

13TH ANNUAL

**INSTITUTE ON
LAKE SUPERIOR GEOLOGY**



Department of Geology

Michigan State University and

Geological Survey Division

Michigan Department of Conservation

East Lansing, Michigan

May 1-2, 1967

13th ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Kellogg Center
Michigan State University
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The Field Trip conducted in connection with the Institute was held in the Grenville Province of Southeastern Ontario, in the Bancroft-Madoc Area, on April 29-30. It was led by Dr. H. B. Stonehouse, Department of Geology, Michigan State University. A Field Trip Guide is available.

PROGRAM

13th Annual

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Kellogg Center
Michigan State University
East Lansing, Michigan

Sunday, April 30, 1967

8:00 - Smoker - Centennial Room, Kellogg Center
10:30 p.m.

Monday, May 1, 1967

7:45 a.m. Registration - Lobby, Kellogg Center

8:40 TECHNICAL SESSION I - AUDITORIUM

Co-chairmen: J. W. Avery and C. E. Dutton

Welcome. C. E. Prouty

The Structural History of the "Archean"

Rocks of Upper Michigan W. E. C. Taylor

Geology of Part of the East Gogebic

Range, Michigan William C. Prinz

Stratigraphy, Structure and Metamorphism

of Upper Animikie Rocks in the

Marenisco-Watersmeet Area Crawford E. Fritts

Keweenawan Volcanic Rocks Near

Ironwood, Michigan Harold A. Hubbard

Mineralogy and Petrology of the Mineral

Lake Intrusion, Northwestern

Wisconsin James F. Olmsted

Structure and Stratigraphy Including Pre-

cambrion Tillite in Eastern Dead River

Basin, Marquette County, Michigan . . Willard P. Puffett

A Study of Clastics in the Negaunee

Iron Formation of Michigan. Robert W. Henny

Influence of Faulting on Deposition of

Clastic Interbeds in Negaunee Iron

Formation Near Palmer, Michigan . . . Jacob E. Gair

Monday, May 1, (continued)

12:30 p.m. Luncheon Big Ten Room

1:30 TECHNICAL SESSION II - AUDITORIUM

Co-Chairmen: R. K. Hogberg and H. B. Stonehouse

- Geochronology in the Lake Superior
Region S. S. Goldich
- K-Ar Hornblende Ages for Granites and
Gneisses and K-Ar Ages for Dikes
in Minnesota Gilbert N. Hanson
- The Geochronology of the Keweenawan
Rocks at White Pine, Michigan Sambhudas Chaudhuri
and Gunter Faure
- Geochemistry of the Nipissing Diabase . . John A. Colwell
- Oxygen Isotopic Evidence of Metamor-
phism in the Biwabik Iron Formation, E. C. Perry, Jr. and
Minnesota J. W. Morse
- A Spectrochemical Method for Differen-
tiating Between Carbonate and
Silicate Facies Thomas Waggoner
- An Aeromagnetic Survey of Lake Huron . . G. B. Secor,
W. J. Hinze,
N. W. O'Hara, and
J. W. Trow
- A Regional Geophysical Study of the
Port Coldwell Complex, Ontario . . J. D. Corbett,
W. J. Hinze, and
G. B. Secor
- Characteristics of Magnetic Data over
Major Subdivisions of the Pre- A. S. MacLaren and
Cambrian Shield B. Charbonneau

ANNUAL BANQUET

6:30 p.m. Big Ten Room, Kellogg Center

Address: "Search for Precambrian Life"
Professor Elso S. Barghoorn
Harvard University

Tuesday, May 2, 1967

8:40 a.m. TECHNICAL SESSION III - AUDITORIUM

Co-Chairmen: L. O. Bacon and A. S. MacLaren

- Gravity Anomalies Over Lake Superior and
Surrounding Area and Their Structural M. J. S. Innes and
Implications. A. K. Goodacre
Heat Flow in Lake Superior J. S. Steinhart, S.R.
Hart, and T. J. Smith
Progress of Geophysical Studies in
Lake Superior Richard J. Wold
Relationship Between Seismic and
Aeromagnetic Surveys in Eastern R. P. Meyer and
Lake Superior L. Ocola
Identification of Seismic Refractors in
the Lake Superior Syncline Henry Halls and
G. F. West
Refraction Seismic Surveys on the Mid-
Continent Gravity Anomaly in S. H. Johnson and
Minnesota and Wisconsin P. R. Farnham
Preliminary Magnetotelluric Resistivity
Results Across the Wisconsin Arch. . Forrest L. Dowling

12:10 p.m. Luncheon Centennial Room

1:20 Business Meeting - Auditorium

1:30 TECHNICAL SESSION IV - AUDITORIUM

Co-Chairmen: R. A. Hoppin and W. T. Swenson

- Hydrocarbon Compounds in Igneous Rocks. E. Wm. Heinrich
Copper Mineralization in Animikie Sedi-
ments of the Eastern Marquette Range,
Michigan. Robert C. Reed
Textures and Compositions of Silicate and
Sulfide Ore Minerals from Mineralized P. W. Weiblen
Zone, Duluth Gabbro Complex Henry Hall
Subdivisions of the Negaunee Iron For-
mation, Sections 7, 8, T 47 N, Joseph J. Mancuso and
R 26 W, Michigan. Jack W. Avery
Evidence on the Physical Environment of
Iron Formation Deposition Gene L. LaBerge
Paleobiology of a Precambrian Shale . . . Elso S. Barghoorn
Some Properties of Michigan Cherts. . . . Allan M. Johnson and
Albert P. Ruotsala

PALEOBIOLOGY OF A PRECAMBRIAN SHALE

Elso S. Barghoorn⁽¹⁾

The existence of both coal and petroleum in shale sequences of Precambrian age in the Lake Superior region has been demonstrated in recent years. Although these "fossil fuels" occur in miniscule amounts in terms of post-Precambrian sediments, they are of great theoretical interest in problems of the antiquity of Precambrian life and the organic geochemical indicators of biological processes in ancient terrestrial environments. Attention is centered here on the paleobiological aspects of the Nonesuch Shale of Northern Michigan, but reference is made also to the much older "Michigamme" coal and associated shale. Concerning the latter, chemical analyses, X-ray diffraction studies, petrographic examination and paleontological study indicates that the coal is a true coal, partially metamorphosed and of biological origin, probably derived from blue-green algae.

The Nonesuch Shale, a 1000 million year old economically important cupriferous sedimentary ore shows remnants of organic preservation interpreted as algal residues and quite remarkably, the presence of small amounts of a syngenetic paraffinic crude oil. Analysis of the oil reveals the presence of a wide range of aliphatic and aromatic hydrocarbons. Gas liquid chromatographic analysis of organic extractives of the shale reveal the presence of the isoprenoid hydrocarbons phytane and pristane, presumably derivatives of chlorophyll breakdown. Another presumed chlorophyll derivative a vanadyl porphyrian complex has been identified. A general discussion is presented concerning the presumed paleoenvironment of the Nonesuch Shale deposition.

⁽¹⁾ Department of Biology, Harvard University; Cambridge, Massachusetts.

THE GEOCHRONOLOGY OF THE KEWEENAWAN
ROCKS AT WHITE PINE, MICHIGAN

Sambhudas Chaudhuri⁽¹⁾ and Gunter Faure⁽²⁾

Age determinations by the total-rock Rb-Sr method of several suites of felsite from the White Pine area of Michigan indicate dates ranging from 978 ± 40 m.y. to 1100 ± 25 m.y. A specimen of felsite from Government Peak of the Porcupine Mountains was dated at 1042 ± 6 m.y. Assuming that the Porcupine Mountains are an anticline, this date sets an upper limit to the time of deposition of the overlying Nonesuch Shale. Another upper limit is provided by dates of 1107 m.y. and 1180 m.y. for two pebbles from the lower sandstone unit in the White Pine Mine.

