Peat is a largely undetermined factor as a metal collector.

Conditions favorable for the occurrence of strata-bound deposits appear to be widespread. Isotope and other geochemical studies are needed for a better understanding of genesis and improved exploration techniques in this renascent mineral industry.

SUGAR LOAF CONGLOMERATE, MARQUETTE COUNTY, MICHIGAN

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A few miles to the north of Sugar Loaf Peak on the shores of Lake Superior is a conglomeratic outcrop which is of particular interest. It is located in Section 20, T. 49 N., R. 25 W., being 6 miles north of Marquette, Michigan.

The boulders making up the conglomerate are up to a foot in diameter and are of weathered granite and red shaly sandstone. They overlie a gray granite and grade into a red, horizontal bedded sandstone believed to be of Cambrian age.

This outcrop, having shaly sandstone boulders along with granite boulders, corroborates the belief as expressed in an article¹ by the writer that the Cambrian sandstone is substantially a product of an older sandstone, probably Sibley.

1. Spiroff, Kiril, 1952, "Sandstones near L'Anse, Michigan". Rocks and Minerals, Vol. 27, No. 3-4, p. 149.

NOTES ON LAKE SUPERIOR TYPE IRON ORES AT BARSUA, ORISSA, INDIA

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The Barsua mine, 250 miles west of Calcutta, was opened in 1961 to supply the new Rourkela steel plant, 42 miles north. Reserves were 117 million tons, between 58.2 and 64.5% iron, more than half sinter ore. Expected output was 3.0 million tons yearly.

Barsua is on the Precambrian Bonai iron range, which extends for 75 miles as a ridge of peaks and saddles from 2,600 to 3,000 feet in elevation, with ore confined to the top. Relief is 1,300 feet. Dips are steep and structures are complex. "Banded hematite-quartzite" about 900 feet thick, is part of the Iron-ore Series, largely shale with local limestone, unconformable on Archaean-type metamorphic rocks. The Series was folded, and intruded by the Singhbhum granite about 2038 m.y. ago.

Six varieties of hematite ore are found. Massive hard cap-ore comprises only 3.7%. Most production comes from porous laminated ore, over 59% iron, comprising about 49% of reserves. Unfortunately at least 34% of total reserves is "Blue Dust", nearly 60% iron but difficult to handle and requiring sintering.

Complex structures seen in the pit have three causes: original soft-rock deformation, seen locally in hematite-jasper; tectonism; slumping due to leaching and oxidation.

Similarities to ores and iron formations of the Animikie are numerous and counterparts of almost all types can be found in Michigan or Minnesota. According to recent work, even the age of the sediments is comparable. In contrast, goethite, magnetite, specularite, and iron silicates seem virtually absent. The ores fade out downward, usually at less than 200 feet. Laterite caps the ferruginous shales and there are over 4 million tons of lateritic ore.

RECENT INVESTIGATION OF RAISED SHORELINES,
EAST SHORE OF LAKE SUPERIOR AND THE SAULT
STE. MARIE AREA

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Geological Survey
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R. E. Deane*

The eastern shoreline of Lake Superior and the Sault Ste. Marie area have yielded some good evidence for the former levels of Lake Superior. The investigations of Stanley (1932) and Farrand (1960) have been added to by surveys of raised or perched beaches at Montreal River Harbour, Batchawana and Sault Ste. Marie. These studies strongly suggest that water planes were present up to nearly the 1,100 ft. contour both in the Batchawana Bay area and at Sault Ste. Marie. These data suggest that Lake Algonquin penetrated into the Superior Basin.

All profiles presented have been surveyed by transit. The report is the preliminary stage of a general program for a more precise correlation of water planes between the Sault Ste. Marie area and the Southern part of Georgian Bay, by the Royal Ontario Museum, and a general investigation of the history of the Lake Huron Basin by the Geological Survey of Canada.

* Deceased.

NEW ZEALAND ILMENITE SANDS

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Ilmenite and lesser amounts of zircon, magnetite, rutile, monazite, and gold occur in beach sands distributed along the West Coast of the South Island for a distance of over 200 miles. Extensive accumulations form raised beaches, associated dunes, and filled lagoons around the outlets of the larger rivers. Detritus deposited off-shore was sorted and transported along the coasts by northward-trending littoral currents, and resorted by wave and eventually wind action. The sands have a uniform grain-size distribution with the various mineral reporting into size classes according to their hydraulic equivalences. Ubiquitous quartz is accompanied by heavy silicates, mica, and some spinels. The ilmenite is found in discontinuous lenses in the beaches and in lesser amounts distributed throughout the dunes.

Clean ilmenite grains from the active beaches have nearly a stoichiometric ratio of iron to titanium, but microscopic study shows minor rutile intergrowths occurring along the basal planes, minor hematite composites containing ilmenite ex-solution bodies, and clouds of silicate inclusions less than 10 microns in size. Leucoxenization is not notable; apparently the New Zealand climate has not been favorable for this process.

A consolidated "iron pan", conforming with the ground surface, is a feature of the old beaches, and the sands in both the old beaches and dunes are coated with yellow iron oxide and contain concretions up to several inches in diameter. These features, along with the presence of heavy silicates, complicate mineral separations by conventional methods, and the fine inclusions in the ilmenite are a problem in making a commercial product.

* Fulbright-Hayes Grantee (1965), University of Otago, Dunedin, New Zealand.

AEROMAGNETIC, GRAVITY, AND SUB-BOTTOM
PROFILING STUDIES IN WESTERN LAKE SUPERIOR

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The structure of western Lake Superior is studied by magnetic, gravity, and sub-bottom profiling surveys. About 7,500 miles of north-south aeromagnetic tracks were flown, 275 bottom gravity stations occupied, and 900 miles of sub-bottom profiles obtained. The magnetic and gravity surveys support the structural interpretation of White (1966)* for the far western part of the area and indicate a medial ridge, extending southwestward from the western end of Isle Royale that divides the area east of the Bayfield Peninsula into north and south basins or synclines. The north syncline is cut by a fault that extends westward from Isle Royale, runs north of Isle Royale, and continues eastward to the edge of the survey area. Another fault extends from Isle St. Ignace to the eastern end of Isle Royale and may continue southwestward along the medial ridge. The sub-bottom reflection profiles show many interesting details, such as sediment-filled troughs and old stream channels. The penetration of the reflected wave was 0.25 sec., distinct horizons deeper than 0.1 sec. being commonly observed.

* White, W. S., "The Tectonics of the Keweenaw Basin, Western Lake Superior Region:" U. S. Geol. Surv. Prof. Paper 524 E 23p. 1966.

SOME ASPECTS OF HURONIAN PALEOGEOGRAPHY AND SEDIMENTATION IN THE CANADIAN SHIELD

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A sequence of formations almost identical to those of the "original" Huronian occurs in the McGregor Bay area, north-east of Manitoulin Island in Lake Huron. The pre-Gowganda Proterozoic rocks of the north shore of Lake Huron appear to be a unique occurrence in Canada. In the north shore region the unconformity beneath the Gowganda Formation is local and an unbroken succession of Proterozoic rocks occurs at McGregor Bay. However, rocks thought to be correlatives of the Gowganda Formation and younger Aphebian sedimentary rocks are widespread throughout the Churchill Province and may be recognized in parts of the Superior and Slave Provinces, so that the unconformity beneath the Gowganda Formation is of regional significance.

In the McGregor Bay area the Gowganda Formation conformably overlies the Serpent Formation and is followed in upward succession by the Lorrain Formation, a banded "cherty" quartzite, a white vitreous quartzite, and ferruginous slates, siltstones and quartzite. The iron-bearing beds are thought to be approximate equivalents of the Animikie iron formations of Port Arthur and the south shore of Lake Superior. The oldest Proterozoic rocks of Michigan and adjoining areas are thought to be correlatives of the Cobalt Group of Ontario. The absence of the older Huronian rocks in the north-central United States may be attributed to the presence of a positive area there in pre-Cobalt times.

Paleocurrent analysis and dimensional fabric analysis indicate an essentially southerly direction of transport of the Huronian sediments of the McGregor Bay area. Abundant sedimentary structures indicate that all the Huronian sediments of the McGregor Bay area were deposited in shallow-water conditions.

A comparison of the Lower Proterozoic sediments of Canada with those of south-west Greenland, Scandinavia, India, and Australia suggests the existence of frigid conditions over a large part of the earth's surface at that time.

UNIQUE INTERGROWTH OF CALCITE AND PYRITE

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A rather unique intergrowth of calcite and pyrite is here described. These crystals were found in the Groveland Iron Mine of the Hanna Mining Company near Iron Mountain, Michigan. The pyrite and calcite show evidence of simultaneous crystallization. The pyrite grew on the vertical symmetry planes of the calcite with the triad symmetry axis of the pyrite parallel to the triad inversion axis of the calcite. This intergrowth gives the geometric symmetry of the Ditrigonal hemimorphic class to the combination. It is felt that because the intergrowth does not satisfy the symmetry of the calcite in its entirety, the pyrite was the "seed" crystal to the intergrowth. The interspacings of the planes in the calcite in the direction of the triad axis is very close to the spacings of the planes in the pyrite in the direction of the triad axis, and it is felt that this similarity in spacings was the controlling factor to this unique intergrowth.

More work is needed in the field of crystallogeny. Evidence of partial parallel orientation of crystals may be characteristic of simultaneous crystallization that can be used in the interpretation of age relations in mineral deposition.

AREAL DESCRIPTIONS

and

GUIDEBOOKS

1. Sault Ste. Marie Area
2. Manitouwadge, Ontario
3. Elliot Lake, Ontario
4. Sudbury, Ontario

REGIONAL GEOLOGY OF THE SAULT STE. MARIE AREA

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Sault Ste. Marie, Michigan

INTRODUCTION

The contact between the Precambrian Canadian Shield and the main body of Paleozoic rocks to the south is nowhere more obvious than in the Sault Ste. Marie area. Here a marked unconformity is reflected in changes in the vegetation and topography. The result is that the visitor going from one area to the next is immediately aware of the marked difference between the two regions.

This paper will be confined to the areas near or adjacent to the twin cities of Sault Ste. Marie in Michigan and Ontario, although better known areas of geological interest can be found beyond the limits of this discussion, at Blind River to the east and Wawa to the north. For the student of geology the area is rich in diversity of lithology, structures, topography, and mineralogy. Being close to Lakes Superior and Huron, and to the St. Mary's River, it is an area of considerable natural beauty which has become a popular tourist center for visitors from both Canada and the United States.

Although regional geological studies of this region have been made since early in the nineteenth century, only a few have dealt specifically with areas involved in this paper, and some of these are noted in the references.* Since the discovery of uranium at Theano Point, copper in commercial quantities near Mamainse, Ontario, and dolomite in Chippewa and Mackinac Counties in Michigan, more detailed work has been carried on. However, there are many interesting, unsolved geological problems throughout the district, to say nothing of the fact that there is still a considerable potential for the discovery of new, economically valuable, deposits.

Location

Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan are situated north and south, respectively, of the rapids in the St. Mary's River. These rapids are fifteen miles downriver from the outlet of Whitefish Bay, Lake Superior, and forty-seven miles upriver from Lake Huron. The general direction of the river is slightly north of east from Whitefish Bay to St. Mary's Rapids. At the rapids, which are also the location of the famous locks, and over the head of which passes the International Bridge linking

* Numbers refer to references listed at the end of this paper.

the two cities, the river drops about twenty feet and then turns southward and flows into Lake Huron at Detour.

Climate and Vegetation

The area immediately surrounding the two Saults has a typical northern continental climate modified by the proximity of Lake Superior. The latter lies in the path of the prevailing winds, and most of the major air masses in migrating eastward have to pass over the lake before reaching the Saults. It is interesting to note that this area lies only a relatively short distance south of a tongue of sub-Arctic climate which encompasses the southern tip of James Bay. The severity of the winters increases rapidly landward from the shores of the lake, particularly in the Ontario section of the area.

Total precipitation approaches 30 inches annually, and average mean temperatures range from 64.6°F in July to 15.8°F in January.¹⁷ Inland from the lake it is not uncommon to find temperatures of -40°F, and unofficial records are far below that.

A noticeable difference in vegetation separates the areas underlain by Precambrian rock from those underlain by Paleozoics, even though a veneer of Pleistocene deposits partially covers them all. Originally there was probably a greater similarity of vegetation between the two areas, but cultivation and more intensive logging of the flat lands characteristic of the Paleozoic areas have radically changed the flora.

The vegetation on the Precambrian areas consists mostly of maple, birch, and aspen, and extensive areas of coniferous growth. Such farm land as exists is generally confined to small glacial drift-filled valleys between rocky hills with little soil cover. The Paleozoic areas, on the other hand, comprise broad areas of farm land, forested areas of hardwood, including beech, and extensive sand plains and swamps on which conifers dominate. Dense cedar growth characterizes the southern part of the Paleozoic area.

GEOLOGY

This paper deals with five distinguishable subsections of the geology of the Sault Ste. Marie area and its environs, viz.

1. Granite Complex
2. Metamorphic Complex
3. Keweenawan
4. Paleozoics
5. Glaciation

Granite Complex

From Sault Ste. Marie, Ontario northward to the Montreal River and westward to Lake Superior, lies an area which, with the exception of the Keweenaw, to be described later, consists almost entirely of granite and granite gneiss.^{10,12} In this area there are a few extensions of the metasediments and meta-volcanics to be found farther east, but anyone travelling through this country is bound to be impressed by the overwhelming amount of granite and granite-like rocks.

The granites are mostly pink and quite uniform in the southern end of the area. Both gray and reddish varieties, sometimes porphyritic and often with pegmatitic phases, occur in the northern end. Granodiorite, monzonite, and related phanerites are also present in smaller amounts. The gneisses are well banded and are very likely metasediments; they contain large masses of amphibolite and biotite schists, which may be xenoliths of partially granitized basic volcanics or intrusives. The granites are mapped as Algoman but more intensive study of the batholiths is likely to show several different ages of granite activity. Some younger granites¹⁰ have been recognized but a complete description of the age relationships is beyond the scope of this paper.

The entire granite area is cut by basic dikes.¹⁴ The dikes are often sheared to some degree and have been altered to chloritic and sericitic equivalents. Some fresh diabase dikes are obviously of a younger age, and are presumed to be Keweenaw.

Characteristically the granite areas are rugged, with relief as much as 800 feet. The drainage is youthful with several lakes and many swift-running streams. The soil is generally thin except in the valleys, and in many places the granites form rugged rock bluffs. Where the basic dikes cut the granite masses, differential erosion of the dikes has resulted in deep chasms, the most obvious example of which is at the mouth of the Montreal River. Here the walls of the canyon are practically the contact surfaces of the dike which is now visible only during stages of low water.

The area here called the Granite Complex has not produced any commercially valuable deposits, although some near misses have occurred and there is a possibility that a copper porphyry type of deposit will be developed near the edge of the Keweenaw.³ The original discovery of uranium in 1948 by Robert Campbell, which set off one of the greatest staking rushes in history, occurred in the northern end of this area at Theano Point.¹⁴ Here mineralization is found along the contacts of one of the dikes cutting a pegmatitic phase of the granite. Pitchblende and related minerals are sufficiently concentrated in hydrothermal veins to have warranted some serious development work. Several other similar occurrences of pitchblende were found, the most noteworthy of which was in a similar geological environment north of the Montreal River on the property which has become the Ranwick mine. Here specimens

of massive pitchblende are found along with some selenides such as clausthalite, $PbSe$, and a mineral close to Klockmannite, $CuSe$. Native selenium has also been reported. Although an adit was driven into the potential ore zone, bulk sampling yielded results too low to continue further development. The mine has since become a tourist attraction and the property continues to yield excellent samples of pitchblende for the mineral collector.

Several pits and adits scattered throughout the area are testimony to earlier hopes of developing some of the mineralized veins which contain chalcopyrite, galena, and spalerite, but none of them has proved of sufficient size or grade to be minable.

Metamorphic Complex

Extending eastward from the Granite Complex to the area north of and including Bruce Mines, the geology is radically different. The dominant rock types of this extensive area are metasediments and metavolcanics with some large basic igneous intrusives. This area includes part of the type section of the Huronian.²

This area is dominated by prominent hills of quartzite, metaconglomerate, and diabase. The topography in many parts is quite rough, with relief about 600 feet. In some of the valleys between the ridges north of the town of Bruce Mines enough glacial debris has accumulated to provide soil for farming, and although the flat areas are not very extensive, they seem to be relatively fertile. The area also contains many lakes; drainage is in the youthful stage.

The general strike is northwesterly, and in the abundant outcrops north of Bruce Mines the ridges and valleys tend to follow the regional strike. The Murray fault has been traced through the middle of the area and strikes northwesterly as well.² Secondary faults probably associated with the Murray fault system occur throughout the area. With the Murray fault almost along its axis, the main structure is a syncline, boldly outlined by resistant quartzite ridges. To the south a parallel-ling anticline can be traced, with the south limb exposed along Highway 17 near Desbarats where some conspicuous ripple marks are preserved in the quartzites outcropping in road cuts along the highway. (See Elliot Lake guidebook in this program.)

