

TECHNICAL SESSIONS

ABSTRACTS

For

15TH ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Sponsored by

DEPARTMENT OF GEOLOGY

WISCONSIN STATE UNIVERSITY, OSHKOSH, WISCONSIN

May 8-9, 1969

15th Annual
Institute on Lake Superior Geology

Wisconsin State University
Oshkosh, Wisconsin

May 8-9, 1969

Institute Board of Directors

- *J. W. Avery (Treasurer), Jones & Laughlin Steel Corp.,
Negaunee, Michigan
- *R. C. Reed (Secretary), Michigan Geological Survey, Lansing,
Michigan.
- A. K. Snelgrove, Michigan Technological University, Houghton,
Michigan.
- W. J. Hinze, Michigan State University, East Lansing, Michigan
- A. B. Dickas, Wisconsin State University, Superior, Wisconsin
- G. L. LaBerge, Wisconsin State University, Oshkosh, Wisconsin

*Permanent members.

Local Committee

G. L. LaBerge (General Chairman)	N. W. Jones
B. E. Karges	R. G. Hennings
B. K. McKnight	Sally LaBerge

Field Trip Committee

L. W. Weis	} Co-leaders
C. E. Dutton	
G. L. LaBerge	

P R O G R A M

Wednesday, May 7, 1969

- 7:30 a.m. Field trip to exposures of a variety of volcanic,
to sedimentary, and intrusive rocks in a volcanic belt
5:30 p.m. in central Wisconsin. Co-leaders: L. W. Weis,
C. E. Dutton, and G. L. LaBerge.

Thursday, May 8, 1969

- 7:30 a.m. Registration and coffee hour, gymnasium (basement),
to Swart Campus School.
9:00 a.m. Technical Sessions, Little Theater (second floor), Swart
Campus School.
8:45 a.m. Welcome, Roger E. Guiles, President, Wisconsin State
University, Oshkosh.

Session I

Co-chairmen: Gregory Mursky and M. E. Ostrom

- 9:00 Rubidium-Strontium ages of Keewauwan
intrusives near Mellen and South Range,
Wisconsin S. Chaudhuri, D. G. Brookins, and G. Faure
9:20 K-Ar dating of two dyke-swarms from the
north shore of Lake Superior D. York and H. C. Halls
9:30 Isotopic dating of the Baraboo and
Waterloo Quartzites R. H. Dott, Jr.
9:40 Geology of the Saganaga-Northern Light Lakes
area, Minnesota-Ontario S. S. Goldich and G. N. Hanson
10:00 Coffee break (in gymnasium downstairs)
10:30 Precambrian granitic rocks and pre-Keewatin(?)
para-gneiss of the Nashwauk-Buhl sector,
Northern Minnesota--metamorphic or
igneous complex? S. Viswanathan and W. C. Phinney
10:50 Rare Earths in rocks and minerals of the Duluth
Complex ... T. P. Paster, E. B. Denechaud, and L. A. Haskin
11:10 Solution and deposition of iron in
sediments George H. Spencer, Jr.
11:30 Lunch Break (Student Union)

Session II

Co-chairmen: Wm. J. Hinze and I. Edgar Odom

- 1:00 The Geology of the South Range Quadrangle, Douglas
County, Wisconsin R. W. Johnson and J. T. Mengel, Jr.
1:20 Relationships of regional magnetics to the
bedrock geology of the South Range Quadrangle,
Douglas County, Wisconsin ... A. B. Dickas, E. W. Frodeson,
B. A. Kososki, and C. A. Wolosin

Thursday, May 8, 1969 (continued)

Session II (continued)

- 1:40 Shallow seismic refraction profiles in western Lake Superior and their relation to geologic structures . Rodolfo Anzoleaga, L. C. Ocola and R. P. Meyer
- 2:00 Shallow seismic studies in western Lake Superior Richard J. Wold
- 2:20 High resolution seismic profiling in Green Bay Robert P. Meyer
- 2:40 Coffee break
- 3:10 Electrical anisotropy studies of Michigan Precambrian rocks Donald G. Hill
- 3:30 A regional gravity survey of southwestern Minnesota Rodney J. Ikola
- 3:50 A reconnaissance paleomagnetic study of the South Range Lava Series in the western Upper Peninsula of Michigan R. Middleton, J. Murray and G. Aho
- 4:10 Seismic refraction studies of the Ames Anticline, Ames, Iowa .. L. V. A. Sendlein and Wm. P. Staub
- 4:30 A magneto-telluric study of the northeastern Lake Superior area Hans Tammemogi
- 5:20-6:30 Cocktail Hour, Pioneer Inn
- 6:30-7:30 Banquet, Pioneer Inn
- 7:45 Address: by Professor Paul M. Clifford, of McMaster University speaking on "Structural evolution in a Keewatin belt and the nature of Archaean orogenesis".