Nine samples of mineralized and unmineralized rock from the basal section of the Nonesuch Shale exposed in the mine workings of the White Pine Mine were analyzed. These samples form a good co-linear array in coordinates of $\text{Rb}^{87} / \text{Sr}^{86}$ and $\text{Sr}^{87} / \text{Sr}^{86}$. The apparent age, calculated from the slope of the isochron, is 1075 ± 50 m.y. The initial $\text{Sr}^{87} / \text{Sr}^{86}$ ratio is 0.7080 ± 0.001 . The apparent age for the Nonesuch Shale is interpreted to be slightly greater than the time of deposition because of the probable incorporation of inherited radiogenic Sr^{87} into the sediment at the time of deposition.

The isotope composition of strontium of a thin bed of limestone in the basal portion of the Nonesuch Shale was measured. The $\text{Sr}^{87} / \text{Sr}^{86}$ ratio was found to be 0.7058. Using the data of Hurley, Fairbairn and Pinson on the isotope composition of carbonate rocks, a time of deposition of about 1000 m.y. is indicated for this limestone. This appears to be the first age determination of a carbonate rock by the isotope composition of its strontium.

The isotope composition of lead extracted from chalcocite in the ore at the White Pine Mine was found to be anomalous. This suggests that the lead in the ore was mixed with radiogenic lead and favors an epigenetic rather than a syngenetic origin for the copper sulfide in the basal portion of the Nonesuch Shale.

(1) Department of Geology, Kansas State University; Manhattan, Kansas.
(2) Department of Geology, The Ohio State University; Columbus, Ohio.

GEOCHEMISTRY OF THE NIPISSING DIABASE

John A. Colwell⁽¹⁾

The Nipissing quartz diabase intrusives occur as sheets and dykes intruding the Huronian rocks in the area between the eastern end of Lake Superior and Lake Temiskaming. An acceptable age for the Nipissing is about 2.1 billion years * , and is significant in placing a lower limit on the age of the Huronian in Ontario.

Petrographic, chemical, and spectrographic studies indicate that the various phases of the diabase, which range from olivine norites to granophyres and aplites can be explained as due to gravitational differentiation of the diabase magma. Lateral as well as vertical differentiation has occurred in the sheet intrusions due to their undulating character.

* References:

- Lowdon, J. A., et al. 1963. Age determinations and geologic studies. Geological Survey of Canada Paper 62-17, p. 92.
- VanSchumus, R. 1965. The geochronology of the Blind River-Bruce Mines Area, Ontario, Canada. Jour. Geol., v. 73, p. 755-780.

(1) Department of Natural Science, Michigan State University;
East Lansing, Michigan.

A REGIONAL GEOPHYSICAL STUDY OF
THE PORT COLDWELL COMPLEX, ONTARIO

John D. Corbett⁽¹⁾, William J. Hinze⁽²⁾, and George B. Secor⁽²⁾

Regional geophysical studies were conducted on the north shore of Lake Superior in the vicinity of Marathon, Ontario, to study the structure of the Port Coldwell Complex, a sub-circular intrusive approximately 16 miles in diameter. Surface geological mapping indicates that the complex is composed predominately of syenitic rocks with a discontinuous peripheral band of gabbro.

A positive magnetic anomaly is associated with the intrusive, but strong negative anomalies correlate with the gabbro on the east and northeast margins. Analysis of a suite of oriented samples shows that the gabbroic rocks have a strong, variable remanent magnetic polarization. The results of two and three dimensional magnetic model analysis, using both induced and remanent magnetic polarizations, proved to be only partially successful in matching the observed anomaly.

A highway gravity profile from White River to Schreiber, Ontario, a distance of 110 miles, shows a positive 65 milligal gravity anomaly over the Port Coldwell Complex. Comparison of this anomaly with the theoretical gravity effect of two and three dimensional models based upon available geological information indicates that the Complex consists primarily of gabbroic rocks extending to a depth of 8 miles. The intrusive is an asymmetric truncated funnel structure having a near vertical contact on the east and an approximate 45° contact on the west.

Combined gravity and magnetic analysis utilizing Poisson's relation was employed as an alternate method of investigating the physical properties of the intrusive. The results of this study verify the presence of a strong remanent magnetic polarization associated with the gabbro along the eastern margin and also indicate a strong, positive remanent magnetic field over the central portion of the complex. This evidence suggests an explanation for the difficulty in matching the observed magnetic anomaly with the magnetic model study.

(1) Geophysical Division, The Anaconda Company; Tooele, Utah.

(2) Department of Geology, Michigan State University; East Lansing, Michigan.

PRELIMINARY MAGNETOTELLURIC RESISTIVITY
RESULTS ACROSS THE WISCONSIN ARCH

Forrest L. Dowling⁽¹⁾

Magnetotelluric resistivity measurements have been made at five of a projected fourteen sites across the Wisconsin Arch. Surface electric impedances are being computed from the measurements to yield apparent resistivity and phase information as a function of frequency. Resistivity models of the crust and upper mantle are fitted to the measured curves. Tentative results are to be presented.

(1) Geophysical and Polar Research Center, University of Wisconsin; Madison, Wisconsin.

STRATIGRAPHY, STRUCTURE, AND METAMORPHISM OF ROCKS
IN THE UPPER PART OF THE ANIMIKIE SERIES IN THE
MARENISCO-WATERSMEET AREA, MICHIGAN *

Crawford E. Fritts⁽¹⁾

Recently completed mapping has shown that a monoclinial sequence including the Copps Formation of Allen and Barrett (1915) and four conformably overlying stratigraphic units is at least 40,000 feet thick. This sequence is placed above the Menominee Group within the Animikie Series of James (1958) and is interpreted as one of the least deformed parts of what Allen and Barrett (1915, p. 131) referred to as the "Michigamme slate series" of late Huronian age. A thin conglomeratic quartzite at the base of their Copps Formation is correlated with Goodrich Quartzite of the Marquette district. At least 10,000 feet of graywacke-slate of the Copps Formation and many thousands of feet of east-trending, graywacke-slate in the upper part of the monocline near Paulding are lithologically similar to rocks in the Marquette and Iron River -Crystal Falls districts mapped as Michigamme Slate, which previously was thought to be about 5,000 feet thick. It would appear that east-trending rocks formerly interpreted as isoclinally folded Michigamme Slate in a broad region east of the map area may actually be part of the monoclinial sequence.