Most of the rocks in this area are considered Lower and Middle Huronian, though some of the greenstones, which have been called the "Basement Series", are possibly Archean.^{2,10} The age relationship of the diabbases and metadiabbases is not completely clear; some of them have been considered Keweenawian, and others probably much older. The Huronian rocks are mostly quartzites, metaconglomerates, and metagraywacke. Minor outcrops of Lower Huronian limestone occur; and some slates and a metamorphosed chert-like siltstone are associated with the more prominent quartzites. One formation in particular deserves special mention

and that is the very colorful Lorraine metaconglomerate which contains jasper and white quartz pebbles in a white matrix and forms a conspicuous horizon.

Economically the area has yielded a few minable deposits, the most noteworthy being the copper deposits of Bruce Mines.² Here, veins of quartz, siderite, ankerite and chalcopyrite cut the diabase and were rich enough to sustain an intermittent operation in the past with a total production of between 300,000 and 400,000 tons of ore since discovery in 1846. Many similar occurrences of chalcopyrite are known throughout the area. Galena and sphalerite in veins cutting metamorphic rocks completely surrounded by granite yielded a small production at Jardun Mines north of Garden River. Other lead-zinc occurrences are also known. Iron formation interbedded with metavolcanics or quartzite, magnetite concentrations as magmatic segregations in some of the larger basic igneous masses, and some vein deposits of specularite in the quartzites have led to prospecting for iron. The last type yielded a small tonnage of high grade ore from the old Stobie mine near Gordon Lake. No substantial quantities of iron ore are known. Gold has been mined from quartz veins near Ophir, north of Bruce Mines, but results were disappointing. The diabase has been quarried for road ballast and a rather extensive processing plant was erected east of the Bruce Mines and operated for a few years during World War I.² More recently the quartzite of the Bellevue ridge has been quarried for use by the Algoma Steel Company in Sault Ste. Marie, Ontario.

Although results of mining attempts have been generally disappointing there is still reason to believe that, with modern techniques, deposits of economic value may yet be found.

Keweenawan

From Harmony Bay north of Sault Ste. Marie, Ontario, and extending north to Mica Bay, the granites and metavolcanics are overlain by basic lavas and clastic sediments of Keweenawan age.¹⁶ As these rocks are similar in all respects to the Keweenawan of Michigan it is reasonable to assume that they represent an extension of the lavas found in Upper Michigan and Michipicoten Island. In this area rocks of Keweenawan age are never more than five miles from the shore. They lie conformably on the erosion surface of the older granites or on the Mamainse diabase, an older and more altered basic rock mass, mapped by Moore¹² as a single lithologic unit but actually containing a variety of metavolcanics. The exact correlation of the Mamainse diabase is not clear and in places it is difficult in the field to distinguish between this rock and the overlying Keweenawan.

The topography of the area underlain by Keweenawan rocks is generally less rugged than the adjacent granite areas, but the total relief is about as great. The area is one of ridges formed by the upturned edges of the flows and the conglomerates, so that the ridges trend in the same direction as the strike of the beds.

Along the shore of Lake Superior these ridges form long peninsulas extending into the lake or islands paralleling the shore. The topographic similarity between this shoreline and that of the northeastern part of the Keweenaw Peninsula of Michigan is striking.

Cutting the Keweenawan are intrusives of felsite and felsite porphyry, which, curiously enough, appear to be more metamorphosed than the enclosing basic lavas. These acidic rocks constitute a very minor part of the Keweenawan.¹⁸

The rocks of the area mapped as Keweenaw are amygdaloidal basalts and basalt porphyries and in the thicker flows the rocks grade into dolerites and gabbro. These flow units are interbedded with conglomerates and sandstones. The dip of the entire Keweenawan is generally westward toward the Lake Superior basin and dips average around 30° . All of the formations have been affected by faulting but no large-scale displacement has been noted. The general direction of the faulting is either parallel to the strike and dipping normal to the beds, or at right angles to these and dipping vertically. Mineralization along the fault zones, some of which are brecciated, is in the form of copper minerals, including minor amounts of native copper. This led to an early interest in the area in hopes of finding deposits similar to those mined in Michigan.

Recent interest in the area has resulted in the development of one producing mine and two promising prospects. The mineralization appears to be of three different types as described by Giblin.³ These are fissure-filled vein deposits, breccia pipe deposits, and disseminated deposits in what appears to be a copper porphyry type of occurrence. The latter two contain molybdenum as well as copper and occur outside the Keweenawan area but all seem to be associated with a post-lava flow period of mineralization, and therefore may be late Keweenawan in age.

Some of the felsites have been explored for hydro-thermal clay deposits.

Paleozoics

South and west of St. Mary's River lies the area described as Paleozoic. Actually areas of Paleozoic rocks can be found in the previously described subdivisions, but these are minor and in themselves would not contribute much to the geological history of the region. This area represents the northern rim of the Michigan Basin, and therefore includes the oldest of the Paleozoic sediments found in the State.¹

The rocks are quite unaltered and nowhere is there any evidence of igneous activity; therefore this subdivision provides a completely different topography as well as lithology from the preceding subdivisions. Dips are very gentle, mostly to the south and occasionally flat. Some local northerly dips are encountered.

The lowest formation in the series is a sandstone which has been correlated with a massive sandstone farther west and is considered therefore to be Middle or Lower Cambrian,⁴ although no direct evidence of this can be found in this area. This sandstone, known as Jacobsville, crops out in numerous places and is especially well defined in the area of the locks. A well drilled to a depth of 1,500 feet south of Sault Ste. Marie, Michigan, failed to penetrate the bottom of this formation, but three miles north of the St. Mary's River along Highway 17, conglomerates in the Root River appears to be the basal conglomerate of the series. If this is the Jacobsville, and the origin of the latter is as postulated by Hamblin,⁴ it really does not fit as part of the Michigan Basin. Overlying this sandstone is the Munising formation which can be seen outcropping along the shores of Whitefish Bay and in the Tahquamenon Falls. This latter sandstone is agreed to be the oldest formation of the Basin and is Upper Cambrian in age. It is quite different in character from the red Jacobsville, being more thoroughly sorted, in some places a very pure quartz sand, and more uniform in thickness. It represents the farthest known advance of the Late Cambrian seas. Some gray sandstone and shales found along the shores of Lake Superior near Mica Bay and Alona Bay are very likely of this age.

Above the Cambrian, the Ordovician is represented by shales and limestones which crop out only sparingly. On St. Joseph's Island the limestone is highly fossiliferous, and crops out only a short distance from the Precambrian basement. The islands from St. Joseph south to the north tip of Drummond in Lake Huron and west to the mainland contain many areas of Ordovician outcrops and in the Neebish cut there are excellent exposures.⁷ The material thrown onto the banks during the excavation yields good Ordovician samples.

The most prominent of the Paleozoic formations are those of Silurian age. They crop out along an east-west, north-facing cuesta and all along the shores of Lake Huron at the south end of this area. These rocks are chiefly dolomite and the cuesta is an extension of the Niagara cuesta of New York and Ontario. In many places the dolomite is exposed or covered by only a very thin overburden. Where Lake Huron and the former glacial Lake Nipissing⁶ have eroded the dolomites, cliffs and other shore line features have been developed.

The Devonian is present in only very minor amounts, outcropping near St. Ignace, particularly along the shores of Lakes Huron and Michigan, and in the cuts along the approaches to the Mackinac Bridge. The Devonian of the Upper Peninsula consists of the Mackinac Breccia, a formation well described by Landes, Ehlers, and Stanley.⁸ Several prominent sea stacks, now stranded by the retreat of the Lake since the Nipissing stage of the glacial development of the Great Lakes, occur along the shore in and near St. Ignace.

Economically the Paleozoic has yielded metallurgical-grade

dolomite as well as dolomite for construction purposes.⁵ Two prominent quarries are operating today, one at Cedarville and the other on Drummond Island. Sandstone of Cambrian age has been used for building stone, but none is quarried today. Pure quartz sandstone of Upper Cambrian age crops out along the shore of Whitefish Bay, particularly at Naomikong Point. Here the sandstone is almost of glass-sand quality without any beneficiation, but development of the deposit is interdicted by the Federal Forest Service, as the area is one being developed for tourists and the two operations are not considered compatible.

Several attempts to find oil in the Paleozoics have failed. No systematic geophysical work for the purpose of locating possible petroleum-bearing structures appears to have been done. Some bituminous shales and shaly limestone have been encountered, and reports of oil in some of the wells dug in the district have led to sporadic interest.¹⁸ As this area represents the margin of the Michigan Basin, and as the sediments are known to become thicker toward the center of the Basin, the possibility of oil and gas traps along pinch-outs or shoe-string deposits cannot be ruled out, although evidence is very meagre.

Glaciation

The entire area has been deeply affected by the Pleistocene glaciation, and all of it was covered during the Mankatoan substage of the Wisconsin.¹³ The evidences of recent glaciation are everywhere present, and it is not improper, in studying an area such as this, to discard the term "Recent" and to include present time in the Pleistocene. During the time of maximum glaciation all of the area being discussed was under the ice, and not even nunataks could have occurred. All of the features which the glaciers left were formed at the bottom of the tremendous ice sheets, or represent features developed during the last stages of the retreat of the ice.

In the resistant rocks of the Precambrian are found large glacial valleys, reminiscent of mountain glaciation. These valleys have a modified U-shaped cross section, and are therefore bounded on both sides by steep rocky walls and have a characteristically flat floor. These valleys appear to radiate away from the highland areas, and were therefore possibly carved out by tongues of ice descending from the ice caps which probably dominated the highlands during the last stages of the glaciation, while the main mass of the ice retreated to the north. This accounts for the east-west direction of the valley of the Goulais, and the north-south direction of the valley of the Root. That these valleys should also tend to follow zones of rock weakness, such as shear zones, columnar jointed dikes, and similar linear features is self-evident.

Glacial grooving and striations are pronounced throughout the outcrop area, and are particularly noticeable in the quartzites

of the Precambrian and some of the dolomite ridges of the Paleozoic. Glacial polish occurs on some of the exposed quartzites and, due to only minor weathering, some exfoliation can be seen. In places where the Precambrian rocks crop out through the glacial drift, typical roches moutonnees are common.

Whereas the area underlain by the Precambrian is characterized by the erosional features of glaciation, the area underlain by the Paleozoics contains mostly constructional features.* Here the topography is dominated by the flat plains which formed the floor of former glacial lakes.⁹ These plains are formed by varved clays and sand, and their featureless surface is broken only by some deeply eroded river valleys, morainal ridges and hills, the prominent dolomite cuesta previously mentioned, and a second, less prominent Cambrian cuesta, over which the Tahquamenon River flows to form the Tahquamenon Falls.

Outwash plains, some with prominent gravel areas, occur south of the edge of the Precambrian, and are common in other parts of the area.

Post-glacial uplift of the entire eastern end of Lake Superior accounts for many of the topographic features in the area.** Raised beaches are common in the area north of Sault Ste. Marie, and are responsible for some thick gravel deposits. To the south, the drowned lower reaches of the rivers, flowing into Lake Superior, such as the Waiska and the Tahquamenon,⁹ are evidence of gradual tilting of the Lake basin.

Economically, the glaciation of the area has resulted in valuable deposits of gravel, many of which have been used for road building and concrete aggregate. The varved clays have provided reasonably fertile farm land, and the sands are being used as fill. The glacial gravels are also a source of excellent ground water, much of which is artesian,¹⁸

* See, however, Farrand et al. abstract in this program.

** See Tovell et al. abstract.

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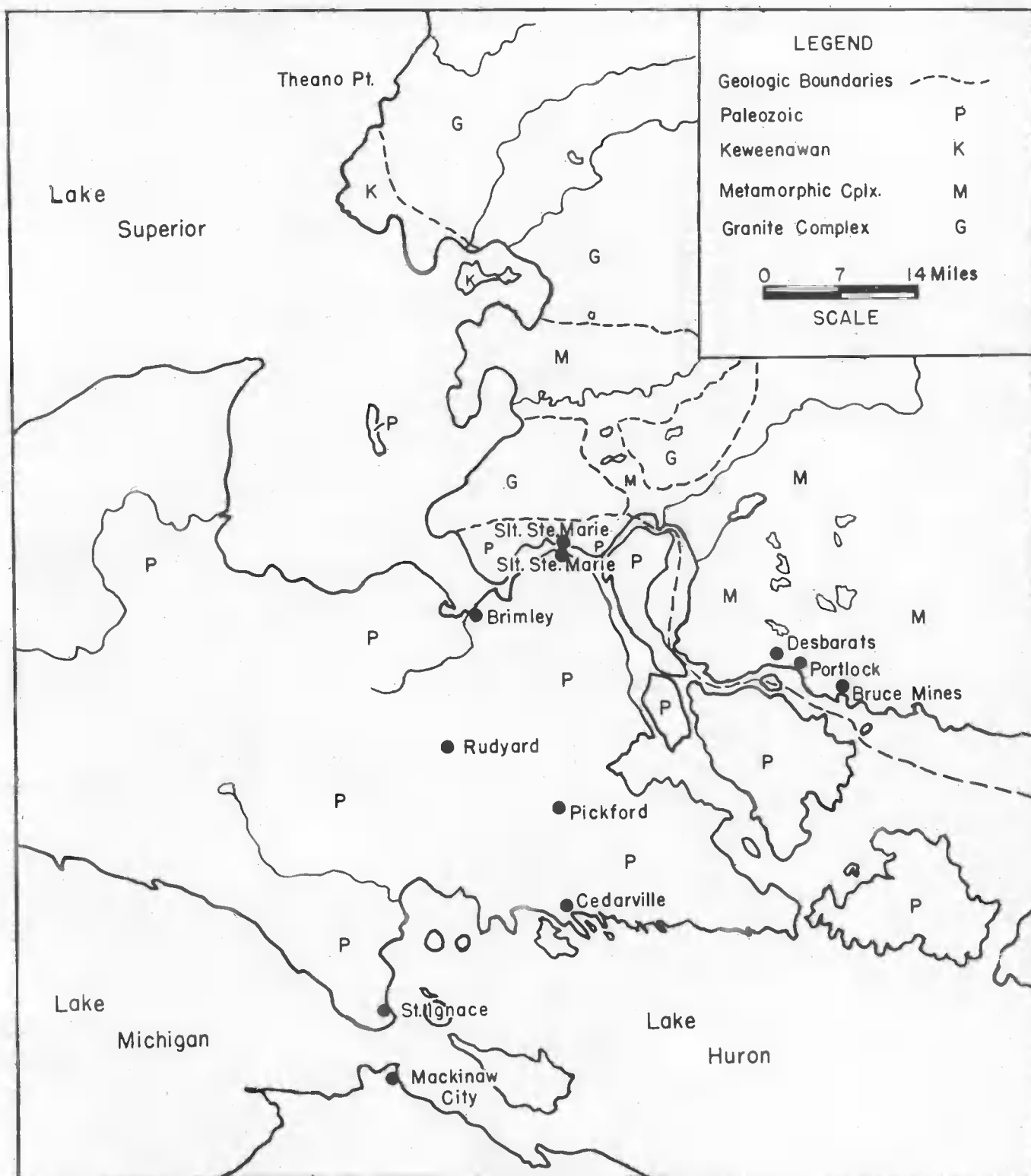


Figure 1. Geology of the Sault Ste. Marie Area

GEOLOGY AND MINERAL DEPOSITS
OF THE
MANITOUWADGE LAKE AREA*

by

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Introduction

In 1931, the Manitouwadge Lake area was surveyed for the Ontario Department of Mines by Dr. J. E. Thomson, now Chief Geologist; and on his geological map, published in 1932, he noted an occurrence of gossan and sulphide mineralization at the site of the now famous Geco mine¹. But despite this it was only many years later that any interest was paid to the discovery. This may be owing to the commonly held opinion that "greenstone" belts of small area do not lead themselves to the occurrence of large mineral deposits - the favourable prospecting area at Manitouwadge Lake is only about 35 miles square. It may also be because of the highly metamorphosed condition of the rocks - many prospectors consider that schists and gneisses are unfavourable to ore deposition. In any event, the area was avoided until as late as 1947, when the sulphide deposit at Manitouwadge Lake was first staked. But even at that time, it was difficult to arouse interest in the discovery; and after two years, the prospector, Moses Fisher, was compelled to let his claims lapse because of failure to attract a mining company to undertake development.

In 1953, two prospectors, Roy Barker and William Dawidowich of Geraldton, Ontario, decided to visit the area. Upon relocating the sulphide deposit, with which they were much impressed, they decided to stake. The sulphide deposit was examined by W. S. Hargraft, consulting mining engineer, and upon his recommendation, the property was quickly taken up by General Engineering Company, Limited; Consolidated Howey Gold Mines, Limited; and H. W. Knight and associates on a partnership basis. Diamond drilling in August and September indicated the possibility of a copper-zinc-silver ore body. Geco Mines, Limited, was incorporated in October, and it was not long before the results of further drilling

* Published by permission of the Provincial Geologist, Ontario Department of Mines. Reprinted from the Second Institute on Lake Superior Geology, "Geological Exploration". A. K. Snelgrove ed., Michigan Tech Press, 1957. Subsequent developments will be discussed at the mine by the author.

1. Thomson, Jas. E., "Geology of the Heron Bay - White Lake Area," Ont. Dept. Mines, Vol. XLI, Pt. 6, pp. 34-47 (with map No. 4i), 1932.

indicated a deposit of such importance that the biggest staking rush in the history of Ontario, and one of the biggest in the history of Canada, was precipitated.

Location of Area, Means of Access

The Manitouwadge Lake area forms a small but very important part of the Heron Bay - White Lake region along the north shore of Lake Superior. As shown in Fig. 1*, it lies about midway between two transcontinental railways, the Canadian National Railways line on the north and the Canadian Pacific line on the south; it is 170 miles east-northeast of the Canadian Lakehead, and 200 miles northeast of Houghton, Michigan.

The area is accessible by an Ontario Department of Mines access road connecting Manitouwadge Lake with the Trans-Canada highway along the north shore of Lake Superior; by a spur railway line built south from Hillsport by the Canadian National Railways; and by a second railway line, built north from Hemlo by the Canadian Pacific Railway.

General Geology

All the consolidated rocks exposed in the Manitouwadge Lake area are of Precambrian age. They have been divided into three main groups:

- (1) A system of closely folded and intensely metamorphosed volcanics and sediments, which, together with horizons of amphibole - biotite gneiss and banded iron formation, are believed to be of Early Archaean age;
- (2) An assemblage of igneous rocks, of post-Early Archaean and possibly of Algoman age; and
- (3) Diabase dikes, which have been correlated tentatively with basic intrusives of Keweenawan age exposed around Lake Nipigon and along the northwest shore of Lake Superior.

Early Archaean

Volcanics: A prominent series made up largely of hornblende schist is exposed south and west of Wowun Lake. It forms

* See instead map on inside back cover for location.

a well-defined belt, up to and possibly, exceeding two miles in width, which extends from this locality southwest to Manitouwadge Lake, and thence westward across the southwest corner of the map area. Two varieties of hornblende schist are present. One shows little evidence of banding; the other is characteristically finely laminated and resembles a thin bedded sediment in structure.

Excellent exposures of the non-laminated hornblende schist are found in the west part of the belt. In places where shearing has not been too intense, vestiges of original pillow structures can be seen. The pillows are somewhat irregular in shape and do not permit satisfactory top determinations. But their presence is significant, for they indicate that the hornblende schist is of volcanic origin. In consideration of the mineralogical composition - the typical schist consists of about 50 percent hornblende with lesser amounts of andesine and a little quartz, sphene, and magnetite - it is probable that the rock is the metamorphosed equivalent of original basic lava.

Thin horizons of laminated hornblende schist separate the lava flows. They are particularly well-developed in the vicinity of Manitouwadge and Mose lakes. The rock itself is similar mineralogically to the variety just described except that, at the expense of plagioclase, quartz is an essential rather than an accessory constituent. A further and more striking difference, of course, is the thin bedded structure - black layers of material rich in hornblende alternate with grey layers rich in plagioclase and quartz. These layers range from a small fraction of an inch to several inches in thickness. The laminated hornblende schist is found in places to contain lenticular fragments of greenstone, from less than an inch to six inches and up to about three inches in thickness. The two characteristics - stratification and fragmental structure - indicate that the original rock was a tuffaceous sediment deposited subaqueously during the period of volcanism.

Sedimentary Gneisses: As the north margin of the volcanic series is approached, well-developed horizons of sedimentary gneisses are found to alternate with bands of hornblende schist. These increase in both number and thickness to the north so that, within a short distance, the series gives way to one in which the principal ferromagnesian mineral is biotite. Four principal varieties of sedimentary gneisses have been recognized. They are biotite gneiss, quartz-oligoclase-biotite gneiss, quartzite, and quartz-microcline gneiss.

In view of the evidence presented by petrologists to the effect that clay minerals combine to form chlorite and sericite, and that these in turn combine to form biotite during metamorphism², it is thought that the biotite gneiss, the quartz-

2. Harker, Alfred, "Metamorphism, A Study of the Transformations of Rock Masses," Methuen & Co., Ltd., London, 11, 45-61, 1950.

oligoclase-biotite gneiss, the quartzite, and the quartz-microcline gneiss are the altered equivalents of shale, argillaceous sandstone, quartz sandstone, and arkose, respectively.

Amphibole-Biotite Gneiss: In many places throughout the series the sedimentary gneisses are found to be interrupted by lenticular masses of amphibole-biotite gneiss of dark colour, coarse to very coarse granularity, and striking appearance. This rock is made up largely of anthophyllite, hornblende, and biotite, with small amounts of quartz, oligoclase, and magnetite. Red garnets are also commonly present. They occur as large porphyroblasts, ranging from about one-half inch to two inches or more in diameter, and in places make up 25 percent of the rock mass. The amphibole-biotite gneiss is frequently found to grade, by disappearance of amphibole and, when present, also of garnet, into typical biotite gneiss. Because of this it is considered to be sedimentary origin - it may represent the highly metamorphosed equivalent of a calcareous, chloritic grit or basic tuffaceous sediment that was developed at the same time as the enclosing rocks. It is included with the sedimentary gneiss on the generalized geological map.

Iron Formation: Commonly intimately associated with the amphibole-biotite gneiss is a peculiar banded rock. This banded rock consists of layers of coarse-grained quartz, from a fraction of an inch to a foot or more in thickness, alternating with equally thin or thinner layers of one or more of amphibole schist, garnetiferous amphibole-biotite schist, and a very coarse amphibolite. In the field it has been variously termed quartz-chlorite rock, quartz-amphibole rock, quartz-amphibole-pyroxene rock, and iron formation. Since the rock is distinctly banded, since the schist or amphibolite layers contain disseminated crystals and thin seams of fine granular magnetite, since individual horizons can be traced by dip needle and magnetometer, and since these horizons are very persistent and follow the folded pattern of the sedimentary gneisses, it is thought that "iron formation" is the most appropriate term.

Post-Early Archaean (Algoman?)

Basic Meta-intrusives: Small lenticular bodies of metagabbro are found in a number of places within or close to the belt of volcanic rocks. These bodies have intrusive relations with the Early Archaean formations, but are themselves cut by granite and pegmatite. For the most part they consist of a medium- to coarse-grained rock made up of about equal amounts of dark-green horn-

blende and plagioclase, with small amounts of biotite, quartz, and magnetite. This rock is generally quite massive in the outcrop.

Granitic Rocks: The most abundant igneous rock found in the Manitouwadge Lake area is biotite granite gneiss. Together with massive granite, migmatite, and pegmatite, it occurs in three principal localities: (1) the extreme southeast corner of the area; (2) the extreme northwest corner; and (3) the whole of the northeast quarter. The granitic rocks to the northwest and southeast are believed to represent a single large mass, in which the Early-Archaeon rocks form a deeply infolded inclusion; those in the northeast quarter of the area are believed to represent a satellite of the main mass, which has been localized along the major synclinal axis (see Structural Geology).

Associated with the granite gneiss, migmatite, and the medium-grained, massive, intrusive biotite granite, and cutting the Early-Archaeon formations, are dikes and sills of pegmatite and aplite. The pegmatite is of three ages. It occurs as: (1) dikes which cut metagabbro inclusions in, and which are themselves truncated by, the massive biotite granite; (2) irregular bodies which grade into, and hence represent a phase of, the massive biotite granite; and (3) dikes, which cut the massive biotite granite. Some of the pegmatites are pre-ore in age, and on the properties of Geco Mines, Limited, and Willroy Mines, Limited, they were instrumental in the localization of the ore deposits.

Algonkian

The youngest rock exposed is diabase. The diabase forms a number of narrow, but fairly persistent north-south dikes, some of which are localized along transverse faults (see Fig. 2). In that these dikes cut sharply across all the other consolidated rocks, including the various granitic rocks, it is thought that they are of Algonkian or Late Precambrian age. It is possible that they could be correlated with similar rocks of Keweenawan age, that crop out to the west of the area in the vicinity of Lake Nipigon.

Structural Geology

Folding: The rock type described as iron formation is the only one that occurs in sufficiently distinct and persistent horizons to be useful in outlining the structural geology. Examination of the generalized geological map of the area shows that, in the vicinity of Wowun Lake on the east, the iron formation and the gneisses strike southwest and dip vertically to steeply north. Proceeding westward to Fox Creek and the Geco mine, however, the formations assume an east-west strike; and still farther west, midway between Fox and Nama Creeks, they strike northwest and dip 50°N. Finally, at the west side of the map area, the formations assume first a northerly strike and then double back on themselves to strike northeast again. They delineate a large trough or synclinal fold, which dip measurements indicate to be asymmetrical and overturned to the north. Other dip measurements, at the nose of the fold, indicate a plunge to the northeast of from 15 to 25 degrees. In the eastern part of the area, lineation and drag folds indicate a steeper plunge of about 40 degrees.

Faulting: After the major folding, the Manitouwadge Lake area suffered a series of disturbances that resulted in the development of a large number of faults. These faults are of three types: (1) Longitudinal or strike faults, which more or less parallel the formations along the south limb of the syncline; (2) transverse faults, which strike in a general north-south direction; and (3) diagonal faults, which strike northwest, obliquely to the other faults. All are represented in the field by deep linear depressions in the topography.

An example of a major strike fault is the Agam Lake fault, which strikes due west, from north of Manitouwadge to almost the west boundary of the map area, just north of and roughly parallel to the belt of volcanic rocks. This fault is pre-ore in age, and is represented by a wide zone of graphitic schist, in places mineralized with pyrite and pyrrhotite. The magnitude and direction of movement along this break have not been determined. However, the fault appears to truncate a number of pre-ore, right-hand transverse faults, and at the same time, appears to be terminated by the north-south, post-ore, left-hand Fox Creek fault.

At least three periods of movement are thus indicated. A possible fourth period of disturbance may be responsible for the fault that extends diagonally across the area from northwest to southeast. In regard to this fault, the offsets shown by the rock formations are of interest. In the northwest section of the area, the formations dip rather flatly to the southeast. Here the displacement was lefthand, or east side to the north. In the

southeast section of the area, the formations dip about 65° to the northwest. Here the displacement was right-hand, or east side to the south. To the east of the Geco mine, the formations dip vertically. Here the formations have been traced across the fault to Wowun Lake without any apparent offset. Such anomalous conditions can be explained satisfactorily by assuming that the displacement along the fault was mainly vertical, and that the relative movement was up on the west side. South of Mose Lake, a diabase dike was localized along this diagonal fault. But the diabase has been brecciated. Further, north of the Geco mine, the fault cuts and offsets two diabase dikes. In view of these facts and the simple vertical displacement indicated, it is thought that the two or more movements represented occurred in Lake Precambrian time.

Mineral Deposits

All the important mineral deposits discovered to date are sulphide replacement bodies. Their locations are shown in Fig. 2. They strike and dip parallel to the formations that contain them, and have been found in or closely associated with either iron formation or a variety of sedimentary rocks. A determination of the lead isotope ratios of a sample of galena, from one of the occurrences, by mass spectrometer is reported by J. T. Wilson of the University of Toronto to indicate an age of $2,600 \pm 120$ million years.³ According to Wilson, the indicated age is close to that of leads found in the Golden Manitou and Barvue deposits in Quebec and the gold ores of Timmins in Ontario. The lead from Manitouwadge Lake, and those from the other deposits, are all much older than the Sudbury nickel-copper ores, which are believed to have been formed in Late Precambrian time. In view of this, it is reasonable to assume that the ore minerals were deposited during the period of granitic intrusion, and that they are of Late Archaean or Algoman age.

Deposits in Iron Formation: Sulphide replacement deposits in iron formation have been found on the properties of Lun-Echo Gold Mines, Limited* about the nose of the Manitouwadge syncline, and Willroy Mines, Limited, on the south limb of the syncline.

As mentioned previously, the iron formation is a banded rock, in which layers of quartz alternate with layers of amphibole schist, garnetiferous amphibole schist, or coarse-grained amphibolite. In

3. Wilson, J. T., personal correspondence.

* Two miles northwest of Nama Creek.

the replacement deposits found in this rock, the metallic sulphides heal fractures in the quartz and occur as either masses or disseminated crystals and grains replacing the minerals of the schist or amphibolite layers. Where massive replacement has occurred, the deposit is a strikingly banded one, in which layers of sulphides alternate with layers of mineralized quartz. On the other hand, where disseminated replacement has occurred, the sulphides appear to be localized along planes of foliation, which they accentuate.

The principal sulphide present is pyrrhotite. It is invariably accompanied by considerable pyrite, subordinate amounts of sphalerite and chalcopyrite, and in some case also by galena. The replacement deposits in iron formation may thus contain values in copper, lead, and zinc. Silver is also usually present, and adds to the over-all value. Some of the deposits tend to be lenticular and of small extent. On the Lun-Echo property, for example, three of them have been thoroughly tested by diamond drilling. In each, commercial grade material, across widths up to and exceeding 25 feet, was indicated. But none of the deposits was found to have a length greater than 500 feet, and each of the three was found to decrease in width and grade with depth. In contrast to the Lun-Echo occurrences, two deposits, located on the Willroy property, appear to be sufficiently rich and large to make ore. These are known as the No. 2 and No. 3 ore zones. At the present time (1956) a vertical 4-compartment shaft is being sunk as a prelude to their underground development.

Geco Ore Body

The Geco ore body is exposed about 600 feet south and 1800 feet east of the Willroy No. 1 zone, and from here extends eastward for a horizontal length of 2,650 feet. Like the Willroy No. 1 zone, it lies within the horizon of highly sericitized quartz-feldspar-biotite gneiss, which is bordered on the north by garnetiferous amphibole-biotite gneiss and biotite granite, and on the south by quartzite. It is a lode fissure rather than a simple disseminated replacement deposit. As shown in Fig. 3, it can be divided conveniently into three sections: the West, Central, and East.

The West section of the ore body lies west of Fox Creek. It has a length of 1,200 feet at the surface, ranges up to 220 feet in thickness, and rakes to the east at about 40 degrees. In part it is in every respect similar to the Willroy No. 1 zone, and consists of highly sericitized gneiss mineralized with metallic sulphides, chiefly pyrite and chalcopyrite, and cut by occasional quartz stringers. But here the sulphides replace the

host rock outward from a narrow, tabular core of massive ore made up of pyrite and sphalerite, with considerable pyrrhotite but relatively small amounts of chalcopyrite. This core occurs near the south wall of the ore body, within a few feet of the sericitized gneiss-quartzite contact. It decreases in width and tends to pinch out both to the west and with depth.

To the east, the West section is cut off sharply by the Fox Creek fault, so that east of the creek, the extension of the ore body lies approximately 250 feet to the north. This extension, or Central section, extends eastward from the fault for a distance of 850 feet, to a point where it is truncated sharply by a zone of north-south diabase dikes. Near the surface the middle section has an average width of 58 feet. Like the West section, it consists of a core of massive sulphides, chiefly pyrite and sphalerite. This is enclosed by an envelope of iron, copper, and subordinate zinc sulphides disseminated throughout sericitized gneiss. But here the core is much wider than in the West section, and the envelope of disseminated material is narrower and, in places, below ore standards. Near the surface, the ore of the Central section is thus rich in zinc but poor in copper. With depth the core of the ore body decreases in width and tends to tongue out, whereas the bordering disseminated ore increases in width and grade. The net result of this is a gradual transition from a high-grade zinc and low-grade copper ore near the surface, to a high-grade copper and low-grade zinc ore at depth. This deep ore, rich in copper but containing low values in zinc, is identical in character to that found in the West section of the ore body, and there is little doubt that it represents the eastward extension of the West section down the general rake of the ore body.

As mentioned above, the Middle section of the ore body is truncated by a zone of north-south diabase dikes. The East section of the ore body lies east of these dikes and extends for a horizontal length of about 600 feet near the surface. It is identical to the central section in character, except for three features: (1) both the core of massive sulphides and the envelope of disseminated ore are narrower and tongue out eastward; (2) the core of massive sulphides attains its maximum thickness of about 50 feet at a depth below the surface of 700 feet, and pinches out upwards; and (3) at the east margin of the zone of diabase dikes, the core is represented by massive pyrrhotite and pyrite, and sphalerite does not become an important constituent until a depth of about 500 feet is reached. The East section, at or close to the present erosion surface, thus represents the upper limit of the east-raking ore body.

The Geco ore body has been tested by diamond drilling to a vertical depth of 1,300 feet. To this depth, the three sections are estimated to contain 15,227,251 tons of ore having an average

grade of 1.76 percent copper, 3.48 percent zinc, and 1.77 ounces of silver per ton.⁶

Mineralization and Paragenesis

The principal ore minerals in all the known deposits are chalcopyrite and sphalerite. Galena is often also present, and is particularly prominent in the Willroy No. 2 ore zone, but nowhere does it occur in sufficient quantity to be of economic importance. Silver is present in every deposit. It has not been recognized as such. Assaying of samples from the Geco ore body indicates that high values in copper are usually accompanied by high values in silver, and the thought has been expressed that the silver is present in solid solution in the chalcopyrite.⁷ A qualitative spectrographic analysis of chalcopyrite from the Geco ore body indicated the presence of tin, which may also prove to be of economic importance.⁸

Associated with ore minerals in all the deposits are quartz, in small veinlets, pyrite, and pyrrhotite. Small amounts of cubanite and marcasite have been found. The paragenesis, as given by Langford⁹ for the Geco occurrence, is as follows:

- (1) formation of pyrite;
- (2) fracturing and introduction of quartz;
- (3) formation of pyrrhotite;
- (4) formation of chalcopyrite, overlapped in part and followed by;
- (5) formation of sphalerite; and
- (6) formation of galena.