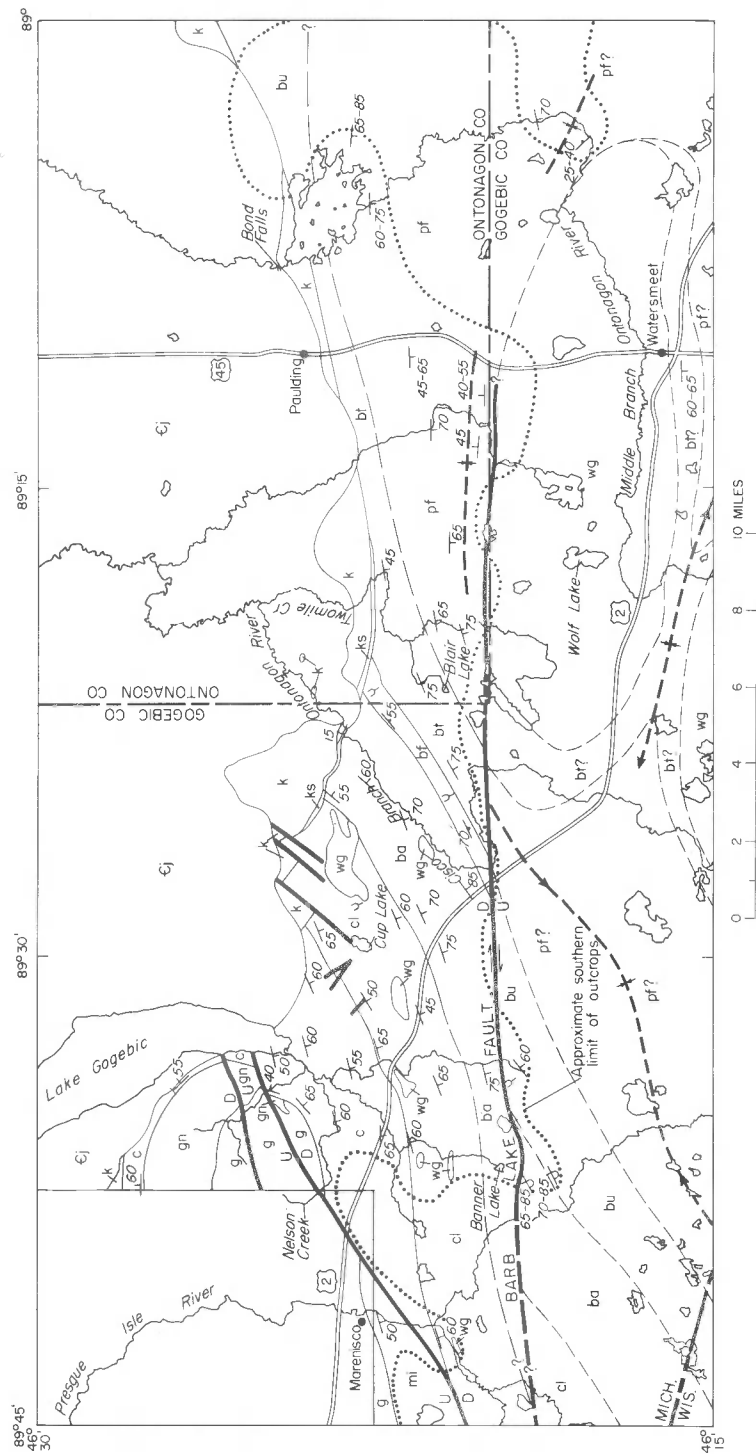
An east-trending fault accounts for a 5-mile apparent right lateral offset of Animikie rocks near Barb Lake and for the abrupt termination of iron-formation at the Banner exploration. The fault also forms the north boundary of a dome-like stock of the Wolf Lake Granite of Allen and Barrett (1915). Emplacement of this granite, metamorphism of the Animikie Series, and displacement along the fault most likely occurred during the Penokean orogeny in post-Animikie, pre-Keweenawan time.

References:

- Allen, R. C., and Barrett, L. P., 1915, Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geol. and Biol. Survey, Pub. 18, geol. ser. 15, p. 13-164.
Hamblin, W. K., 1958, The Cambrian sandstones of northern Michigan: Michigan Geol. Survey Pub. 51, 146 p.
James, H. L., 1958, Stratigraphy of pre-Keweenawan rocks in parts of northern Michigan: U.S. Geol. Survey Prof. Paper 314-C, p. 27-44.

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

(1) U. S. Geological Survey; Denver, Colorado.



CAMBRIAN		Animikie Series		PRECAMBRIAN	
[[[	€j Jacobsville Sandstone of Hamblin (1958) UNCONFORMITY	Upper part	k / ks Keweenaw Series k, mafic lava flows ks, quartzitic sandstone UNCONFORMITY	Graywacke near Blair Lake Upper part includes magnetic iron-formation, especially south of Barb Lake fault	ba

Figure 1.--Generalized geologic map of the Marenisco-Watersmeet area, Mich.

INFLUENCE OF FAULTING ON DEPOSITION OF
CLASTIC INTERBEDS IN NEGAUNEE IRON-FORMATION
NEAR PALMER, MICHIGAN *

Jacob E. Gair⁽¹⁾

Interbeds and lenses of clastic sedimentary rocks--graywacke and impure quartzite--are conspicuous in the chemically deposited hematitic, magnetitic, and sideritic Negaunee Iron-Formation near Palmer, Michigan (S. A. Tyler and W. H. Twenhofel, 1952; J. T. Mengel, 1956; J. F. Davis, 1965.) The clastic interbeds range in thickness from about 1/30 inch to 50 feet. Detrital quartz occurs not only in discrete layers but also as scattered grains in many ferruginous laminae of iron-formation. Clastic sediment in the south-central part of the Palmer basin makes up 5 to 9 percent of the Negaunee: 3 to 6 percent measured in discrete layers and an estimated 2 to 3 percent as scattered quartz grains. In any one drilled section, there are hundreds of rather evenly spaced clastic lenses less than 1/2 inch thick and relatively few irregularly spaced layers more than 1 foot thick. In several drill cores of 300 to 700 feet of iron-formation, only a few intervals of more than 10 feet do not contain some clastic sedimentary beds.

In contrast to the iron-formation near Palmer, the Negaunee of neighboring areas and Precambrian iron-formation generally are virtually devoid of clastic debris. The depositional environment near Palmer during Negaunee time, therefore, must have differed in some respect from that of neighboring areas and from that of most other Precambrian iron-formations.

South of the areas of clastic-bearing iron-formation--along the south edge of the Palmer basin and to the west for about 2 miles along the flank of the Marquette synclinalorium--granitic gneiss older than the Negaunee has been uplifted to the south along conspicuous zones of shearing and faulting. Although most of the movement in the fault zones occurred after deposition of the Negaunee Iron-Formation, it is inferred from the presence of clastic-bearing iron-formation adjacent to the faults that displacement began at least as early as Negaunee time, and that the clastic material in the iron-formation was eroded

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

(1) U. S. Geological Survey; Detroit, Michigan

from the up-faulted areas of gneiss. The numerous small lenses of clastic sediment isolated in the iron-formation suggest that unconsolidated detritus collecting at the edge of upfaulted areas was repeatedly dislodged in small portions by minor crustal movement in the fault zones and dumped into iron-silica muds accumulating to the north.

References:

- Davis, J. F., 1965a (1) A petrologic examination of iron-formation associated graywackes and pyroclastic breccias within the Negaunee formation of the Palmer area, Marquette district, Michigan: Unpub. Ph.D. thesis, University of Wisconsin, 179 p.
- (2) Petrology of Precambrian iron-formation and associated rocks, Palmer area, Marquette district, Michigan: Geol. Soc. Am., Program, 1965 Annual Meeting, p. 42.
- Mengel, J. T., Jr., 1965, The relationship of clastic sediments to iron-formation in the vicinity of Palmer, Michigan: Unpub. M. S. thesis, University of Wisconsin.
- Tyler, S. A. and Twenhofel, W. H., 1952, Sedimentation and stratigraphy of the Huronian of upper Michigan: Am. Jour. Sci., V. 250, p. 1-27; 118-151.

GEOCHRONOLOGY IN THE LAKE SUPERIOR REGION

S. S. Goldich⁽¹⁾

During the past 10 years advances in the analytical techniques and a growing appreciation of the geologic factors have broadened the scope and usefulness of radiometric dating. Specific advances include improvement in the lead-alpha method, application of K-Ar to amphiboles, development of Rb-Sr through the whole-rock and mineral-component technique, and the wider application of U, Th-Pb isotopic analyses.

Early lead-alpha age determinations on Lake Superior rocks are not reliable. The large number of K-Ar and Rb-Sr determinations made in a number of laboratories, largely on micas, are analytically reliable within the limits of error assigned. The micas, however, are highly susceptible to metamorphism, and mica ages, as a result, cannot be assumed to give the time of initial crystallization or formation. In some cases K-Ar ages on hornblende have given some assistance, but the greatest progress in penetrating the metamorphic barriers has come through the use of Rb-Sr and U-Pb analytical procedures.