The presence of ex-solution textures of sphalerite in chalcopyrite and of chalcopyrite in sphalerite indicates that the Geco ore minerals were formed at high temperatures, and that the deposit, according to Lindgren's¹⁰ classification, is of

6. The Northern Miner, April 5, 1965, p. 41.

7. Langford, F. F., "Geology of the Geco Mine in the Manitouwadge Area, District of Thunder Bay," Unpubl. M.A. thesis, Queen's University, Kingston, Ontario, 1955.

8. Op. cit.

9. Op. cit.

10. Lindgren, W., "Mineral Deposits," McGraw-Hill Book Co., Inc., New York, 1933.

hypothermal type.¹¹ This conclusion follows from the work of Buerger,¹² who points out that chalcopyrite unmixes from sphalerite at temperatures of 350 to 400°C, and from the work of Edwards,¹³ who states that sphalerite unmixes from chalcopyrite at temperatures of 500 to 600 C.

Structural Controls of Ore Deposition

One of the most interesting aspects of geological survey work is speculation as to the reasons why ore deposits are where they are after the ore deposits have been discovered and partly developed. Such speculation, in the hope that it may prove useful to further exploration, will constitute the balance of this paper. The structural controls of ore deposition in the Manitouwadge Lake area may be considered under two headings: Major controls, and minor controls.

Major Controls

The major controls over the deposition of the ores were the folded structures and certain pre-ore faults.

Folded Structures: In regard to the folded structures, dip determinations, and measurements of lineation made apparent by the parallel alignment of elongate biotite flakes and prismatic crystals of amphibole, indicate a regional plunge of the formations to the northeast. This plunge ranges from 15-25° in the west section of the area to about 40° in the east section. Of interest is the fact that the rake of all the known ore bodies or mineralized zones, and in the case of the Geco ore body, also of the zonal arrangement of sulphides, is in the same direction and at the same angle as the plunge of the formations.

Pre-Ore Faults: One of the most interesting features of the area is the localization of the Geco and Willroy No. 1 ore bodies along a very persistent horizon of sericitized quartz-feldspar-biotite gneiss. At the Geco mine, this horizon is cut by north-south dikes of pegmatite, which are terminated abruptly

11. Langford, F. F., op cit.

12. Buerger, M. W., "Unmixing of Chalcopyrite from Sphalerite," Am. Mineral., Vol. 25, pp. 534-538, 1934.

13. Edwards, A. B., "Textures of the Ore Minerals," Aust. Inst. of Min. and Met., Melbourne, Australia, 1947.

by the massive sulphide core of the ore body and do not appear in expected positions on the other side of the core. This indicates that the massive sulphides were localized in a fault zone, and that this zone served as a channelway, along which the hydrothermal solutions, that effected the sericitization of the gneiss and the deposition of the ore minerals, actually migrated.

At first consideration, it would appear that this fault zone, which is post-pegmatite in age, was developed after the formation of the major syncline. But the horizon of sericitized gneiss has been traced continuously across the area for a distance of 4 miles, and throughout this length it is everywhere conformable to the folded unaltered sediments enclosing it. Because of this, and because the alteration indicates the presence of a continuous channelway during the epoch of mineralization, it is concluded that the sericitized gneiss represents a bedding fault that was deformed with the other rock formations during the regional folding.

The other ore bodies or mineralized zones in the area do not occur along persistent horizons of altered rock. Nevertheless, it is thought that they also may have been localized along folded bedding faults - faults that were of limited lateral extent and and were formed as parallel structures merely subsidiary to the "break" represented by the sericitized gneiss. In this regard, it is to be noted that mineralized zones containing pyrite and pyrrhotite have been found in numerous localities throughout the area, but that it is only close to the horizon of sericitized gneiss that such zones contain any significant amounts of copper, zinc, or silver.

Minor Controls

The minor features which are known to have exerted some influence in the localization of the ore bodies are: (1) intrusive-sediments contacts; (2) local curves or bends in the formations; and (3) the presence of flat-lying bodies of granite pegmatite.

Intrusive-Sediments Contacts: Examination of Fig. 3 shows that the Geco ore body lies within sericitized gneiss, which is bordered to the north by biotite granite and by garnetiferous amphibole-biotite gneiss. Where the sericitized gneiss is bordered by the granite, the best widths and values in copper have been found. On the other hand, where it is bordered by the garnetiferous amphibole-biotite gneiss, both to the west and to the east, the widths and metallic content decrease, and even the sericitic alteration becomes weak. It would thus appear that the contact, between the granite and the sericitized gneiss, localized the structural adjustments that provided the open spaces necessary for the migration of the ore-forming fluids and the deposition of the metallic sulphides.

A second example, illustrating the effect of intrusive-sediments contacts on the localization of ore, is found in the Willroy No. 3 zone. Here the mineralization lies in a band of iron formation. This iron formation, and the sulphide mineralization within it, have been traced for 2,300 feet. But the zone only attains ore grade where, over a length of 1,200 feet, the iron formation is bordered along its footwall side by a narrow, sill like body of pegmatite.

Local Curves or Bends in the Formations: A second minor but nevertheless important control over the localization of the ore bodies was the presence of local curves or bends in the formations. As shown in Fig. 3, the formations in the vicinity of the Geco ore body strike roughly east-west for a considerable distance, and dip vertically to steeply south. Near the west boundary of the area represented however, the horizon of sericitized gneiss assumes a strike of N. 55° W. and a dip of 65° to 75° N.E. The ore body occurs where the sericitized gneiss strikes east-west and has a vertical or near-vertical dip. Similar conditions are found on the Willroy property. Here there are three ore bodies, all of which trend roughly east-west, and all of which terminate westward at points where their respective host rocks curve sharply to assume northwest strikes and flatter dips.

The reason for the localization of the four ore bodies, along the east-west portions of their favourable host rocks, close to points of deflection in attitude, is found at the Geco mine. It was mentioned previously that the massive sulphide core of the ore body is localized along a fault zone which truncates bodies of pegmatite. In the sericitized gneiss adjacent to the massive sulphides numerous drag folds have been mapped. These drag folds are of two types: one type is "Z" - shaped in plan and is compatible with the major Manitouwadge syncline; the other type is "S" - shaped in plan and hence is a "reverse" structure incompatible with the major field. Such "reverse" drag folds have been found only in the horizon of sericitized gneiss, and it is logical to assume that they are expressions of the movement which culminated in the post-pegmatite faulting. They plunge at about 40° E., and indicate that the block of ground north of the fault moved down and to the west. A relative displacement of this type would result in the development of favourable open spaces along the steep-dipping portions of the fault zone. Thus, as pointed out by Newhouse,¹⁴ if one portion of a fracture surface dips steeply, and the other portion has a lower angle of dip, and if the hanging wall moves relatively down, the hanging wall will ride on the flat-dipping portion as a supporting surface. This will separate the hanging wall from a footwall along the steeply-dipping portion of the fracture surface to form an opening.

14. Newhouse, W. H., "Structural Feature Associated with Ore Deposits," in *Ore Deposits as Related to Structural Features*, Princeton University Princeton, N. J., p. 17, 1942.

Presence of Flat-Lying Bodies of Pegmatite: The third minor control over the localization of the ore bodies in the area was the presence of small, flat-lying bodies of pegmatite extending across horizons of favourable host-rocks. At the Geco mine, the north-south pegmatites that are truncated by the massive sulphide core dip at flat angles, in places eastward, in other places westward. These pegmatites are typically massive, pink, unaltered varieties. But, within a foot or two of their contacts, they are somewhat sericitized, and display fractures healed by metallic sulphides. According to Walter Clarke, chief geologist at Geco Mine, Limited, the disseminated ore in the sericitized gneiss tends to improve in grade as the contacts of these flat-lying bodies are approached. Similar pre-ore pegmatites cut across the ore zone at the Willroy No. 1 ore body. As each of the two pegmatites are approached from below, an increase in the width and/or grade of the ore body is apparent. Because of this it is thought that the flat-lying pegmatites served as relatively impermeable barriers, which inhibited the migration of the ore-forming fluids and thus effected sulphide deposition in the sericitized gneiss at or close to their contacts.

Conclusions

Exploration and development work at the various properties permits tentative acceptance of certain valuable conclusions about the mineralization in the area. These facts are as follows:

- (1) The mineral deposits are of Archaean age and may be related genetically to the granitic rocks.
- (2) All the known mineral deposits are replacement deposits, either disseminated or lode fissure in character, and occur in either iron formation or sedimentary gneiss.
- (3) The mineral deposits were formed at high temperatures, and may be considered as representative of Lindgren's hypothermal class.
- (4) The deposits are controlled in their attitudes by the major folded structures, and rake flatly eastward parallel to lineations.
- (5) They lie within a pre-ore folded fault zone that is represented in the field by a persistent horizon of sericitized quartz-oligoclase-biotite gneiss, or they lie within small, parallel structures close to the horizon of sericitized gneiss.
- (6) All the important ore bodies are found where the formations strike roughly east-west, and adjacent to the east of places where those formations curve sharply to assume a northwest strike and relatively flat dips to the north.
- (7) Two ore bodies, the Geco and the Willroy No. 3, are localized along the contacts between granite or pegmatite and their respective favourable host rocks.
- (8) In two cases, at the Geco mine and in the Willroy No. 1 ore body, flat bodies of pegmatite served as relatively impermeable barriers, which inhibited the migration of the ore-forming fluids

and effected a sulphide deposition in the host rock at or close to their contacts. It is of interest to note that in several localities in the area, the horizon of sericitized gneiss has been found to disappear beneath outcrops of flat-lying pegmatites. Such occur at west end of the Geco ore body, in the extreme northwest corner of the Willroy property, and again between the Nama Creek and Lun-Echo properties. In each of these places favourable ore structures may exist. But it seems unlikely that sulphide bodies can be located beneath the pegmatites by geophysical methods. Rather, it is concluded that successful exploration will necessitate detailed geological mapping, to determine the approximate location and trend of the sericitized gneiss beneath the pegmatites, followed by expensive diamond drilling.

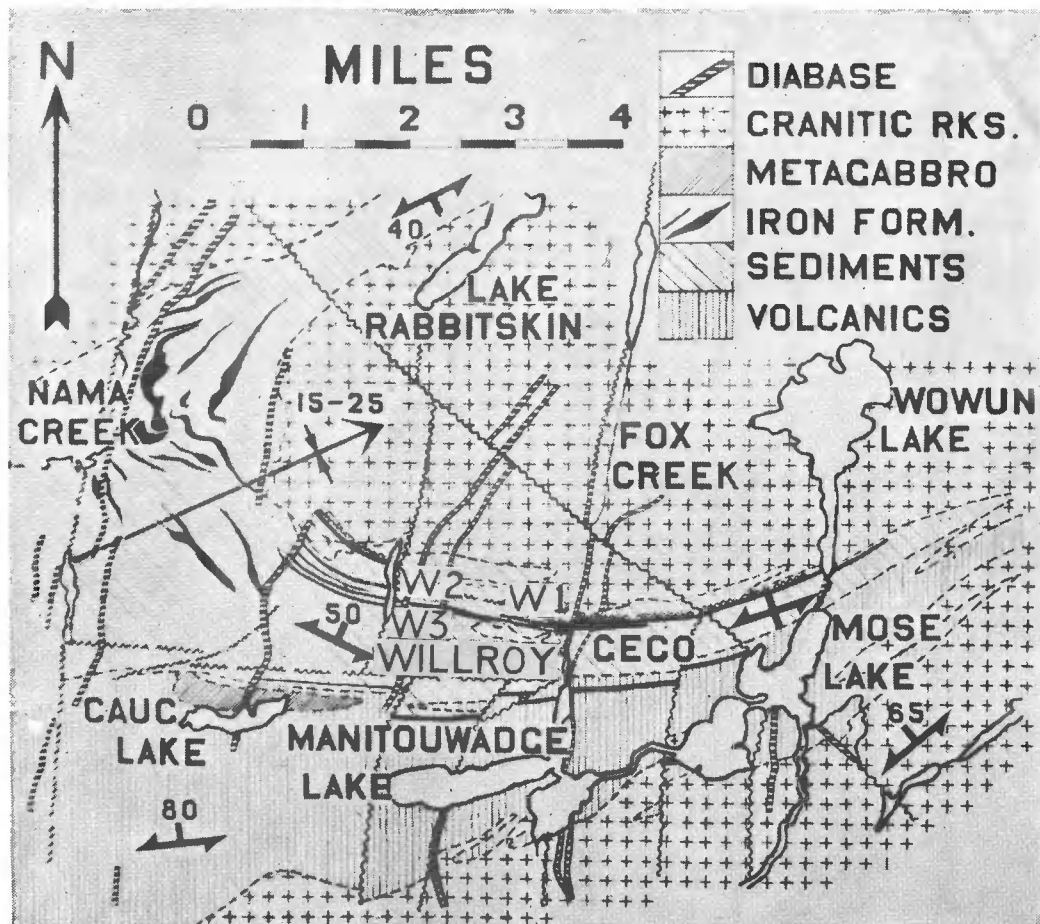


Fig. 2. Generalized geological map of the Manitowadge Lake area.

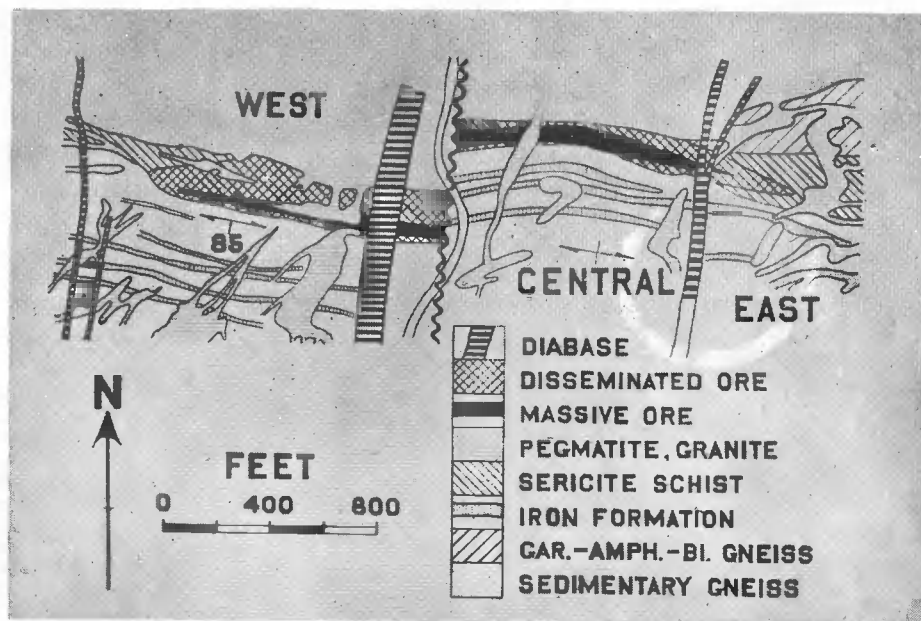


Fig. 3. Surface plan showing generalized geology in the vicinity of the Geco ore body (modified after company plans).

TOUR LOG*

MANITOUWADGE TO SAULT STE. MARIE

The rocks of the region are all Precambrian, ranging in age from Keewatin to Keweenawan.

Mileage

- 0.0 Manitouwadge. Route 614.
- 35.5 Hemlo. Junction Trans-Canada Highway 17, turn east.
- 37.1 STOP 1 Rock cut on N side of road in a gray quartz monzonite gneiss with abundant undigested amphibolitic inclusions. Strong jointing. Glacial grooves and polish.

The dominant rock type at this stop has the composition of a quartz monzonite. Quartz, orthoclase and microcline, sodic andesine, hornblende and biotite are the major minerals. The plagioclase occurs as prophyroblasts with crenulated margins. Orthoclase is found as anhedral grains often intergrown with microcline. Quartz forms in elongated pods or is interstitial and intergrown with feldspars. Myrmekitic intergrowths are common along plagioclase boundaries. Accessory minerals are large euhedral and anhedral grains of dark brown sphene, apatite, zircon and magnetite. Alteration products are pennine, epidote, and sericite.

The dark inclusions in the quartz monzonite are distinctly schistose in thin-section. Dark minerals are hornblende and chloritized biotite. A mosaic of sericitized, untwinned sodic andesine forms the groundmass of the subaligned mafics. Rounded grains of quartz are evenly distributed throughout the section. Unaltered poikilitic microcline porphyroblasts are quite common. Epidote, allanite, sphene, apatite, and magnetite are the minor constituents.

- 67.7 White River. Canadian Pacific Railways divisional point. Scattered outcrops of metasedimentary rocks enroute.
- 105.7 STOP 2 Good exposures of massive quartz diorite in contact with sericitic schist and gneiss. Granite pegmatite and diabase dikes. The route now crosses several infolded belts of Keewatin and Temiskaming metasedimentary and metavolcanic rocks.