K-Ar and Rb-Sr age determinations on micas from the Morton Gneiss of southwestern Minnesota, for example, indicate an age of 2.5-2.6 b.y. The improved lead-alpha method, however, gave an age of 3.0 b.y. for zircon, and isotopic U-Pb determinations on zircon from the Morton Gneiss gave $\text{Pb}^{207}/\text{Pb}^{206}$ ages of 3.2 b.y. and a concordia age of 3.5 b.y.

Isotopic U-Pb age determinations on zircon concentrates and Rb-Sr data for whole-rock and mineral component samples from the Lake Superior region show some of the geologic complexities that are now becoming apparent. One of the geologic factors that complicates the interpretation of radiometric ages is the effect of weathering on the K-Ar, Rb-Sr, and U-Pb decay systems.

(1) Department of Earth and Space Sciences, State University of New York; Stony Brook, New York.

IDENTIFICATION OF SEISMIC REFRACTORS IN THE LAKE SUPERIOR SYNCLINE

H. C. Halls⁽¹⁾ and G. F. West⁽¹⁾

P-wave velocities at hydrostatic pressures of up to 2 kilobars have been measured in Keweenawan volcanic and sandstone cores collected from numerous localities around Lake Superior. Seismic refraction surveys seem to indicate as many as four refractors within the upper 15 Km. of the crust beneath the lake. An attempt here is made to identify the refractors in terms of Keweenawan geology by comparing the velocities obtained in the laboratory and the field. Some implications of these results on the regional structural picture will be presented.

(1) Geophysics Laboratory, Department of Physics; University of Toronto; Toronto, Ontario.

K-Ar HORNBLENDE AGES FOR GRANITES AND GNEISSES
AND K-Ar AGES FOR DIKES IN MINNESOTA

Gilbert N. Hanson⁽¹⁾

A number of investigators have shown that hornblendes retain radiogenic argon during metamorphism to a greater extent than do the micas. As a comparison with K-Ar and Rb-Sr ages for biotite and other ages, such as zircon U-Pb, K-Ar ages have been determined on hornblende concentrates from six igneous and metamorphic rocks in Minnesota.

Hornblende from the Giants Range Granite near Ely gives an average K-Ar age of 2.6 by, from the Saganaga Granite an average age of 2.65 by, from the Knife Lake schist near Birch Lake an age of 2.65 by, from the Rockville Porphyritic Granite at Rockville an age of 1.80 by, from the Morton Quartz Monzonite Gneiss at Morton an average age of 2.6 by, and from the hornblende-pyroxene gneiss at Granite Falls an age of 2.75 by. In each case the hornblende age is essentially the same or older than the biotite ages and essentially the same or younger than the zircon U-Pb ages.

Mineral and whole-rock K-Ar ages indicate that besides the late Keweenawan mafic intrusions at about 1.1 by there are two more periods of mafic intrusion in Minnesota at 1.6-1.8 by and at about 2.1 by.

(1) Department of Earth and Space Sciences, State University of New York; Stony Brook, New York.

HYDROCARBON COMPOUNDS IN IGNEOUS ROCKS

E. Wm. Heinrich⁽¹⁾

Solid uraniferous hydrocarbon compounds in igneous and hydrothermal rocks have long been known (1868) from Swedish (granite-gneiss, iron-ore skarns, pegmatites, veins), Canadian (pegmatites), and Australian occurrences (Cu lodes). In 1928 Ellsworth applied "thucholite" (Th, U, C, H, O-lite) to radioactive hydrocarbon in pegmatites in Ontario and Quebec. Since then other occurrences of thucholite have been noted in veins and lodes, including Boliden, Sweden; Goldfields, Saskatchewan; Port Arthur and Blind River, Ontario; Laxey, Isle of Man; Witwatersrand, South Africa; and Front Range, Colorado. Non-radioactive hydrocarbons in such deposits, being less conspicuous, have not been recorded as frequently. Among these are solid bitumen and methane in the Keweenaw Cu-bearing basalts of northern Michigan. Until recently all such material was reported only from calc-alkalic igneous rocks (granite to basalt) and their derivative dikes, veins and lodes.

In the late 1950's organic compounds (solid and gaseous) were discovered in alkalic rocks of the Kola Peninsula, U.S.S.R. In the Khibina and Lovozero massifs large quantities of hydrocarbon gases occur in intergranular pores, microfractures and vacuoles in minerals. They are composed of 70-90% hydrocarbons and 3-10% hydrogen with some CO₂ and CO. Among the hydrocarbons methane predominates; also present are ethane, propane, commonly isobutane, rarely pentane. Volumes up to 243 cm³/kg have been obtained.

In Colorado carbonatites and related thorium veins in the Wet Mountain district (Fremont and Custer Counties) and in the Iron Hill district (Gunnison County) have long been known to emit fetid gas when broken. Our studies on the Goldie carbonatite show this gas is a mixture of C₅ and C₆ hydrocarbons along with F₂, HF and F₂O. The fluorine has been derived from the radioactive structural degradation of fluorite, and the noisome odor comes from the fluorinated hydrocarbons.

Several genetic theories have been applied to the origin of thucholites: 1) radioactive polymerization of natural gas or petroleum; 2) interaction of uraninite and aqueous solutions containing organic materials (oil-water emulsion); 3) derivation from humic coal constituents. Whatever the process, there is evidence that this carbon at one time was biogenic-sedimentary. For gaseous

(Continued next page)

(1) Department of Geology and Mineralogy, The University of Michigan; Ann Arbor, Michigan.

and solid hydrocarbons of alkalic rocks and carbonatites the evidence is strong that these compounds are primary and magmatic or hydrothermal and that the carbon is juvenile:

1. They occur in primary vacuoles formed and filled at the time of crystallization of such host rock-forming species as nepheline.
2. The ratios of individual hydrocarbon compounds are specific for a particular mineral.
3. Wall rocks of the complexes contain anomalously high amounts of methane for about 100 meters from the contact.
4. No geologically realistic models can be constructed that show that sedimentary natural gas or petroleum could have reached the alkalic rocks.
5. The $^{12}\text{C}/^{13}\text{C}$ ratio of gases and bitumens from alkalic rocks differs markedly from those of sedimentary gases and petroleum.

A STUDY OF CLASTICS IN THE NEGAUNEE IRON FORMATION OF MICHIGAN

Robert W. Henny⁽¹⁾

An investigation was conducted on the relationships between a number of clastic lens-shaped bodies and a portion of the Negaunee Iron Formation. The principal study area was located at the abandoned Moore Mine in the Cascade Range, a downfaulted block on the southern flank of the Marquette Synclinorium, approximately 12 miles south of Negaunee, Michigan. Here the iron formation is continuously exposed in cross-sectional profile along its strike for a distance of 0.3 mile (360 feet wide.)

More than forty clastic lenses ranging from a foot to over a hundred feet in length and up to fifty feet in width were mapped in detail. The depositional relationships between the lenses and the iron formation are varied; the majority of lenses are essentially conformable with the iron formation. Some of the conformable lenses are gradational at their lateral boundaries, some exhibit miniaturized on-lap off-lap features, while others have merely warped the underlying layers of iron formation. The unconformable lenses are of two types, channel fills and isolated blocks.

The iron formation contains a two percent background of rounded sand grains which are equally dispersed among the chert and hematite layers. This percentage of sand grains is observed to increase noticeably when a clastic lens is approached from beneath.