*From "Geology of the Lake Superior Region", National Science Foundation, Fourth Summer Conference for Geology Teachers, Michigan Technological University, June, 1965. James M. Neilson, Conference Director; Joseph P. Dobell, Associate Director (who is also responsible for petrographic descriptions). Reproduced by permission.

MileageSTOP 2, cont'd.

Meta-rhyolite. In a thin section of the distinctly schistose "meta-rhyolite" the major minerals, in order of abundance, are quartz, orthoclase, muscovite, biotite, and epidote. Orthoclase occurs as scattered large subhedral crystals and in intergranular positions throughout the rock. It also occurs with quartz in the pink lenses so prominent in hand specimens. The single thin section examined provided no convincing evidence that the rock is a metavolcanic.

- 118.3 Rock cuts in phyllitic sericite schist south of Catfish Lake.
- 119.3 STOP 3 Outcrops of Dore Conglomerate and lineated rhyolite breccia. Dore Conglomerate. The matrix of the Dore conglomerate in this area is a quartz mica schist. Biotite is more abundant than muscovite. Numerous oligoclase crystals look like original clastic fragments. An altered pebble of granite is elongated parallel to the schistosity and sheathed with biotite. Feldspars in the pebble have been fractured and are separated by fine grained feldspar or bands of quartz.
- 123.5 Magpie River, incised in glacial sandplain.
- 124.5 Wawa intersection. Continue on Highway 17.
- 128.0 Road intersection. Road to right leads to Michipicoten Harbour; continue on Highway 17, to left.
- 128.8 Michipicoten River.
- 140.3 Old Woman River and Lake Superior to the west.
- 146.7 Rock cut at Red Rocks Lake.
- 157.5 STOP 4 Outcrops of amphibolite, biotite-chlorite schist, pillow lavas (?) etc.

A thin section of the amphibolite prominent at this stop was examined. About 65% of the rock consists of pale green hornblende, 25% is andesine and 5 to 7% is biotite. Minor constituents are quartz, pyrrhotite, pyrite, sphene, hematite and chlorite. The chlorite is restricted to fracture zones.

- 166.2 Coldwater River.
- 170.3 Sand River.
- 177.3 STOP 5 Agawa Bay scenic lookout. A series of large rock cuts with good exposures will be seen for the next seven miles. Quartz monzonite and other rock types.

Mileage

At this stop a distinctly sheeted white rock of quartz monzonitic composition predominates. A point-count modal analysis indicates that microcline comprises 35% of the rock, oligoclase 34%, quartz 29% and micas less than 1%. The texture is granular and seriate. Rounded grains of quartz occur as inclusions in turbid oligoclase and a second generation of quartz partially replaces the oligoclase. Biotite, now much altered to chlorite, was probably contemporaneous with the oligoclase. The clear rims of albite which occur on most of the oligoclase grains appears to be earlier than the second generation of quartz. Microcline and muscovite, in this order, are the last minerals to form. A few grains of garnet, partially altered to chlorite, and zircon are present.

Gradational with the quartz monzoite is a coarser grained light pink granite phase. In this rock quartz and microcline are the major minerals. Oligoclase grains have been partially altered to sericite and frequently have clear albite rims. Chloritized biotite and a few flakes of muscovite are present.

A third rock type noted at this stop occurs as inclusions of tightly folded micaschist. The chevron folding is marked in hand specimen by thin quartz bands and in thin section by biotite which forms good polygonal arcs. About 20% of the rock is biotite, 45% quartz and 30% orthoclase. Zircon, magnetite and apatite are minor accessories.

178.2 Agawa River.

180.4 Agawa Bay campground in Lake Superior Provincial Park.

189.1 Ranwick Uranium "tourist" mine.

190.7 Note stratification in glacial gravels on left.

191.7 STOP 6 Montreal River. Gorge was created by erosion of columnar-jointed basalt dikes intruding granite gneiss.

This very fine-grained rock shows no alteration except the chlorite on slickensided joint surfaces. Fresh laths of labradorite surround rounded grains of augite and pigeonite in a typical diabasic fabric. Magnetite and apatite are the minor accessories.

193.9 Elevated Glacial Lake Algonquin cobblestone beach about 200 feet above present lake levels.

198.4 Alona Bay Lookout. Granite gneiss exposed in cut.

203.4 Extensive road cuts in Archean rocks.

207.4 STOP 7 Mamainse Bay on Lake Superior. Contact of Keweenawan amygdaloidal basalts and granite boulder conglomerate. The flows and beds parallel the shore and dip to the west under Lake Superior.

Mileage

Amygdaloidal basalt. Laths of partially albitized calcic plagioclase indicate an original diabasic texture. Pyroxenes have altered to chlorite and "limonite". Magnetite is abundant. Two types of amygdules are present. In one type the wall of the cavity is lined with a thin band of carbonate which is followed by wider bands of a chlorite and a center filling of carbonate.

In the second type there may be several concentric bands of carbonate separated by chlorite or by chalcedony zones and the center filling is chalcedony.

In hand specimen, the chalcedony is a pinkish white color and calcite is pink to light red to faintly greenish in color.

214.4 Keweenaw basaltic flows are much in evidence along the highway in this area.

226.3 Batchawana River.

232.3 STOP 8 Chippewa River. Xenolithic inclusion of diabase in granitic gneiss at falls.

Gneiss. The gneiss is the major rock type at this stop. Dark bands in this rock consist dominantly of actinolite, chlorite, epidote and albite together with small amounts of quartz, carbonate, sphene and apatite.

Light colored bands are quartz and orthoclase together with small amounts of oligoclase. The feldspars are turbid with alteration products. Acicular clusters of actinolite and rounded grains of epidote and sphene are present and some chlorite was noted. The opaque minerals are limonite-stained pyrite and magnetite.

242.5 Batchawana Bay. Rock cut. Rough road for 5 miles.

254.9 Goulais River.

262.0 STOP 9 Rock cut. Altered diabase dike cutting granitic gneiss; note crushing in contact zones. Lamprophyre near south contact.

In this dike the diabasic texture is fairly well preserved. The pyroxene (augite) is altered to amphibole along the margins of crystals and the plagioclase (An₆₅) is partially or completely altered to an aggregate of sericite, epidote group minerals, and carbonate. Minor constituents are magnetite, biotite, chlorite and sphene.

272.4 Sault Ste. Marie, Ontario

THE RELATIONSHIP OF MINERALIZATION TO THE
PRECAMBRIAN STRATIGRAPHY, BLIND RIVER AREA, ONTARIO*

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6. Distribution of copper deposits relative to Nipissing diabase.

ABSTRACT

This paper is a result of a continuing investigation, begun in 1953, by government geologists and mining companies. The Archean rocks are Keewatin greenstones intruded by Algoman granites for which the geological age has been determined as about 2,500 million years. These granitic rocks consist of gneissic granodiorites and massive, slightly radioactive quartz monzonite. The Archean complex was eroded to a peneplain with valleys in the less resistant rock types. The Lower Huronian consists of the Lower Mississagi Formation, the Middle Mississagi Formation, the Upper Mississagi Formation, the Bruce Conglomerate, the Espanola Formation, and the Serpent Formation. These formations contain a great variety of sedimentary rocks such as conglomerate, argillite, siltstone, greywacke, limestone, and quartzite. Thickness and facies changes indicate a northwesterly source, northerly overlap, and deposition in shallow water controlled by basement topography. The Lower Huronian formations unconformably overlie the Archean rocks and in turn are unconformably overlain by the Middle Huronian formations. The Middle Huronian rocks consist of the Gowganda and Lorrain formations of conglomerate, greywacke, quartzite, and arkose. There are three phases of post-Huronian igneous activity: (1) dikes and sills of Nipissing diabase; (2) the Cutler granite; and (3) dikes of olivine diabase.

Age dating methods give the age of the Nipissing diabase as 2,130 million years, and the granite at Cutler as 1,750 million years (Penokean orogeny). A few dikes of Keweenawan olivine diabase are tentatively dated at 1,100 million years.

Copper mineralization is associated with the Nipissing diabase. Uranium ores in quartz-pebble conglomerates, near the base of the Lower Mississagi Formation, are generally considered to be placer deposits modified by later events. Uranium production from the Blind River mining camp to the end of 1962 was valued at \$944,373,250. This was derived from 44,937,871 tons of ore grading approximately 0.1 percent U_3O_8 .

INTRODUCTION

This paper is a discussion of the Precambrian rocks and mineralization in the Blind River - Elliot Lake area of Ontario (Fig. 1).^{*} Blind River is located on the north shore of Lake Huron half way between Sudbury and Sault Ste. Marie. The town of Elliot Lake (Fig. 2) lies 20 miles northeast of Blind River. The area is served by the Canadian Pacific railway, the Trans-Canada highway and by other roads.

Early geological mapping was carried out by Logan and Murray following the discovery of copper at Bruce Mines in 1846 (Logan 1863, Chap. 4). Later mapping was carried out by W. H. Collins in 1915 (Collins 1925). In 1953 uranium was discovered in the district which subsequently became Canada's chief source of uranium. Since 1953 extensive geological work has been carried out by the Ontario Department of Mines, the Geological Survey of Canada, mining companies, and interested individuals. The Ontario Department of Mines has been responsible for regional mapping; this was carried out by E. M. Abraham in 1953-1956 (Abraham 1953, 1957) and has been continued by the writer since 1957 (Robertson, J. A. 1960 *et seq.*) J. P. McDowell (1957, 1963) investigated the sedimentary features of the host rocks of the uranium mineralization.

ACKNOWLEDGMENTS

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* See instead map on inside back cover for location.

GENERAL GEOLOGY

The bedrock of the area falls into three broad units, the distribution of which is shown on Fig. 2. These are: (1) the Archean basement consisting of Algoman granite and Keewatin-type greenstone; (2) the Huronian sedimentary rocks made up of the Bruce Group and the Cobalt Group and (3) the Post-Huronian intrusive rocks comprising the Nipissing diabase, the Cutler granite, and olivine diabase believed to be Keweenawan in age (only the Cutler granite is shown in Fig. 2).

The structure is also illustrated on Fig. 2. In the north is the Quirke syncline and in the south the Chiblow anticline, the south limb of which is repeated by a major east-striking fault - the Murray Fault. The fold axes strike slightly north of west and plunge gently west giving the sedimentary units a reverse-S shaped outcrop. Bedding-plane slips, thrust faults, and near-vertical faults which strike either northwest or parallel to the axial planes of the folds are common. The fault pattern, jointing, dragfolds, and other structural features suggest a north-south compression formed the folds.

Figure 3 is a Table of Formations giving more detail than it is possible to show on Fig. 2. It has been Department policy to retain Collins' nomenclature making modifications only where necessary. S. M. Roscoe (1957) and P. J. Pienaar (1963) of the Geological Survey of Canada have introduced a nomenclature using local names. The differences are in names rather than in ideas.

The Keewatin-type rocks underlie the eastern portion of the Quirke syncline and are exposed to the southeast of the syncline. The rock-types found include massive and pillow lavas, pyroclastic rocks, and sedimentary rocks including lean iron formation. Strike is northwest and dips generally steep northeast. Metamorphism is of chlorite facies rising to amphibolite in hybrid zones close to contacts with the Algoman granite.

Granitic rocks of Algoman age (2,500 million years; Fairbairn, Lowdon, Van Schmus et al 1963) from approximately half the area shown on Fig. 2. These granitic rocks may be divided into two broad groups: (1) medium- to coarse-grained, gneissic to massive granodiorite, generally grey to pink in colour with abundant inclusions derived from the Keewatin, and (2) massive red quartz monzonite generally without inclusions and slightly radioactive. A body of the second type is found in the Quirke Lake area.

The Huronian sedimentary rocks lie unconformably on the Algoman-Keewatin complex. A topographic low was developed over the greenstone belt, with local ridges controlled by the harder members (Fig. 5). Remnants of pre-Huronian soils are preserved particularly over the granitic rocks. The present chemical constitution of these soils suggests that they were formed under reducing conditions.

The Lower Mississagi Formation contains the known uranium deposits and has been studied in detail. The general sequence consists of greenish arkose with or without uraniferous quartz-pebble conglomerate bands and beds followed by grey quartzite, followed near Elliot Lake by argillite and impure quartzite. Cross-bedding and pebble orientation studies by McDowell (1957, 1963) and Pienaar (1963) indicate the currents flowed from the northwest but were markedly influenced by basement topography. Ore-conglomerates occur largely in valleys in the basement surface (Fig. 5). Thickness of the Lower Mississagi Formation increases from 0 at the north shore of Quirke Lake through 600 feet near Elliot Lake to more than 1,000 feet south of the Murray Fault. As northward overlap is pronounced (Fig. 4) ore-beds at Pronto, Nordic, and Quirke are progressively younger.

The Middle Mississagi Formation normally consists of a basal polymictic conglomerate followed by argillite. The conglomerate was used as a marker horizon during exploration drilling. The upper part of the argillite sequence is characterized by ripple marks. The argillite thickens from less than 100 feet at the north shore of Quirke Lake to over 750 feet near Elliot Lake (Fig. 4). Near the crest of the Chiblow anticline the conglomerate is about 5 feet thick and the argillite only 40 feet but on the south limb of the Chiblow anticline, both north and south of the Murray Fault, the Middle Mississagi is represented by 800 feet of quartzite and siltstone. This indicates deeper water to the south of the area mapped.

The Upper Mississagi Formation consists of greenish arkose on the north limb of the Quirke syncline but elsewhere of well-bedded grey quartzite. Thickness ranges from 600 feet at Quirke Lake to 1,500 feet near Elliot Lake and to a maximum of 2,700 feet on the south limb of the Chiblow anticline, repeated south of the Murray Fault at Blind River. Current direction is from the northwest but the influence of basement topography is much diminished. Facies and thickening relationships again indicate deeper water to the south and southeast.

The Upper Mississagi Formation is followed disconformably by the Bruce Conglomerate - which consists of boulders of white granite and greenstone in a partially sorted, slightly pyritic, siliceous greywacke matrix. The conglomerate can be traced throughout the entire district. There are marked local variations in thickness but the unit is generally less than 200 feet thick.

The Espanola Formation consists of three units, all of which are mappable within the Elliot Lake district; a lower unit, characterized by limestone - the Bruce Limestone; a middle unit, characterized by mudstone and greywacke - the Espanola Greywacke; and an upper unit having a marked development of ferruginous dolomite - the Espanola Limestone. Throughout much of the area mapped the Cobalt Group rests unconformably on the Bruce Limestone.

The Bruce Limestone consists of thinly interbedded cream-coloured limestone and siltstone. Differential weathering and drag-folding give the rock a spectacular appearance. Where the unit is complete, the thickness is generally 100 feet.

The Espanola Greywacke and Espanola Limestone members can be only distinguished by the brown-weathering dolomite bands. Both members are characterized by intraformational breccias, siltstone and conglomerate dikes, mud cracks, and ripple marks. These indicate shallow water deposition and tectonic disturbance. Occasional quartzite beds show crossbedding from the northwest and become more common to the northwest. Where complete the thickness of the Espanola Greywacke is 300-400 feet and that of the Espanola Limestone 150 feet.

The Espanola Formation is overlain by the Serpent Formation - a white feldspathic quartzite only exposed in the northern and eastern sections of the Quirke syncline. The maximum known thickness of the Serpent Formation is 1,100 feet. Crossbedding, and lithology and thickness changes in individual members again show derivation from the northwest. Ripple marks and mud cracks indicate shallow water conditions.

The lateral variation in thickness of the formations of the Bruce Group is illustrated in Fig. 4.

The Bruce Group is followed unconformably by the Cobalt Group which in the Blind River - Elliot Lake area consists of the Gowganda Formation and the Lorrain Formation. Within the map-area the Gowganda Formation rests on all formations between the Upper Mississagi and the Serpent Formation. Locally the contact can be seen truncating the bedding of the underlying formation and consolidated fragments of the underlying rocks are found in the lowermost beds of the Gowganda Formation.

The Gowganda Formation is a heterogeneous assemblage of conglomerate, greywacke, quartzite, and argillite. These rock types are found throughout the sequence though the lower part is characterized by boulder conglomerate and the upper by quartzite and argillite. Within the area mapped the Gowganda Formation is about 2,000 feet thick.

The origin of the Gowganda Formation is in doubt. Dense boulder conglomerates, quartzites, and argillites are definitely water laid; varved conglomerates and greywackes probably formed under conditions characterized by alternate freezing and thawing although some authorities would ascribe these rocks to turbidity currents; and sparse boulder conglomerates with disrupted greywacke matrix may be either tillites or mudflow deposits.

Locally in the Quirke syncline the Gowganda Formation is overlain by a few hundred feet of well-stratified, crossbedded, arkosic quartzite tentatively correlated with the basal Lorrain. The well-known white quartzite with jasper conglomerate has not been found in the area.

Following Huronian times the region was subjected to tectonic stress. The folding and faulting (briefly summarized earlier) and the intrusion of the Nipissing diabase took place. The Nipissing diabase is divided into two phases: the earlier comprises large irregular sill-like gabbro bodies and the later numerous vertical dikes striking either northwest or west. The gabbroic bodies, the distribution of which shows marked structural control (Fig. 6), are differentiated from gabbro to diorite and, in some cases, to granophyre. The copper deposits of the district are related spatially and genetically to these gabbroic bodies. Alteration (albitization, chloritization, and carbonatization) associated with either dikes or sills is on a small scale but has locally affected the uranium deposits. According to Van Schmus (Van Schmus *et al* 1963) the gabbroic bodies have a probable age of $2,170 \pm 200$ million years,¹ and a minimum age of 1,950 million years.

The only granite of probably post-Huronian age is the Cutler Batholith to the south of Spragge. Age determinations, obtained by Fairbairn (1960), Wetherill (1960), and the Geological Survey of Canada (Lowdon 1961 *et seq.*) whilst obscure in interpretation, range between 1,750 and 1,300 million years and determinations on metamorphic mica in adjacent rocks give 1,400 million years.

Sedimentary rocks of probable Huronian age on the islands south of the Cutler batholith show an increase in metamorphism towards the Cutler batholith. Stauroilite schists and meta-quartzite are found between the batholith and the Murray Fault and as inclusions in the batholith. These rocks, long thought to be Archean in age, may be the metamorphosed equivalent of the southern facies of the Middle Mississagi Formation and therefore of Huronian age. Volcanic rocks at Spragge may be the equivalent of Huronian volcanic rocks described by Frarey (1961, 1962) at Thessalon. However, no volcanic rocks have been identified in the undoubted Huronian rocks of the Blind River area as found north of the Murray Fault. The relationships of the Cutler batholith will be further studied in the coming field season.

A few olivine diabase dikes strike northwest throughout the district. Van Schmus (personal communication) has recently established an age of $1,190 \pm 50$ million years for olivine diabase which cuts the Cutler granite. Similar olivine diabase dikes are found throughout the north shore of Lake Huron and elsewhere give a date of 1,000 - 1,100 million years (Lowdon *et al* 1963).

The olivine diabase dikes are displaced by the Murray Fault indicating late tectonic disturbance. At surface the fault has a vertical to steep southerly dip. The vertical displacement of the fault is 6,000 stratigraphic feet, south side up and the horizontal displacement measured on magnetic anomalies associated with olivine diabase dikes is 5,000 feet north side east.

1. Subsequently modified to $2,130 \pm 80$ million years; Van Schmus, personal communication.

ECONOMIC GEOLOGY

Two types of ore deposit have aroused interest - the uranium-bearing conglomerates and post-Huronian copper-bearing quartz-sulphide veins. Investigations into the possible use of Bruce Limestone as a neutralizing agent in the Uranium mills and the use of Nipissing gabbro as road material were both dropped at an early stage.

The uranium deposits are found (Fig. 5) as quartz-pebble pyritic conglomerate beds in zones controlled by basement topography. In the Quirke syncline the relationship of the uraniferous conglomerates to granite-greenstone contact areas and valleys over softer zones in the greenstone belt is clearly demonstrated by surface drilling and mining operations. At Pronto, however, there is no clear relationship to basement geology which raises the possibility that there may be other economic uranium deposits underlain by granite.

The ore-zones strike northwest-southeast and are controlled by basement structures. Original sedimentary structures preserved in the rocks indicate the zones are parallel to the depositional currents. The Quirke zone (the largest in the area) is 32,000 feet long and from 6,000 to 9,000 feet wide. The Nordic zone is 19,000 feet long and from 4,400 to 6,000 feet wide. The Pronto deposit and the unworked zones are of smaller dimensions.

The uraniferous quartz-pebble conglomerate and green arkose sequence is characteristic of the Lower Mississagi Formation and has been used by Thomson (1962) as a marker horizon in tracing the Archean-Huronian boundary between Lake Timagami and Blind River. Locally where overlap brings Upper Mississagi into close proximity with the basement, arkose with thin, slightly radioactive pebble bands is found. The uranium-mineralization is thus associated with the basal beds of the Huronian and the distribution over a wide area suggests a syngenetic origin.

The conglomerates consist of well-rounded, well sorted, quartz pebbles in a matrix of quartz, feldspar and sericite and have an average pyrite content of 15 percent. Monazite and zircon are characteristic heavy minerals. Brannerite and uraninite are found in the matrix. Thucholite is found locally and may line fissures in the ore beds. The ore-minerals are brannerite, uraninite, and monazite. Roscoe has shown the uranium-thorium ratio (1:3) is comparable to that of the basement. The lateral variation in the ore-mineral and uranium-thorium ratios as studies by Roscoe (1959) and D. Robertson (1962) are best explained by the relative stability of monazite during transportation. Locally, individual conglomerate bands may assay as high as 20 lbs. or more U_3O_8 per ton, but over mining widths of the order of 9-30 feet average grade is 2-3 lbs. U_3O_8 per ton.

The arkose interbedded with the ore conglomerate is generally greenish in colour and is crossbedded.

It is probable that the conglomerate accumulated as placer deposits derived from weathered red-phase Algoman granite and that the uranium-bearing minerals were altered and redistributed during diagenesis, during the different periods of tectonic stress, and definitely during the introduction of diabase. There is no evidence in the area mapped by the writer, of crosscutting uranium mineralization. Alternative theories include deposition from hydrothermal fluids derived from post-Huronian granite as suggested by Davidson (1957) and biogenic precipitation of uranium derived from weathered basement but transported in solution as proposed by Derry (1960).

Although almost one billion dollars worth of uranium oxide have been extracted there are large drill-indicated reserves left. When marketing conditions for uranium improve, the Elliot Lake area should again be a major producer. By-products include small amounts of thorium and rare earths.

The copper deposits of the north shore of Lake Huron have been known since the 1840's. These are normally veins of quartz, chalcopryrite, with or without pyrite, specularite, and carbonate. Favourable structural conditions occur near or in large differentiated Nipissing gabbro bodies (see Fig. 6). In the area under discussion the veins trend parallel to the major fold axes and to the Murray Fault. Contact metasomatic deposits are also found associated with the upper contacts of sill-like gabbro-bodies. Prospecting has been carried out and a few properties have shipped small tonnages of ore. The main producer in the area is the Pater mine at Spragge where 700 tons of 2.0 percent copper are hoisted a day and treated at the Pronto concentrator. At Pater, quartz, pyrrhotite, and chalcopryrite, are found in a shear zone slightly oblique to the Murray Fault and located in the metamorphic rocks of possible Huronian age. Epidiorite is thought to represent metamorphosed Nipissing gabbro.

CONCLUSION

The area is one of extreme importance in the long-range economy of the country in this nuclear age. The deposits of uranium and copper should continue to interest the prospector, miner, and the public.

The Blind River - Elliot Lake area contains excellent exposures of extremely interesting Precambrian rocks of diverse type. The area is readily accessible and is ideal for research programmes.

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DESCRIPTION OF STOPS

Between Highway 17 - Highway 548 junction and Desbarats
East of Sault Ste. Marie, Ontario

Stop 1 Lorrain Formation. In this area three members of the Lorrain Formation are exposed as follows:

1a 1/2 mile east of junction (22 miles east of Sault Ste. Marie). Roadside outcrops of pink to buff-coloured, medium to coarse-grained quartzite of the Lorrain Formation, member #3. In this vicinity, the member attains a thickness of 2,000 feet. It is commonly feldspathic or pebbly (quartz and jasper) and characterized by large cross-beds.

1b About 1/2 mile east is a series of outcrops, mostly of pinkish quartzose siltstone or fine-grained quartzite, in part spotted with hematite clots, of Lorrain member #2. Some purplish layers nearby. The quartzite is somewhat similar to host rock at disseminated copper showings about 1.5 miles north of this locality.

1c Large roadcut 1 mile to the east. Prominent display of ripple marks in greyish siltstone-quartzite, just above the base of Lorrain member #1. Successive bedding planes exhibit widely divergent ripple mark orientation. Shear zone on south side of road.

Stops 1a and b are regarded as optional; stop 1c will be sufficiently long to permit taking of photographs.

STOP 2 Proceed 7 miles east to second roadcut past Portlock side-road. The cut is in Gowganda Formation, about 1,300 feet below the top of this unit, which here is striking about N60E and dipping 20 NW. Greywacke-argillite, making up the bulk of the rock, carries disoriented fragments of pink-grey siltstone and sparser granitoid clasts. The sedimentary pieces are thought to represent an interbed disrupted by penecontemporaneous slide or slump.

STOP 3 Continue 3 miles east to junction of Highway 17 and Centre Line sideroad. Granophyric Nipissing diabase is on south side, and on the sideroad just north of the highway are outcrops of sparse conglomerate of the Bruce Conglomerate Formation and grey laminated limestone of the Bruce Limestone member of the Espanola Formation. These sedimentary units are thin here, probably not exceeding 100 feet. The diabase is part of a large sill which follows around the Bruce Mines anticline.

Bruce Mines Proceed one mile into Bruce Mines. This village is of historical interest. It was the first settlement on the north shore of Lake Huron, established at the site of the earliest copper mining operation by the white man in mainland Canada. Mining was done sporadically for about 75 years, up to 1921. The deposits consisted of quartz-

carbonate veins mineralized with chalcopyrite, pyrite, specularite and bornite. Similar veins are widespread in the district, and will be seen at Stop 5. The classical work of Logan and Murray followed the discovery of Bruce Mines.

Stop 4 From Bruce Mines continue east for about 15 miles to outcrops at the east end of the Thessalon by-pass. This is at the western margin of the Thessalon Formation, a volcanic assemblage previously classed as (a) Keewatin (Archean) or (b) Keweenawan, but now included in the Huronian. The formation consists mainly of uniform-looking, fine-grained metabasalt, commonly amygdaloidal, but generally lacking other volcanic features. As well as here at Thessalon, such volcanic rocks, correlated with the Thessalon Formation, occur in the Huronian sequence about 14 miles north of Bruce Mines and also about 9 miles northeast of Sault Ste. Marie; at this last area they have been named the Duncan Formation. In all three areas, thin sedimentary intercalations are found, including quartz-pebble conglomerate beds generally similar to the Elliot Lake uranium ore. At this stop, the metabasalt is exposed, and a few hundred feet to the north along Highway 129 are a few beds of feldspathic quartzite, probably interbeds.

Highway Three miles east on Highway 17, just east of Livingstone Creek. Low roadcuts here of Archean gneiss, pre-Huronian basement. This basement rise extends southeastward for about 20 miles almost to Blind River. It is bounded on the north by the Murray Fault and passes under Lake Huron on the south. The basal Huronian contact is visible only at a few places, notably on small islands in Lake Huron south of this stop. The regolith frequently mentioned in descriptions of Elliot Lake district has not been recognized in this vicinity. An age determination using hornblende obtained at this stop, done in the G.S.C. laboratory, gave a figure of 2620 m.y., indicating the maximum age of the Huronian. Its minimum age, as determined by dating whole rock and mineral samples from the intrusive Nipissing diabase, is approximately 2150 m.y.

STOP 5 Continuing eastward, Highway 17 soon leaves the basement terrane at Sowerby, where it crosses the concealed Murray Fault and traverses the Gowganda Formation for about 4 miles to this stop. At this stratigraphic level the formation is characterized by conglomeratic greywacke-argillite ("tillite") and a few low outcrops are visible along the road in this interval. At this stop a roadcut exposes a quartz stockwork in sparse greywacke conglomerate and feldspathic quartzite; chalcopyrite, specularite, siderite and calcite occur in the veins, which are quite typical of the numerous vein copper occurrences in this district.

Highway Eastward, the highway continues to follow the Gowganda

Formation from about 20 miles, keeping close to the north-east side of the Mississagi River from the town of Iron Bridge on. At the large, right-angle bend in the river not far above its mouth, the highway recrosses the Murray Fault, crosses the narrow eastern extremity of the basement rocks seen at Stop 7, and follows feldspathic quartzite of the Lower Mississagi (Matinenda) Formation to the town of Blind River.

From Blind River eastwards for 6 miles, the road follows quartzites and argillites of the Middle Mississagi Formation to Algoma Mills. At Algoma Mills (Lake Lauzon) the Murray Fault crosses the road. From Lake Lauzon to Pronto subdivision (4 miles) the road lies in sparse (tillite ?) conglomerates, greywackes, etc. of the Gowganda Formation. The discovery locality for the Blind River uranium deposits is at Pronto Mine. From Pronto eastwards through Spragge to the junction of Highways 108 and 17 the road follows the Murray Fault. Undoubted Lower Huronian rocks lie north of the road for distances of 1/4 to 1 mile and to the south lie metamorphic rocks (mafic metavolcanics, schists, and epidiorites) and the Cutler Batholith (probable age 1750 m.y.). At Spragge is the Pater Mine - the only producing copper mine on the north shore.

From the junction of 108 and 17, follow 108 to Elliot Lake (18 miles).

The Murray Fault is crossed immediately north of Highway 17 and to the east of the road greenish arkoses of the Upper Mississagi can be seen resting on a local high in the granitic basement. Granitic rocks and gneisses cut by numerous diabase dikes are exposed in road cuts to Depot Lake. From Depot Lake to Buckles Mine the road follows the strike of Keewatin sediments. These are greywackes and lean iron formation. At Buckles the scarp of the Lower Mississagi is clearly visible. Northwest of Buckles the road follows a fault which displaces the Lower Mississagi.

Elliot Lake Programme

Sunday Transportation will leave the hotel at 8 a.m. Stops for the Elliot Lake trip will be marked on map 2032. Stops 12, 13, 14 are on the road from Quirke Mine to Flack Lake and the White River Road. They lie in the uppermost formations of the Cobalt Group - not exposed elsewhere in the Blind River area. These stops will only be made if time permits.

Stop 6 Upper Mississagi Formation: well-bedded feldspathic quartzites. Note cross-bedding, also bedding-plane lineations.

Stop 7 Uppermost beds of Upper Mississagi Formation, contact with Bruce Conglomerate. Bruce Conglomerate (characteristic composition, texture, weathering) reworked tillite? Nipissing diabase transgressive sill; texture, banding, alteration and metamorphism of country rock. Contact Bruce Conglomerate - Bruce Limestone. Bruce Limestone, bedding, composition, drag-folds, metamorphic minerals - idocrase, grossularite, wollastonite; thin sill of diabase west side of road.

Stop 8 Gowganda Formation

8a Tillite type sparse boulder greywacke conglomerate. Note composition, texture, striated boulders.

8b Well bedded dense conglomerate + quartzite beds and lenses. Note composition, texture, boulder shapes, packing, graded bedding.

Stop 9 Unconformity between Gowganda and Serpent formations (Denison Side Road).

Stop 10 Panel side road to Serpent River and Quirke Lake. Location of mines - Influence of Geology on Topography. Outcrop of Middle Mississagi conglomerate. Note delicate banding (varving?) and rafted pebbles in more argillaceous sections. Intersection of cleavage and bedding.

Stop 11 Return to Highway 108. Road largely over Espanola Formation. Outcrop at junction of Panel Road and road to Quirke No. 2 shaft. Espanola, dolomitic mudstones, note siltstone dikes, intraformational breccia, bedding, weathering, other outcrop on road show mudcracks, ripple marks, ball structures, etc.

Stop 12 West of Quirke Mine road climbs up onto Archean basement (granite). After about three miles granite gives way to Keewatin massive and pillowed mafic Keewatin lavas. These become strongly shattered and a prominent valley represents the outcrop of the Flack Lake Fault. North of this fault is the Rawhide syncline of which only the north limb is preserved. The upper units of the Cobalt Group are well exposed along the highway which runs through some of the finest scenery in the district.

Return to Elliot Lake for lunch which will be at 1 p.m.

At lunch representatives of the mining companies will join the group and they will give brief descriptions of the geology and other features of interest at their operations.