The clastics consist of metamorphized mixtures of rounded and angular fragments of chert, hematite, quartz, quartzite and granite, together with varying quantities of sand all in a matrix consisting of varying proportions of shale, chert and hematite. Petrographic and binocular analyses were used to divide the clastics into five lithological groups and a number of sub-groups on the basis of their mineralogical and textural characteristics. It is deemed significant that only one lithology is found in a given lens and that a particular lithology always maintains the same depositional relationship with the iron formation. A method for chemically disaggregating some of the clastics was developed enabling roundness, sphericity, and size distribution analyses to be made. Results showed the sand grains to be similar to those found in typical beach washed sands.

Using the above relationships, mechanisms of deposition are postulated for each lens type. The analysis is then extended to several other clastic zones in the immediate vicinity with areal correlations made.

(Continued next page)

(1) Department of Geology, Michigan State University; East Lansing, Michigan.

Conclusions would support a shallow water environment of deposition where chert and hematite were deposited in alternating layers under proper environmental conditions. The major source of clastics was derived from a low lying land mass to the south. Except for one occurrence all the clastics observed appeared to have been well worked sediments prior to their transportation into the basin. Re-worked beach sands were regularly supplied to the basin while occasionally off-shore currents created lenses and beds of sands out into the basin. The dispersion of these sands appears to have been a normal condition in the area since they are observed throughout the area.

During intervals when portions of the basin were above wave base or even above water level, clastics were introduced to the basin by stream transport. Finally at a few localized areas large masses of clastics were rapidly deposited via slides and/or turbidity currents.

KEWEENAWAN VOLCANIC ROCKS NEAR IRONWOOD, MICHIGAN *

Harold A. Hubbard⁽¹⁾

Two sequences of Keweenawan volcanic rocks are present in the Ironwood area, Michigan, west of the 90th meridian. A younger sequence, about 15,000 feet thick, is equivalent to the Portage Lake Lava Series of Keweenaw Point. An older sequence of traps of the South Range, about 8,000 feet thick, is separated stratigraphically from the younger rocks by more than 7,000 feet of sedimentary rocks. These volcanic rocks have previously been described as one continuous sequence.

The equivalents of the Portage Lake may be traced to outcrops of the Portage Lake Lava Series on Keweenaw Point by a continuous broad band of large linear magnetic anomalies. Their lithologic continuity is also confirmed by the presence of many ophitic basalts and volcanic conglomerates in both areas.

The upper flows of the South Range contain groundmass feldspars that are uniformly more sodic, and generally finer grained, than the Portage Lake flows. A few of the upper South Range flows are porphyritic, having feldspar phenocrysts as much as 1-1/2 inches across. The lowermost South Range flows are interbedded with a few well-sorted lower Keweenawan-type sandstones. West of Bessemer, the lowest flow is a "pillow" lava whose emplacement locally contorted the upper few inches of the underlying even-bedded sandstone layer. These features indicate that the lower Keweenawan sandstones in the South Range traps probably are an uninterrupted sequence. Re-examination of regional relationships may show that the oldest volcanic rocks in some localities should be assigned to the lower Keweenawan or that the middle Keweenawan should be sub-divided.

Although no consolidated rocks are exposed in the 2-mile-wide belt between the uppermost South Range extrusive rock and the lowermost Portage Lake flow, the belt is characterized by uniformly small magnetic anomalies that differ in character from those of the South Range and Portage Lake volcanic sequences. These unexposed units

(Continued next page)

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

(1) U. S. Geological Survey; Washington, D. C.

are probably sedimentary rocks or acid volcanic rocks. East of the Ironwood area, the band of linear magnetic anomalies associated with the South Range traps diverges from that of the Portage Lake.

Kenneth Books of the U. S. Geological Survey has found that the paleomagnetic field directions of the Portage Lake Lava Series near Ironwood are similar to those of the lavas of Keweenaw Point, and that the paleomagnetic field directions of the South Range traps are distinctly different. The paleomagnetic properties of the rocks within each sequence are internally consistent. For these reasons a significant age difference between the sequences is indicated.

GRAVITY ANOMALIES OVER LAKE SUPERIOR AND SURROUNDING AREA AND THEIR STRUCTURAL IMPLICATIONS

M. J. S. Innes⁽¹⁾ and A. K. Goodacre⁽¹⁾

During 1963 and 1964 the Dominion Observatory carried out reconnaissance underwater gravity measurements in Lake Superior, and regional gravity surveys over the adjacent Canadian Shield in Ontario. These surveys outlined large areas of relatively positive Bouguer anomalies in Lake Superior and in a zone extending 600 km north from Chapleau through Kapuskasing to Moosonee on James Bay. The anomalous areas reflect large quantities of basic material that have been emplaced high within the crustal column, perhaps through process of crustal rifting. Geological and geophysical mapping by provincial and federal government departments has defined a north to north-east trending zone of shearing and faulting with associated linear magnetic anomalies. This fault zone, and the gravity and magnetic anomaly belts cut directly across regional trends of early Precambrian rocks. Uplifted blocks of high-grade metamorphic rocks, minor basic and ultrabasic intrusions, and the presence of alkaline intrusive complexes together with the disappearance of the Archaean volcanic-sedimentary rocks along the axis of the gravity high suggest that the Kapuskasing fault zone may be a deeply-eroded counterpart of an East African rift valley. Gravity and magnetic anomaly patterns over the Michigan Basin suggest a possible extension of this structure to the south.

(1) Dominion Observatory, Department of Energy, Mines, and Resources; Ottawa, Ontario.

SOME PROPERTIES OF MICHIGAN CHERTS

Allan M. Johnson⁽¹⁾ and Albert P. Ruotsala⁽¹⁾

Michigan Pleistocene gravel deposits contain some aggregate types that fail under freeze-thaw and other severe conditions. Cherts, of the variety associated with carbonate rocks, comprise a large percentage of the non-durable aggregate.

The major minerals comprising cherts, in highly variable proportions, are quartz, calcite, and dolomite. X-ray diffraction patterns exhibited peaks attributable to clay minerals and possibly some unstable hydrated calcium silicates.

Textures of the minerals comprising cherts also vary considerably. Petrographic studies of quartz showed that sizes varied from coarse sand to cryptocrystalline varieties. An X-ray line broadening technique indicated an average grain size of 700 angstroms for cryptocrystalline quartz.

Water vapor adsorption values were variable and apparently reflected the available surface area. Cation-exchange capacities of Michigan cherts were found to be low and on the order of those exhibited by kaolinite (3 to 15 meq/100 gm). Evidently these two phenomena are related.

Dissolution rates of calcium and magnesium from cherts were also variable and may be useful in predicting the durability of chert under freeze-thaw conditions.

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REFRACTION SEISMIC SURVEYS ON THE MID-CONTINENT GRAVITY ANOMALY IN MINNESOTA AND WISCONSIN

S. H. Johnson⁽¹⁾ and P. R. Farnham⁽¹⁾

Steep gravity and magnetic gradients over the prominent Mid-continent gravity anomaly suggest major faulting of Middle Keweenawan basic igneous rocks which are thought to underlie Upper Keweenawan red clastics into southeastern Minnesota. Seventy short (4-8 miles) refraction profiles were taken at regular intervals perpendicular to the anomaly trend. Results indicate a vertical displacement of at least 7000 feet along the southward projection of the Douglas fault into eastern Minnesota and a similar vertical displacement along the projection of the Lake Owen fault in western Wisconsin. The resulting horst structure is bounded on both sides by thick wedges of presumably Upper Keweenawan red clastics. No clastics appear to overlie the horst except in possible graben structures within the western part of the horst itself. The presence of thick wedges of sedimentary material on both sides of the horst as suggested by gravity data is confirmed. Underlying the red clastics in the flanking sedimentary troughs appear to be Keweenawan basic extrusive igneous rocks close to the fault and older Precambrian crystalline basement at a greater distance from it. In southeastern Minnesota, the basement is overlain by up to 4000 feet or more of Keweenawan red clastic sandstones and Paleozoic sediments.