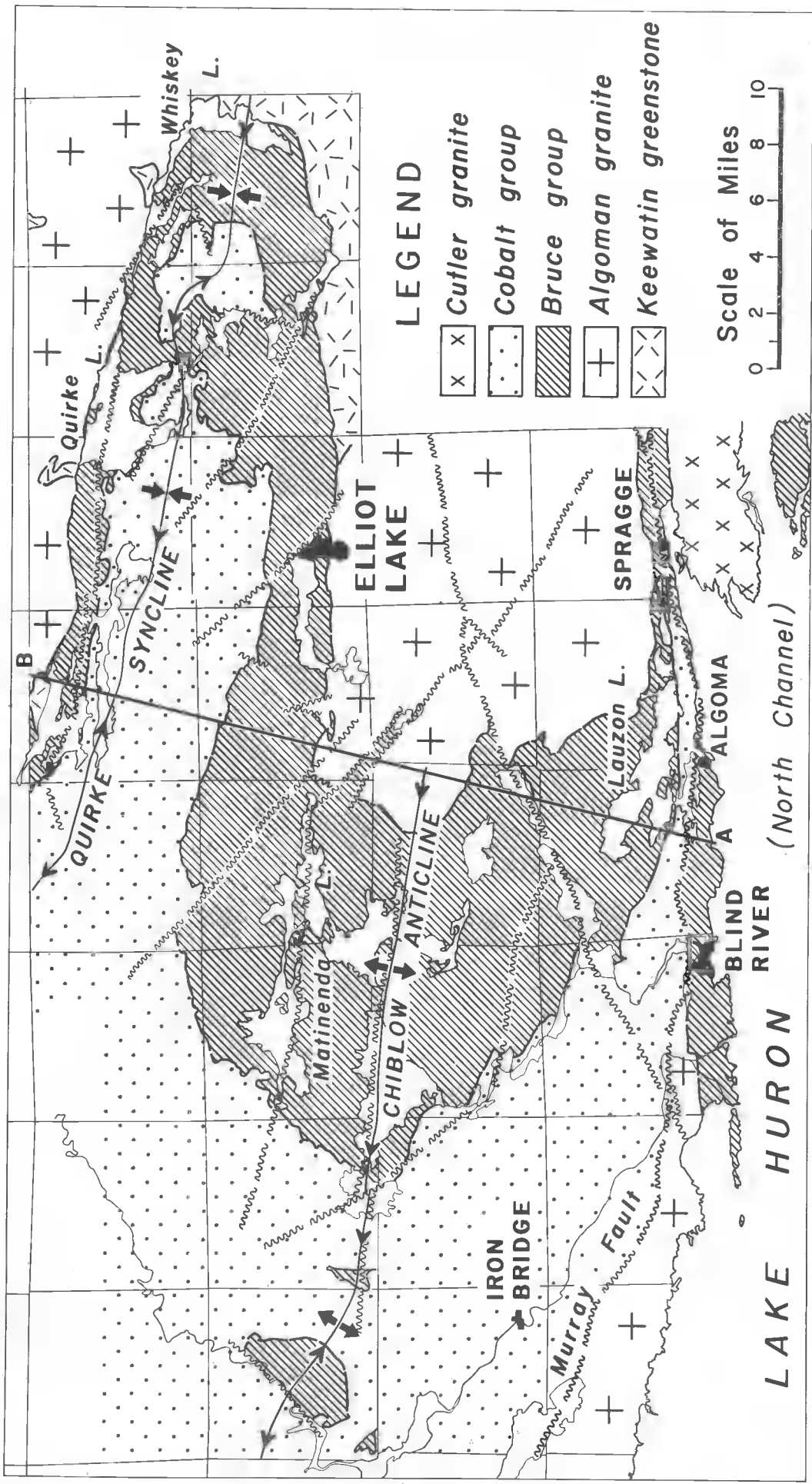
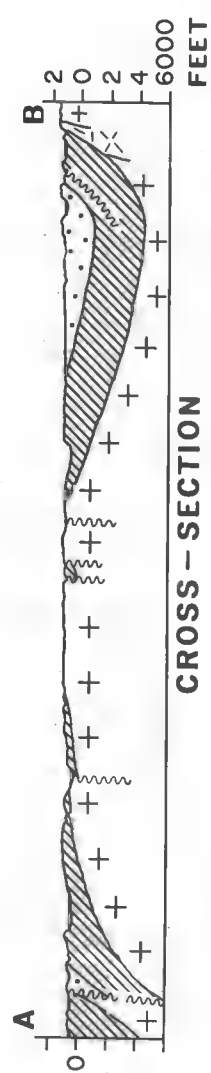
Following lunch the group will leave the hotel (2:30 p.m.) and proceed south on Highway 108.

- Stop 15 If time permits a brief stop will be made at Buckles Mine to discuss the influence of geology on scenery.
- Stop 16 Texaco gas station, junction of Highways 108 and 17. Staurolite-mica schists of the Spragge Group (believed meta-Huronian); note twinning on some crystals, alteration to pinnite, and crude grading.
- Stop 17 3 1/2 miles west. Brief stop at Murray Fault. One of the few localities where this fault is exposed.
- Stop 18 Pronto Mine. This is the discovery area.

Points of Interest

1. Albitization of feldspathic quartzites at junction of mine road and access trail.
 2. Bedding, composition, colour, and texture of Lower Mississagi Formation and changes as ore-zone is approached.
 3. Discovery locality
 4. Pre-Huronian regolith and Archean - Huronian contact
 5. Surface workings - the only excellent exposures of typical ore-conglomerates. Note also hanging wall quartzites.
 6. Pronto Thrust Fault
- Formal termination of field trip.

FIG. 2
BLIND RIVER AREA
GENERAL GEOLOGY



UNIT	LITHOLOGY	AGE MILLION YEARS
CENOZOIC		
RECENT & PLEISTOCENE	<i>Sand, gravel</i>	
GREAT UNCONFORMITY		
PRECAMBRIAN		
PROTEROZOIC		
KEWEENAWAN	<i>Olivine diabase</i>	1,190
INTRUSIVE		
PENOKEAN	<i>Granite</i>	1,750
INTRUSIVE		
NIPISSING	<i>Quartz diabase</i>	2,130
INTRUSIVE		
HURONIAN		
COBALT GROUP		
LORRAIN	<i>Quartzite</i>	
GOWGANDA	<i>Conglomerate, greywacke</i>	
UNCONFORMITY		
BRUCE GROUP		
SERPENT	<i>Quartzite</i>	
ESPANOLA	<i>Limestone, greywacke</i>	
BRUCE CONGLOMERATE ..	<i>Conglomerate</i>	
UPPER MISSISSAGI	<i>Quartzite</i>	
MIDDLE MISSISSAGI	<i>Argillite</i>	
	<i>Conglomerate</i>	
LOWER MISSISSAGI	<i>Argillite</i>	
	<i>Quartzite, ±U-conglomerate</i>	
	<i>Conglomerate</i>	
	<i>Arkose + U-conglomerate</i>	
UNCONFORMITY		
ARCHEAN		
ALGOMAN	<i>Granite</i>	2,500
INTRUSIVE		
KEEWATIN	<i>Volcanic and sedimentary rocks</i>	

FIG.3 TABLE OF FORMATIONS

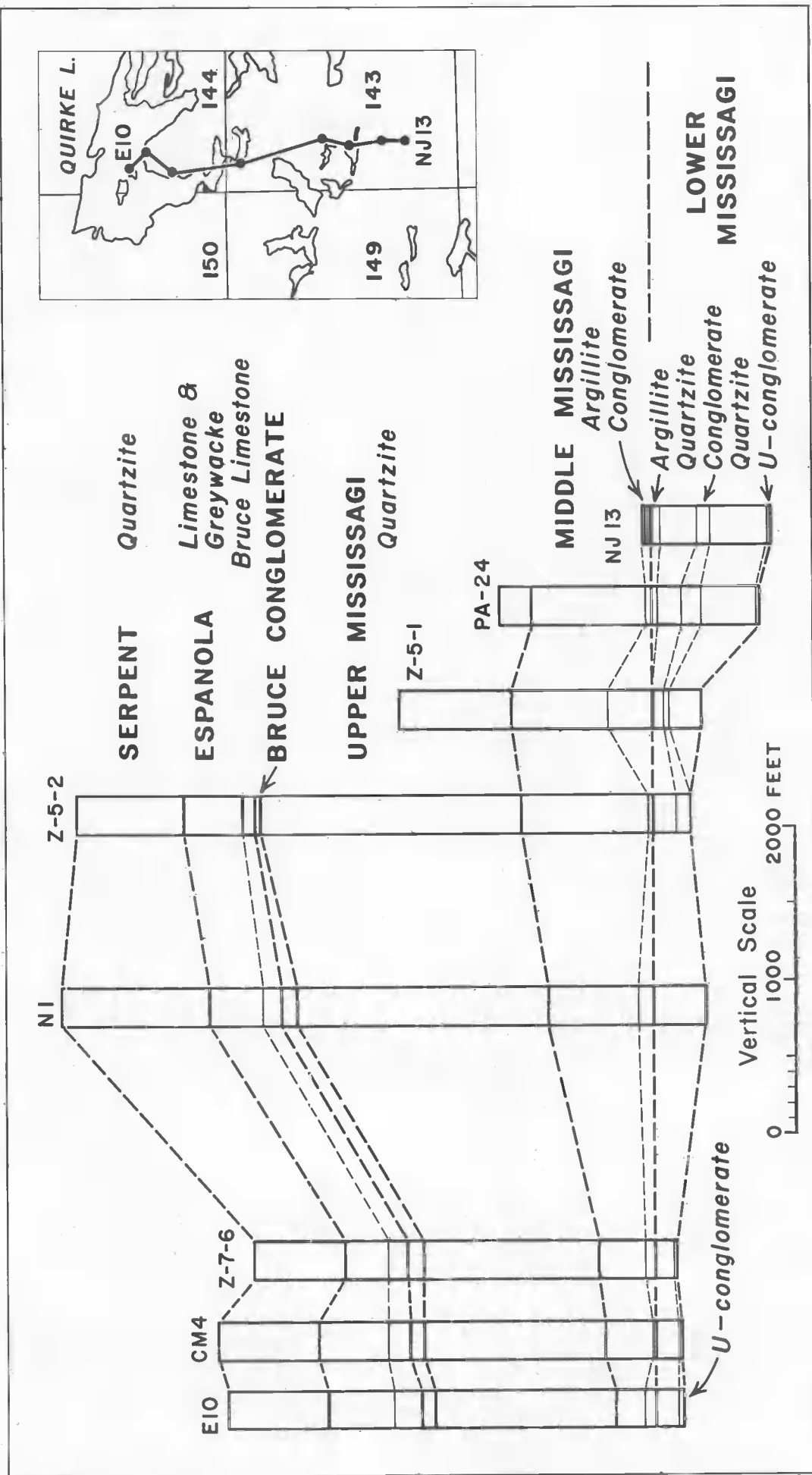
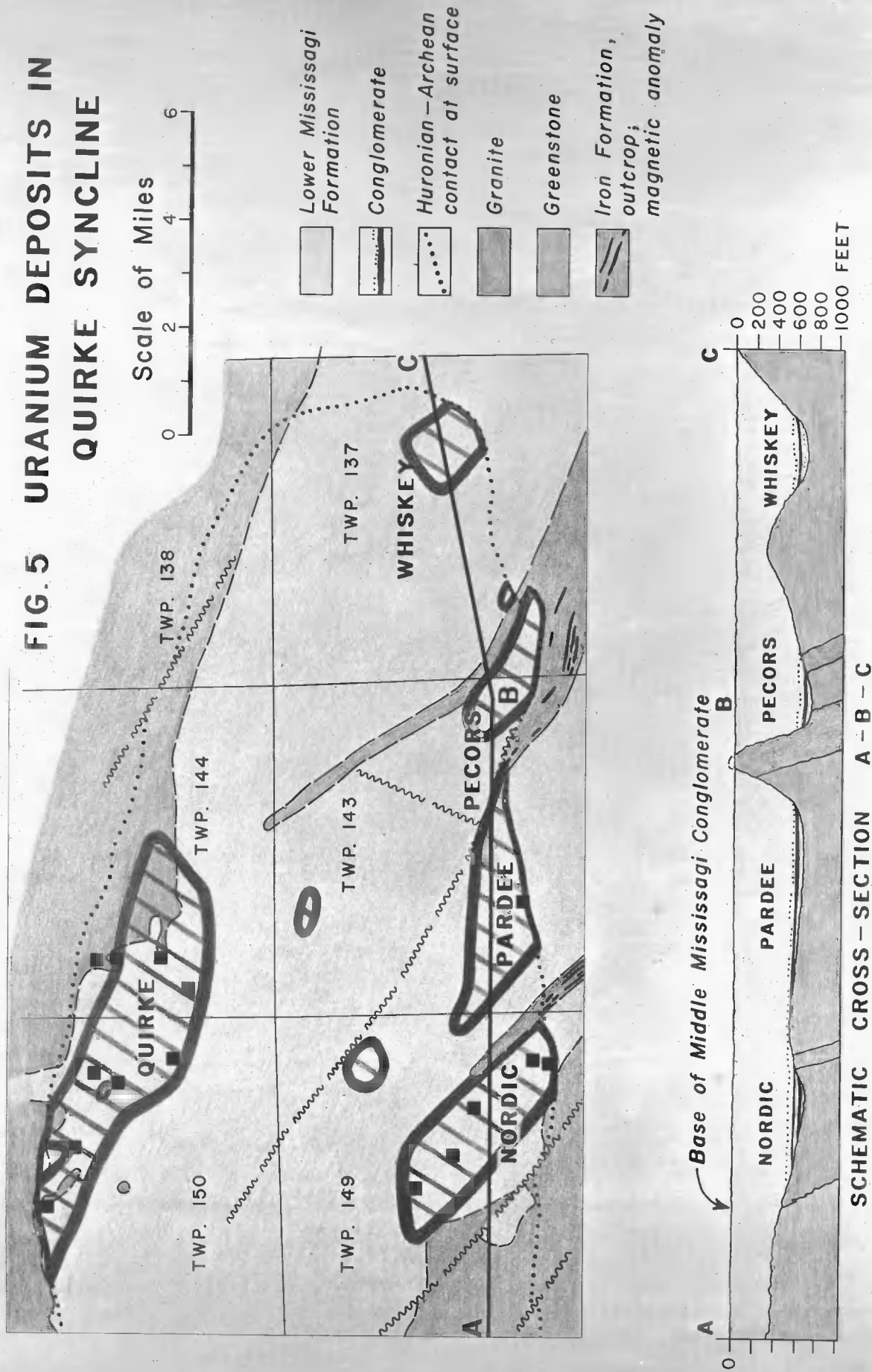


FIG. 4 LATERAL VARIATION IN BRUCE GROUP

FIG. 5 URANIUM DEPOSITS IN QUIRKE SYNCLINE



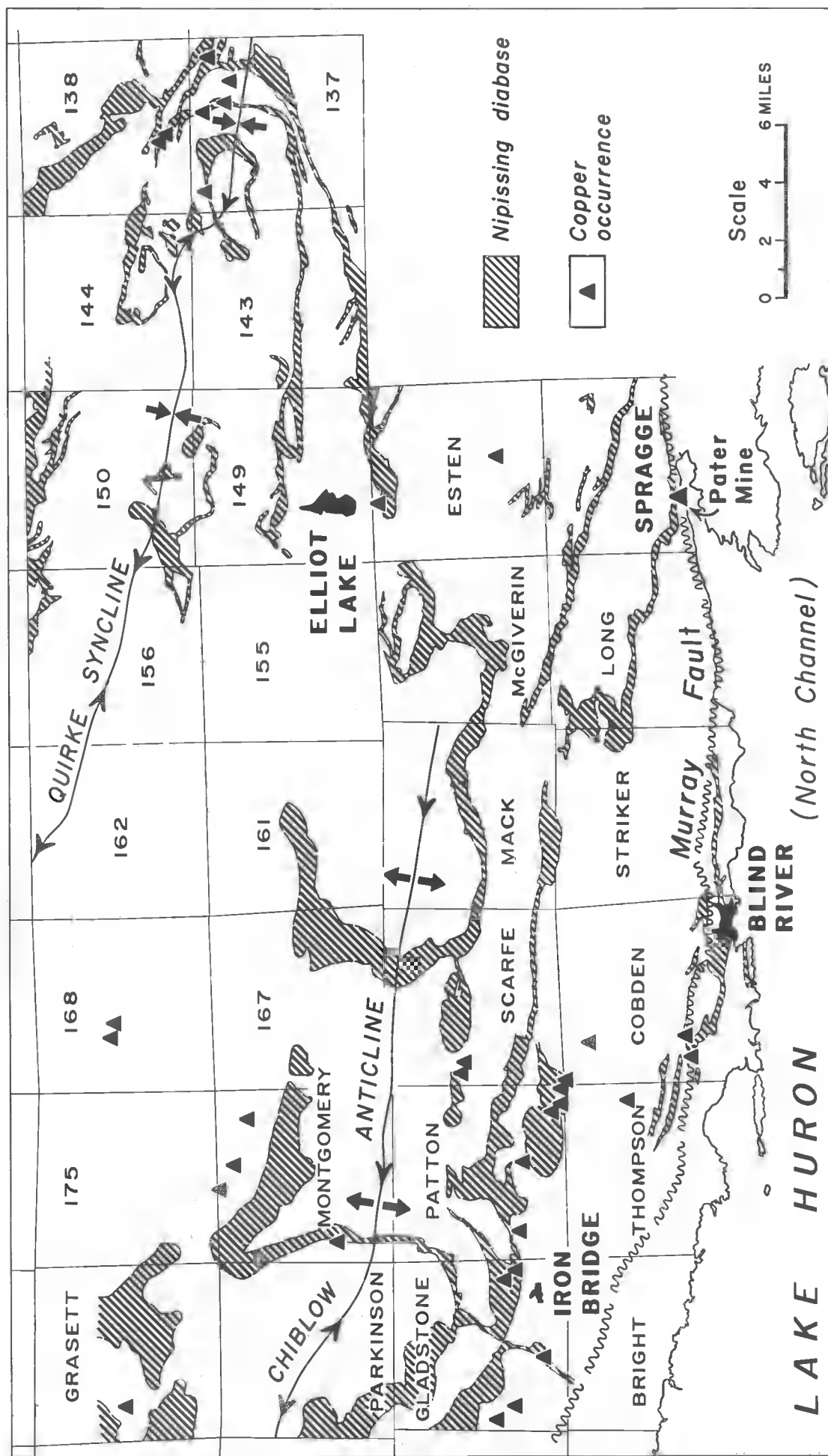


FIG.6 DISTRIBUTION OF COPPER DEPOSITS RELATIVE TO NIPISSING DIABASE

SUDBURY NICKEL IRRUPTIVE TOUR

Organized at the request of
the Society of Economic Geologists and the
Institute on Lake Superior Geology

Prepared
by
Sudbury Field Trip Committee:

K. D. Card, Ontario Department of Mines
J. M. Holloway, International Nickel Co. of Canada, Ltd.
P. Potapoff, Falconbridge Nickel Mines, Ltd.
D. Rousell, Laurentian University
B. E. Souch, International Nickel Co. of Canada, Ltd.
G. Thrall, International Nickel Co. of Canada, Ltd.
J. S. Stevenson, McGill University (Leader)

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Geological map, Sudbury Basin

SUDBURY NICKEL IRRUPTIVE TOUR

INTRODUCTION

Sudbury has been going for a long time. To quote from Hewitt (1964) p. 88 - "The first mine that was located in the Sudbury area was the Murray mine; it was discovered in 1883 along the right of way during construction of the Canadian Pacific Railway. A gossan zone was observed in a rockcut (1) and copper mineralization was identified. The mine was opened in 1889, and the ore was smelted and refined at Swansea in Wales. From 1884 to 1890 prospecting continued in the Sudbury area and during those first few years many of the major deposits of nickel-copper ore, including the Frood, Creighton, Stobie, and Copper Cliff mines, were discovered."

Since that early period, many important discoveries have been made, and today we have 18 producing mines. These include (see accompanying map for location): in the South Range, from the west to the east; the Totten, Crean Hill, Ellen Pit, Creighton, Clarabelle, Murray, Frood-Stobie, Garson, Falconbridge, East, and Maclellan mines; and in the North Range, from west to east: Hardy, Boundary, Onaping, Levack, Fecunis and North mines. As active mines, but not producing at the moment, we have, in the South Range, the Copper Cliff North, Little Stobie, and Kirkwood mines, and in the North Range, the Coleman and Strathcona mines. As indicating the continued growth of mining in the Sudbury Basin area, it may be of interest to note that this past summer (1965) International Nickel opened No. 9 shaft at its Creighton mine. This shaft will go down to 7,150 feet, making it the deepest continuous mine shaft from surface in the Western Hemisphere.

-
- (1) Although not marked as a stop on the accompanying sketch map, we will try to stop en route briefly at the Discovery cut and see ore in place.

GEOLOGY

The nickel irruptive, because it contains the world's largest concentration of nickel sulfide ores, is for that very reason, unique in its geology, and all geological studies of it should be made with that in mind. The irruptive is a late Precambrian layered complex whose dominantly inward dipping members form a north-easterly trending ellipse 37 miles long by 17 miles wide.

The rocks southeasterly outside the basin consist of a conformable series of steeply dipping, southward facing, volcanics and sediments intruded by Murray and Creighton granites and by the Sudbury gabbro. Elsewhere around the basin, the rocks consist of a complex of granites, gneisses and included basic rocks. The rocks outside the basin are cut by breccia zones, a fraction of an inch to a mile in width; this breccia is known as the Sudbury breccia, or more locally, the Frood breccia.

The rocks inside the basin comprise the Whitewater series of gently dipping volcanic breccia and tuff, slate and greywacke (sandstone).

The irruptive consists principally of micropegmatite (granophyre) and, below this, norite. These rocks are layered, but the layering is quite gross and requires detailed mapping with careful attention to the petrography to bring out the layering. The uppermost phase of the micropegmatite and therefore of the irruptive, is a quartzite breccia that is matrixed by irruptive derived igneous material, referred to by Stevenson (1963, p. 415) as pepper-and-salt micropegmatite. This breccia forms a layer between the more normal micropegmatite and the overlying volcanic breccia. The border rock at the base of the norite is the well-known quartz-diorite, the principal occurrences of which are the tongues or dikes commonly known as the offsets, that extend outward from the norite.

Primary features, structural and petrographic, of the irruptive are best studied in the North Range rocks. This is because the South Range rocks, in contrast to those of the North Range, have been subjected to extensive overthrusting and consequently, the primary layering and petrographic features have been considerably modified by dynamic metamorphism and recrystallization.

With respect to the orebodies themselves, their occurrence has been very succinctly described by Hewitt (1964, p. 91) as follows: "The nickel-copper sulphide orebodies are found along the footwall contact of the norite in mineralized shear zones or in mineralized embayments of quartz diorite. These are called "contact" or "marginal" deposits; Creighton, Falconbridge, Levack, Murray and Garson are of this type. Orebodies also are found in the quartz diorite offsets. The Frood-Stobie, Worthington, Victoria, Nickel Offset, and Copper Cliff orebodies are of

the offset type. Three main types of ore are recognized: disseminated sulphides largely in quartz diorite; massive sulphides along zones of shearing and brecciation; sulphide veins, and stringers in sheared and brecciated quartz diorite and country rock. The ore may lie in either the quartz diorite or the adjacent footwall country rocks. Both the Creighton and Falconbridge mines have been developed to depths greater than 6,500 feet.

"The principal ore minerals are pentlandite, nickeliferous pyrrhotite, chalcopyrite, cubanite, niccolite, gersdorffite, maucherite, and sperrylite. The average grade of ore is about 2 percent nickel and 2 percent copper, but it varies from ore-body to orebody." The principal ore-minerals are indeed those mentioned by Hewitt but it is interesting to note that Hawley (1962, p. 41) states that some 40 metallic minerals occur.

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TOUR LOG

With respect to this particular tour, we thought that, because of the very close relation between the ore-bodies and the irruptive and therefore because of the fundamental importance of the irruptive, we might take advantage of the detailed studies that are currently being made of the irruptive and would restrict our tour, in the time that is available, to the irruptive itself. The briefing and discussion on Saturday evening at Laurentian University and the stops on Sunday, have therefore been arranged with this specific objective in mind.

We will reach our first stop by driving from Sudbury through Copper Cliff to near the Copper Cliff North and Clarabelle mines, and en route we will have several views, no stops, of Inco's Copper Cliff Smelter.

STOP 1. Copper Cliff offset, Clarabelle Road. This is a type locality for the quartz-diorite phase of the norite. Ore specimens from nearby mines will be provided here.

We will drive from Stop 1 east to the Levack highway, thence north 1-1/2 miles to the Discovery Cut at the Murray Mine, stop here briefly and return south along the highway to Regent St. in Sudbury and then along Frood Road, driving by the Frood and Stobie Mines, joining Highway 69 and thence to Stop 2.

STOP 2 South Range norite, both the fresh "brown-black" norite and the widespread, altered "green norite".

From here we will continue northward along Highway 69, across the norite and into the micropegmatite, Stop 3.

STOP 3 Typical South Range, foliated micropegmatite.

From Stop 3 we will drive north along 69 over a hill of black Onaping tuff into the farmlands of the Chelmsford valley underlain by Onwatin slate and the Chelmsford sandstone. We will continue through Val Caron, and Hanmer to the turn-off, to the right of the Ella (Capreol) Lake-West Bay road, one mile south of Capreol. We will drive along this road for about 3 miles to Stop 4, 1/2 north of the Ella Lake campground.

Stops 4 and 5 will be concerned with the North Range phase of the irruptive.

STOP 4 North Range Norite.

This is on the township line between Norman and Capreol townships. We will walk westward along this line and in doing so will cross several members of the irruptive, which here trends north.

Stop 4a: outcrops along the road are of lower gray norite.

Stop 4b: westward across the slough, a fine-grained, sharp-textured norite, overlying the medium-grained gray norite, outcrops on the hillside.

Stop 4c: outcrops of fine-grained mafic phase of the last, on the same hillside.

Stop 4d: farther west up the hillside, outcrops of pink norite.

Stop 4e: the last of the outcrops on this line are of the lowermost member of the micropegmatite, a coarse-grained, salmon-coloured member.

Return to buses for trail lunch in Ella Lake campgrounds, and drive back along Ella Lake road to C. N. Railway crossing; this is Stop 5.

STOP 5 North Range Micropegmatite.

Walk westward along the railway.

Stop 5a: outcrop along railway of upper micropegmatite, a fine to medium gray member.

Stop 5b: farther west on railway, outcrop of breccia at top of micropegmatite.

From here we will walk along the railway a short distance, to a tote-road of the new hydro line (incidentally, one of the new E.H.V. lines of the Ontario Hydro), then northwards to Stop 5c. En route, most of the outcrops on left (west) side of the road are of Onaping volcanic breccia.

Stop 5c: about 1000' north along tote-road on the south side to study outcrops of breccia and the uppermost phases of the irruptive.

Stop 5d: continue along tote-road for a short distance to look at other outcrops of the irruptive and the breccia.

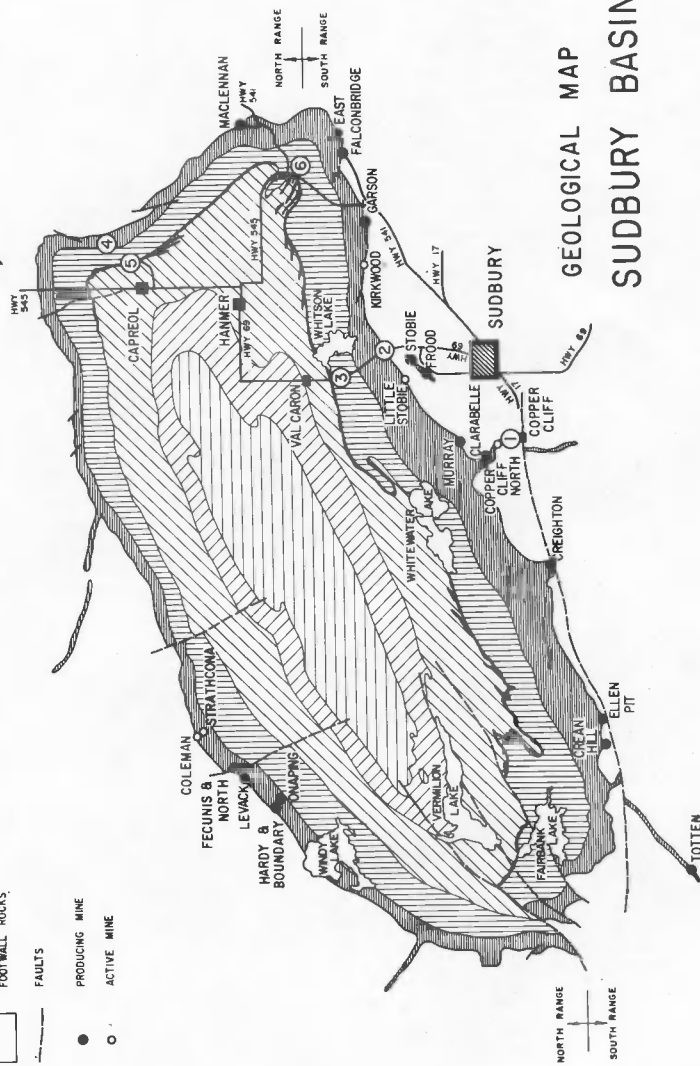
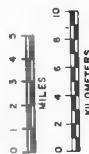
Return via tote-road and railway to bus, drive back along Ella Lake road to Highway 69, turn south on 69 then left on the Garson-Falconbridge road, route 545 to Stop 6 which is 1/2-mile south of the junction of 545 with 541.

STOP 6 Typical South Range, foliated micropegmatite.

From this stop we will drive south over South Range norite, turn left, geologically at the footwall, and continue in footwall greenstone, to Falconbridge townsite, where we will have a chance to drive by the Falconbridge Smelter and be able to see in the distance towards the east, the headframes of the Falconbridge and the East mines. Ore specimens from nearby mines will be provided here. From Falconbridge we will return and drive southwesterly past the Garson mine and back to Sudbury.

LEGEND

-  MICROPEGMATITE
-  NICKEL INTRUSIVE
-  NORTH
-  CHELMSFORD SANDSTONE
-  ONWATIN SLATE
-  DRAPING TUFF
-  QUARTZITE BRECCIA (WHERE MAPPED TO DATE)
-  FOOTWALL ROCKS
-  FAULTS
-  PRODUCING MINE
-  ACTIVE MINE

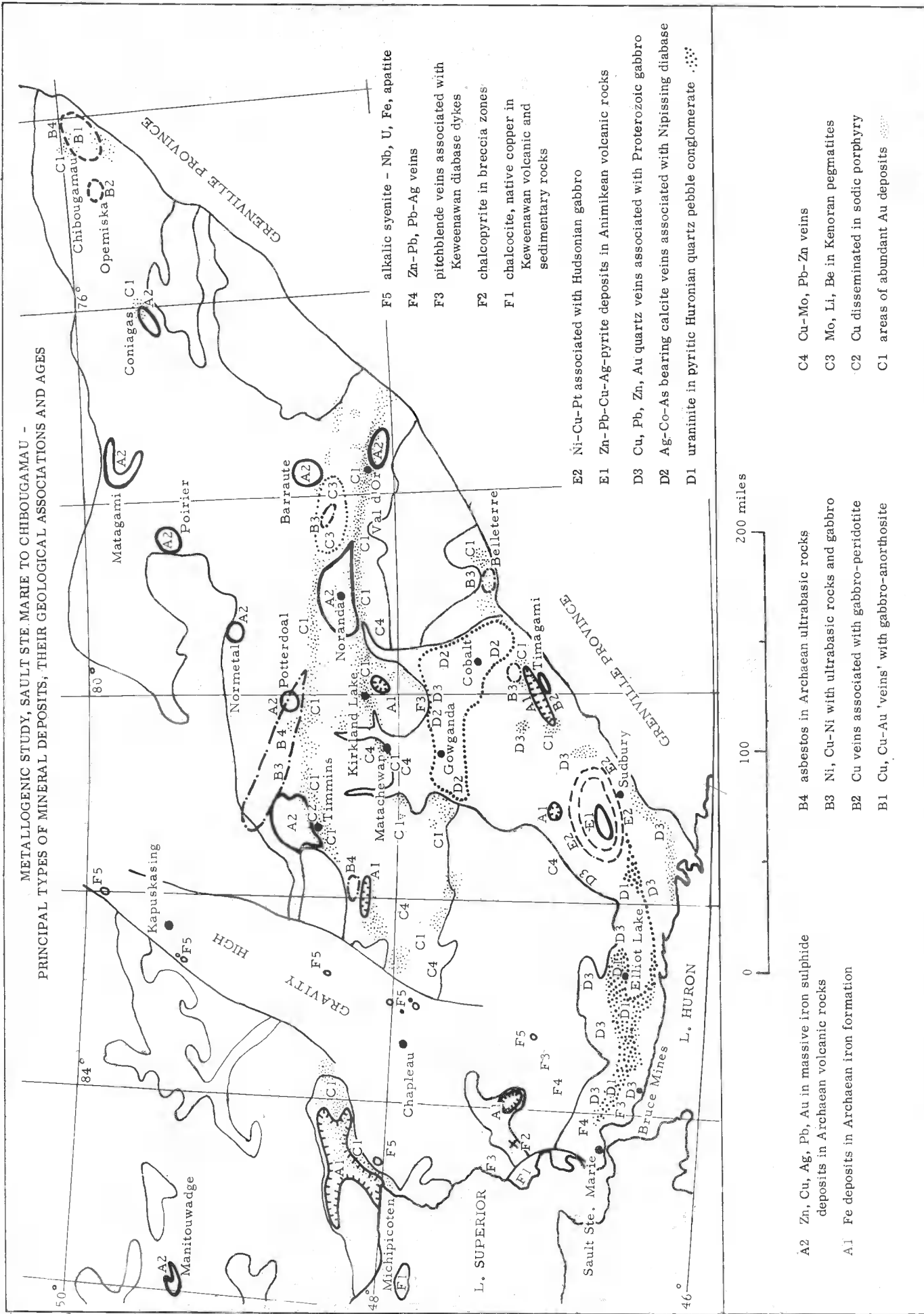


GEOLOGICAL MAP
SUDBURY BASIN

PREVIOUS ANNUAL MEETINGS
of
INSTITUTE ON LAKE SUPERIOR GEOLOGY

First 1955	Minneapolis, Minnesota	University of Minnesota
Second 1956	Houghton, Michigan	Michigan College of Mining and Technology
Third 1957	East Lansing, Michigan	Michigan State University
Fourth 1958	Duluth, Minnesota	University of Minnesota, Duluth
Fifth 1959	Minneapolis, Minnesota	University of Minnesota
Sixth 1960	Madison, Wisconsin	Geology Department, University of Wisconsin and Wisconsin Geological and Natural History Survey
Seventh 1961	Port Arthur, Ontario	Canadian Institute of Mining and Metallurgy, Lakehead Branch, and Ontario Department of Mines.
Eighth 1962	Houghton, Michigan	Michigan College of Mining and Technology
Ninth 1963	Duluth, Minnesota	University of Minnesota, Duluth
Tenth 1964	Ishpeming, Michigan	Mining Companies: Inland Steel, Cleveland-Cliffs Iron, Jones and Laughlin, North Range
Eleventh 1965	St. Paul, Minnesota	Minnesota Geological Survey and University of Minnesota

METALLOGENIC STUDY, SAULT STE MARIE TO CHIBOUGAMAU - PRINCIPAL TYPES OF MINERAL DEPOSITS, THEIR GEOLOGICAL ASSOCIATIONS AND AGES



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(see abstract)