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EVIDENCE ON THE PHYSICAL ENVIRONMENT OF IRON-FORMATION DEPOSITION

Gene L. LaBerge⁽¹⁾

Physical features, such as size, shape, and character of the grains, bedding characteristics, and sedimentary textures and structures indicate that iron-formations may have behaved essentially as particulate sediments at the time of deposition. Granule-bearing iron-formations have a grain size and a variety of sedimentary features remarkably similar to those of sandstones. Non-granular (even-bedded or "banded") iron-formations have a grain size and bedding characteristics similar in many respects to siltstones or argillites. There are, in fact, a number of important similarities between iron-formations and clastic limestones which will be pointed out.

Microscopic features in granule bearing iron-formations suggest that many granules have been formed by reworking of earlier formed silt size particles--perhaps from a non-granular iron deposit. In other words, it appears that most iron-formations, particularly the chert in them, may have been initially deposited as silt size particles. The factors controlling the size of these "original(?)" silt size particles is problematical; however, it is possible that their size may have been organically controlled.

Physical conditions, such as depth of water, current action, and wave action would have been paramount in determining whether the resulting deposit was thinly laminated silt size particles or more massively bedded and of sand size grains. If this hypothesis is correct, the nature of observable physical features should provide important clues regarding the depositional environment--both physical and chemical--in which iron-formations formed.

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CHARACTERISTICS OF MAGNETIC DATA OVER MAJOR SUBDIVISIONS OF THE PRECAMBRIAN SHIELD

A. S. MacLaren⁽¹⁾ and Brian Charbonneau⁽¹⁾

Airborne magnetic data when correlated with regional geology indicate major dislocations at contacts of subdivisions of the Canadian Precambrian Shield. These are described between the Superior and Churchill provinces in Manitoba, between the Grenville and Superior provinces south of Sudbury and east of Chibougamau in Quebec.

An internal disruption of the crust in the Superior province is described and contrasted with the "fronts" between the Churchill and Superior provinces and between the Grenville and Superior provinces.

It is concluded that airborne magnetic data is useful in the delineation of major rift zones and sub-provinces in Precambrian Shield areas.

⁽¹⁾ Geological Survey of Canada; Ottawa, Ontario.

SUBDIVISIONS OF THE NEGAUNEE IRON FORMATION
SECTIONS 7, 8, T47N, R26W, MICHIGAN

Joseph J. Mancuso⁽¹⁾ and Jack W. Avery⁽²⁾

Accurate stratigraphic correlations within the Negaunee Iron Formation have been difficult previously because of the apparent mineralogical and textural uniformity present coupled with the lack of persistent marker horizons. However, recent work on the unoxidized and related oxidized iron formation of sections 7 & 8 T47N, R26W has made it possible to subdivide the Negaunee Iron Formation into 8 members based on mineralogy, texture, and metallurgical analyses. The subdivisions, which vary in thickness from less than 50' to over 300', were originally distinguished for economic reasons, but have been clarified, refined and extended to include several marker horizons which can be traced laterally for more than a mile. Members were picked to include layers which could be recognized and traced through the unoxidized iron formation and its oxidized equivalents. (All of the hematite and goethite that has been noted is secondary after magnetite, siderite, or iron silicate.)

Because of stratigraphic work the structure of the northeastern portion of the Marquette Range has been greatly clarified. The extreme apparent thickening of the iron formation and the apparent complex system of diabase sills can be successfully explained by repetition due to a series of east-west and north-west trending fault systems.

The correlations can be traced very generally south through the Bellevue and Empire sections of Cleveland Cliffs but more detailed work must be done in order to delineate facies changes and thickness changes in the individual members.

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(2) Jones & Laughlin Steel Corporation; Negaunee, Michigan.

RELATIONSHIP BETWEEN SEISMIC AND AEROMAGNETIC
SURVEYS, EASTERN LAKE SUPERIOR

R. P. Meyer⁽¹⁾ and L. Ocola⁽¹⁾

In the course of seismic work along the 1963 east-west Main Line a fault has been found in about the position predicted from aeromagnetic data (Hinze, et al) . Seismic evidence rests principally on the redundancy of data provided by three remote-controlled tape recording buoys moored northeast of Keweenaw Point combined with data taken by the University of Toronto at Otter Cove, Ontario, in 1963 (Steinhart) .

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MINERALOGY AND PETROLOGY OF THE MINERAL LAKE INTRUSION, NORTHWESTERN WISCONSIN

James F. Olmsted⁽¹⁾

The Mineral Lake Intrusion is a 4500 meter thick tabular body which has been emplaced near the base of the Middle Keweenaw volcanic series of northwestern Wisconsin. It is a moderately well differentiated strataform intrusive consisting of: ultrabasics 1%, anorthositic olivine gabbro 11%, gabbroic anorthosite and anorthosite 73%, ferrodiorite 8% and granitic rocks 7%. A basal chill zone has been located and its iron rich composition indicates that it is not representative of the whole intrusive but is the product of the differentiation.

A pronounced primary laminar arrangement of plagioclase laths is developed parallel to the base of the intrusion, suggesting the direction of flow during emplacement, but with rare exception, compositional layering is absent. Cryptic zoning of the mineral constituents has been determined with compositions varying from the base upward as follows: Clinopyroxene (Wo_{39} , En_{42} , Fs_{19}) to (Wo_{36} , En_{28} , Fs_{36}), Orthopyroxene (En_{70} , Fs_{30}) to (En_{42} , Fs_{58}), Olivine (Fo_{65} , Fa_{35}) to (Fo_{22} , Fa_{78}) and Plagioclase (An_{60}) to (An_{20}). Plagioclase composition is constant from just above the basal chill zone nearly to the base of the ferrodiorite, suggesting that during crystallization the plagioclase was in contact with a large volume of liquid. Olivine is confined to the lower anorthositic olivine gabbro and the ferrodiorite.

The trend of fractionation toward enrichment in iron and decrease in silica is similar to that of most large basic intrusions in which crystallization took place under low P_{O_2} conditions. This is confirmed by the strongly reduced state of iron throughout much of the intrusion. The highly anorthositic composition is explained by early crystallization of large amounts of mafic minerals which tended to settle in the magma body during its upward transport, while the lower density, more tabular plagioclase crystals were carried upward and concentrated at higher levels. The iron rich chill zone further indicates that considerable amounts of magnesian mafic minerals were removed from the magma before it reached the present level of exposure.

(Continued next page)

(1) College of Arts and Sciences, State University of New York; Plattsburgh, New York.

The strong orientation of the plagioclase laths and lack of compositional banding supports the view that any movement of the magma was in one direction (parallel to the base and upward along its tilted surface) rather than in the form of convection currents. This hypothesis is further supported by the presence of small volumes of ultrabasic rocks near the base and gradual upward decrease in mafic content until the anorthositic composition is obtained.

OXYGEN ISOTOPIC EVIDENCE OF METAMORPHISM IN THE BIWABIC IRON-FORMATION, MINNESOTA

E. C. Perry, Jr.⁽¹⁾ and J. W. Morse⁽¹⁾

Oxygen isotope fractionation between coexisting quartz and magnetite (expressed as $1000 \ln \alpha_{OM}$) has been measured in samples collected along the easternmost 60 miles of the Biwabic Iron-formation outcrop belt. Fractionation varies from about 7.5 (corresponding to about 700° C) at the Duluth Gabbro Complex contact to a maximum value of 24.3 (which probably corresponds to a temperature of $\leq 100^\circ$ C). The metamorphic aureole produced by the Duluth Gabbro Complex is narrow and isotope fractionation measured between Auroa and Keewatin is constant within 1.5 units.

⁽¹⁾ Minnesota Geological Survey, The University of Minnesota;
Minneapolis, Minnesota.

GEOLOGY OF PART OF THE EAST GOGEBIC
IRON RANGE, MICHIGAN *

William C. Prinz⁽¹⁾

Recent work in and near T. 47 N., R 44 W. in the East Gogebic iron range essentially substantiates the mapping reported by R. C. Allen and L. P. Barrett in 1915, with a few noteworthy exceptions. Apparent thickening of the Ironwood Iron-Formation is now attributed to repetition of beds by strike faults; and the so-called "great graywacke-slate member" of the Ironwood is probably the Palms Quartzite brought up along these faults. Mafic volcanic breccia or agglomerate, tuff, and greenstone in the eastern part of the township are interbedded with rocks equivalent to either the upper part of the Ironwood Iron-Formation or the Tyler Slate. These strata are overlain unconformably by the Copps Formation of Allen and Barrett (1915). Large sills of mafic igneous rock that cut the Ironwood Iron-Formation have been metamorphosed, and one of them is truncated by Keweenawan basalt flows; they are therefore older than the Keweenawan.

The unconformity at the base of the Copps still is recognized as one of great magnitude, but no evidence has been found to indicate that granite was emplaced during the post-Ironwood, pre-Copps interval. In this area, the Presque Isle Granite is a mixture of granite gneiss, and schist of early rather than middle Precambrian age. Rocks formerly described as "metamorphic phases" of the Palms Quartzite adjacent to the granite are mainly lower Precambrian gneiss. The close proximity of iron-formation and gneiss in the southeastern part of the township and the local absence of the Palms Quartzite are explained by faulting.

The geologic structure of the Animikie Series is complex in the eastern part of T. 47 N., R. 44 W. and the western part of T. 47 N., R. 43 W. To the west the period of major deformation of these rocks postdated the Keweenawan basalt flows, whereas to the east it was pre-Keweenawan.

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

(1) U. S. Geological Survey; Beltsville, Maryland.

STRUCTURE AND STRATIGRAPHY, INCLUDING PRECAMBRIAN TILLITE,
IN EASTERN DEAD RIVER BASIN, MARQUETTE COUNTY, MICHIGAN *

Willard P. Puffett⁽¹⁾

The Dead River Basin in Marquette County, Michigan is a northwest-trending lowland floored by metasedimentary rocks of middle Precambrian age. Lower Precambrian rocks bound this basin in the Negaunee 7 1/2' quadrangle; they include layered amphibolite and massive greenstone of the Mona Schist on the north border and granodiorite and syenite on the east and south. Sheared metavolcanic rocks, mainly rhyolitic tuff, extend into the central part of the basin from the east, separating metasedimentary rocks on the south from those on the north.

The metasedimentary rocks in the southern part of the basin include thin conglomerate, ferruginous graywacke, a thin iron-formation, and a thick sequence of slate, in part pyritic and carbonaceous. These strata are correlated with the Michigamme Slate.

The metasedimentary rocks underlying the north flank of the basin are markedly different from those on the south, and include coarse conglomerate as much as several hundred feet thick, conglomeratic graywacke, and chloritic graywacke and slate. A few contorted thin beds of pinkish-gray arkose are interbedded in the slates. These north-flanking rocks are probably in the basal part of the Animikie Series and are much older than the metasedimentary rocks underlying the southern part of the basin, which have been downfaulted for hundreds to thousands of feet along a zone of shearing now occupied by the metavolcanic rocks.

Of particular interest in the northern group of strata are widely scattered rounded to subangular boulders of granitic rocks in the slates and graywackes. These boulders range in size from a few inches to nearly two feet in diameter. In some areas only one or two boulders are present in exposures of several hundred square feet of slates and graywackes; in other areas the boulders form lenses or beds that can be traced for several tens of feet. The anomalous occurrence of the very coarse material in the slates and graywackes is a significant and identifying feature of rocks that are considered tillites in other Precambrian terranes, and a glacial origin is suggested for the metasedimentary rocks north of Dead River in the Negaunee 7 1/2' quadrangle.

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

⁽¹⁾ U. S. Geological Survey; Marquette, Michigan.

COPPER MINERALIZATION IN ANIMIKIE SEDIMENTS OF THE
EASTERN MARQUETTE RANGE, MICHIGAN

R. C. Reed⁽¹⁾

Early exploration in Kona dolomite of Middle Precambrian age exposed copper mineralization at three locations in the eastern Marquette iron range. Veins of copper minerals were also encountered in iron formation in a mine at Ishpeming, Michigan. This is one of two areas of significant copper in Animikie sediments known to the writer.

The eastern-most mineralization is located in the NE 1/4 NW 1/4 section 1, T. 47 N., R. 25 W. Chalcocite occurs in a tan, highly-sheared siliceous slate, in veins and irregular masses, occasionally replacing pyrite. It is closely associated with quartz, chlorite, sericite and minor dolomite. At depth, some native copper is also found in red quartzite, occupying fractures and interstitially replacing quartz boundaries.

Chalcopyrite replaced by minor bornite is found approximately 4500 feet to the west in the NW 1/4 SE 1/4 section 2 of the same township. It occurs in veins, pods and coarse clastic bands in gray and tan slate. This mineralization, also, is associated with quartz, dolomite, chlorite and sericite.

On the north limb of the syncline, near Enchantment Lake, copper was exposed by a test pit in the SW 1/4 NE 1/4 section 32, T. 48 N., R 25 W. Chalcopyrite, bornite, chalcocite are present in siliceous dolomite and vein quartz. Specular hematite and pyrite also occur.

Veins of copper mineralization were exposed by development in the Cliffs Shaft iron mine in section 10, T. 47 N., R 27 W. The veins cut the upper part of the Negaunee iron formation approximately 725 feet below the surface. The dominant mineral is bornite followed by chalcopyrite, pyrite and hematite. Bornite replaces chalcopyrite and is in turn penetrated by specular hematite. Most of the pyrite occurs as somewhat spherical masses of crystals enclosed in quartz.

Spectrographic analysis of ore samples from the Kona formation show the mineralized rock to be practically devoid of trace elements. Some titanium and manganese exist and barium and strontium were found in the eastern-most mineralized area.

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(1) Geological Survey Division, Michigan Department of Conservation;
Lansing, Michigan.

It is concluded that this mineralization most nearly approximates copper sulphides with some native metal found within and surrounding intrusives in the Keweenawan of Michigan. Similar mineralization has been reported within and adjacent to Keweenawan diabase intruding Animikie sediments in Minnesota.

G. B. Secor⁽¹⁾, W. J. Hinze⁽¹⁾, N. W. O'Hara⁽¹⁾ and J. W. Trow⁽¹⁾

A regional aeromagnetic survey was conducted to determine the basement geology and tectonics of Lake Huron. During this survey approximately 6100 miles of flight lines spaced at six mile intervals were recorded with a digital recording proton precession magnetometer.

The analysis of the aeromagnetic data combined with known geology suggests the following interpretation. The gneiss-amphibolite assemblage of Grenville age found in the northwestern portion of the Parry Sound District extends under Georgian Bay to the eastern shore of the Bruce Peninsula. A granite gneiss province underlies the Bruce Peninsula and continues southward toward Lake St. Clair. A discontinuous belt of positive magnetic anomalies extends from the Thumb of Michigan northeasterly to Killarney, Ontario. These anomalies originate from basic rocks, perhaps amphibolite such as are encountered elsewhere in the Grenville Province. The western portion of Lake Huron is divided into four major magnetic provinces with approximately east-west boundaries. The northern province coincides with the Penokean Fold Belt. The province immediately to the south in the vicinity of the North Channel is predominately granitic. This province lies adjacent to a basic igneous complex which extends south to Rogers City, Michigan. The province south of Rogers City and north of Alpena, Michigan has tentatively been correlated with an extension of the Animikie lithologies from the Northern Peninsula of Michigan. The Grenville Front trends southwesterly from the vicinity of Killarney, Ontario, through the eastern end of Manitoulin Island and continues southward to the northern tip of the Thumb of Michigan.

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HEAT FLOW IN LAKE SUPERIOR

John S. Steinhart⁽¹⁾, S. R. Hart⁽¹⁾, and T. J. Smith⁽¹⁾

The Lake Superior region is of particular interest to heat flow studies because of its location on-trend with the mid-continent gravity high and its situation on a crust which reaches anomalous thickness (>55 km). During summer 1966, 92 heat flow stations were occupied from the U. S. Coast Guard cutter Woodrush, concentrated chiefly in the central and western areas of the lake. Using oceanic sediment probe techniques, 75 of these stations achieved sediment penetrations (5-7 meters) such that corrections for the annual temperature cycle of the bottom water are rather small ($<10\%$). Uncorrected heat flow values for these stations range from $0.43 - 1.24 \mu \text{ cal/cm}^2\text{-sec}$, and delineate two distinct regions: a belt along the western shore characterized by low values ($0.4 - 0.9$) and a central region of higher but very uniform values ($1.0 - 1.2$). The twenty measurements in this central region, covering an area of 5000 km^2 , show a mean deviation of less than 5%, and the average value for the region agrees within 10% with adjacent land borehole measurements reported by Roy and Birch. Values in the eastern lake are too scattered to establish a pattern but suggest at least a small region of lower values ($0.7 - 0.8$), with variations of up to 0.4 occurring in lateral distances of 15 km. A general correlation seems to exist between crustal structure and heat flow in the Lake Superior region.

The new data on the mean annual bottom water temperature of Lake Superior, considered with the data already in hand, supports the hypothesis that mean annual bottom temperature of temperate lakes is independent of climatic differences. This means that the heat flow measured in such lakes is not affected by small long term temperature fluctuations, provided the lake stays in the temperate class.

(1) Department of Terrestrial Magnetism, Carnegie Institution of Washington; Washington, D. C.

A SPECTROCHEMICAL METHOD FOR DIFFERENTIATING BETWEEN CARBONATE AND SILICATE FACIES

Thomas Waggoner⁽¹⁾

A spectrochemical method of differentiating a predominantly magnetite-chert-carbonate facies from a magnetite-chert-silicate facies has been developed and successfully applied to the primary magnetite-chert deposits of the Negaunee Iron Formation.

Interpretation of the spectrochemical data depends on the distribution of the elements: magnesium, manganese, aluminum and iron. Manganese ions substitute readily for cations in the iron carbonates and only to a very minor extent in the iron silicates; the amount of manganese present can be used to approximate the quantity of carbonate present. A plot of manganese values versus magnesium values shows a trend of both elements which indicate higher concentrations of carbonate and possibly silicate. The Mn substitution is controlled by ion availability.

To evaluate the amount of silicate present when both Mg and Mn values are high, a plot of magnesium values versus aluminum is considered. Aluminum occurs exclusively in the iron silicates which are products of a similar chemical environment to those of carbonates and magnetite. The comparative analysis becomes vague when detrital feldspar contributes to the aluminum values.

High iron values in conjunction with low Mn and Mg values may show the presence of iron oxides, but caution must be exercised in accepting the apparent analysis due to the variable iron substitution of both the carbonate and silicates. Similarly, low Mg and Mn values with lower Fe show a predominance of chert. Indications are that the actual silica and phosphorous values do not help evaluate the facies types.

Silica cannot be used to correlate facies types due to its erratic occurrence which is governed by stability fields not sufficiently clear at the time of the present study.

Phosphorous has little value in making an accurate correlation due to its dependence on a pH condition and not on the other elements or their stability fields.

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⁽¹⁾ The Cleveland-Cliffs Iron Company; Ishpeming, Michigan.

A practical use for determining a carbonate facies from a silicate facies is in ore separation and blending. Silicate ore is twice as hard as carbonate ore so that metallurgical difficulties are apparent. To predetermine the type facies, the spectrochemical method could be utilized, when standardized, for given types of carbonate-silicate ore.

TEXTURES AND COMPOSITIONS OF SILICATE AND
SULFIDE ORE MINERALS FROM MINERALIZED ZONE,
DULUTH GABBRO COMPLEX

P. W. Weiblen⁽¹⁾ and Henry Hall⁽¹⁾

Mineralized gabbro samples from International Nickel Company's test pit on Spruce Road, near the South Kawishiwi River, Lake County, Minnesota, have been studied by microscopic and electron microprobe methods, as a first step in an investigation of the textures and compositions of the mineralized rocks of the Duluth Gabbro Complex.

The predominant rock type is a troctolite containing 10-20 percent olivine (Fa_{50}), 50-70 percent plagioclase (zoned An_{50-65}), 15-30 percent pyroxene ($\text{En}_{35}\text{Fs}_{20}\text{Wo}_{45}$ and $\text{En}_{61}\text{Fs}_{36}\text{Wo}_3$), 5-10 percent sulfide, 5-10 percent iron oxides, and minor biotite. Plagioclase and olivine occur as cumulate minerals; other phases are interstitial. Grab samples range in modal composition from anorthosite to troctolite having as much as 50 percent olivine. Silicate grains range in size from a few millimeters to several centimeters.

The sulfide minerals have three textural modes of occurrence:

- 1) Interstitial, associated with or enclosed in interstitial pyroxene.
- 2) Myrmekitic intergrowth with late stage interstitial pyroxene and plagioclase.
- 3) Fine-grained inclusions in silicates.

The textures suggest that the sulfide minerals formed from an immiscible sulfide melt in a silicate melt in which gravity settling was the dominant rock-forming process.

Chalcopyrite, cubanite, pentlandite, hexagonal and monoclinic pyrrhotite, and sparse sphalerite are the sulfide phases. Chalcopyrite and cubanite are intergrown; pentlandite forms separate grains, commonly euhedral, fractured, and enclosed in chalcopyrite or pyrrhotite. Sphalerite occurs as inclusions. Compositions of chalcopyrite, cubanite, pentlandite, and pyrrhotite are approximately stoichiometric within the error of electron microprobe analyses (1-5 percent).

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Minneapolis, Minnesota

PROGRESS OF GEOPHYSICAL STUDIES IN LAKE SUPERIOR

Richard J. Wold⁽¹⁾

Since 1964 the University of Wisconsin has been conducting an underwater gravity survey of Lake Superior and has occupied a total of 759 gravity stations. Since 1965 it has also been conducting a sub-bottom profiling survey, obtaining over 2300 miles of profiles. The results of the studies through 1965 were reported at the 1966 meeting of the Institute on Lake Superior Geology.

Last seasons gravity efforts were concentrated east of 86° W longitude and west of 88° W longitude. The Isle Royale fault can be traced eastward to at least 88° W longitude. Between Isle Royale and the Keweenaw Peninsula a gravity low seems to reflect the synclinal structure. East of 86° W longitude a relative gravity high indicates that the Keweenaw basic volcanics pass eastward through Michipicoten Island and turns south off Cape Gargantua. The gravity high continues its trend south just touching Mamainse Pt. where the gravity expression of the volcanics disappears.

The sub-bottom profiling appears to have penetrated to bedrock (upper Keweenaw or Lower Cambrian sandstone) in most areas. A few sub-bottom valleys were found, notably the deep trough just south of Beaver Bay, Minnesota which contains over 1000 feet of sediments. In the area between Isle Royale and the north shore up to 750 feet of sediments were penetrated. Most of the deep north-south topographic features in eastern Lake Superior are filled with about 400 feet of sediments. A north-south profile in the center of a valley at $85^{\circ}16'W$ longitude showed several deep gouges or east-west sub-bottom valleys, with the largest being over 10 miles wide with over 600 feet of sediments.

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