Friday, May 9, 1969

Session III

Co-chairmen: A. E. Boerner and Robert C. Reed

- 9:00 Geology of the southern part of the Duluth Complex, Minnesota Bill Bonnichsen
- 9:20 Felsic rock associations of the Duluth Complex Donald M. Davidson, Jr.
- 9:40 Petrology of the Rearing Pond Intrusion, Mellen, Wisconsin James F. Olmsted
- 10:00 Coffee break
- 10:30 Hydrothermal alteration of a breccia pipe deposit, Batchawana Bay, Ontario George A. Armbrust
- 10:50 The Rainy Lake "greenstone" belt Richard W. Ojakangas
- 11:10 Exploration of the Round Lake Anomaly, Sawyer County, Wisconsin Wayne R. Zwickey
- 11:30 Lunch Break (Student Union)
- 1:00 Business Meeting (Little Theater, Swart Campus School)

Friday, May 9, 1969 (continued)

Session IV

Co-chairmen: Richard A. Hoppin and John S. Owens

- 1:30 Mafic dikes in the Precambrian rocks of Gogebic
County, Michigan Robert G. Schmidt and Virgil A. Trent
- 1:50 Geologic examination of pipeline trench through
the East Gogebic Range, Michigan Virgil A. Trent
- 2:10 Rejuvenated Precambrian faults as a
cause of Paleozoic structures in
southeastern Minnesota G. B. Morey and D. G. Rensink
- 2:30 Statistical study of the Portage Lake
Lava Series Stephen C. Nordeng
- 2:50 Coffee break
- 3:20 Organic structures from the Negaunee
(iron) Formation, Marquette Range,
Michigan Thomas G. Wygant and Joseph J. Mancuso
- 3:40 Formation of Longshore Bars and Troughs,
Lake Superior, Ontario John S. Mothersill
- 4:10 Stratigraphical and sedimentological
comparison of early Proterozoic
rocks of S.E. Wyoming and the Great
Lakes region Grant M. Young

Saturday, May 10, 1969

- 7:30 a.m. Field trip to exposures of a variety of volcanic,
to sedimentary, and intrusive rocks in a volcanic belt
- 5:30 p.m. in central Wisconsin. Co-leaders: L. W. Weis,
C. E. Dutton, and G. L. LaBerge.

AUTHORS AND TECHNICAL SESSION CHAIRMEN

AHO, G. Michigan Technological University,
Houghton, Michigan

ANZOLEAGA, RODOLFO University of Wisconsin, Madison,
Wisconsin

ARMBRUST, GEORGE A. Northern Iowa University, Cedar Falls,
Iowa

BOERNER, A. E. Anaconda-American Brass Ltd., Port
Arthur, Ontario

BONNICHSEN, BILL Cornell University, Ithaca, New York

BROOKINS, D. G. Kansas State University, Manhattan, Kansas

CHAUDHURI, SAMBUNDAS Kansas State University, Manhattan, Kansas

CLIFFORD, PAUL M. MacMaster University, Hamilton, Ontario

DAVIDSON, DONALD M., JR. University of Minnesota-Duluth, Duluth,
Minnesota

DENECHAUD, E. B. University of Wisconsin, Madison,
Wisconsin

DICKAS, A. B. Wisconsin State University, Superior,
Wisconsin

DOTT, ROBERT H., JR. University of Wisconsin, Madison,
Wisconsin

DUTTON, CARL E. U.S. Geological Survey, Madison, Wisconsin

FAURE, GUNTER Ohio State University, Columbus, Ohio

FRODESON, E. W. Wisconsin State University, Superior,
Wisconsin

GOLDICH, S. S. Northern Illinois University, DeKalb,
Illinois

HALLS, H. C. University of Toronto, Toronto, Ontario

HANSON, GILBERT N. State University of New York, Stony
Brook, New York

HASKIN, LARRY A. University of Wisconsin, Madison,
Wisconsin

HILL, DONALD G. Michigan State University, East Lansing,
Michigan

HINZE, WILLIAM J. Michigan State University, East Lansing,
Michigan

HOPPIN, RICHARD A. University of Iowa, Iowa City, Iowa

IKOLA, RODNEY J. Minnesota Geological Survey, Minneapolis,
Minnesota

JOHNSON, R. W. Wisconsin State University, Superior,
Wisconsin

KOSOSKI, B. A. Wisconsin State University, Superior,
Wisconsin

LaBERGE, GENE L. Wisconsin State University, Oshkosh,
Wisconsin

MANCUSO, JOSEPH J. Bowling Green State University, Bowling
Green, Ohio

MENGEL, JOSEPH T., JR. . . . Wisconsin State University, Superior,
Wisconsin

MEYER, ROBERT P. University of Wisconsin, Madison,
Wisconsin

MIDDLETON, R. Michigan Technological University,
Houghton, Michigan

MOREY, G. B. Minnesota Geological Survey, Minneapolis,
Minnesota

MOTHERSILL, JOHN S. Lakehead University, Port Arthur, Ontario

MURRAY, J. Michigan Technological University,
Houghton, Michigan

MURSKY, GREGORY University of Wisconsin, Madison,
Wisconsin

NORDENG, STEPHEN C. Michigan Technological University,
Houghton, Michigan

OCOLA, LEONIDAS C. University of Wisconsin, Madison,
Wisconsin

ODOM, I. EDGAR Northern Illinois University, DeKalb,
Illinois

OJAKANGAS, RICHARD W. University of Minnesota-Duluth, Duluth,
Minnesota

OLMSTED, JAMES F. State University of New York, College at
Plattsburg, Plattsburg, New York

OSTROM, M. E.	Wisconsin Geological Survey, Madison, Wisconsin
OWENS, JOHN S.	The Hanna Mining Co., Agents, Hibbing, Minnesota
PASTER, T. P.	University of Wisconsin, Madison, Wisconsin
PHINNEY, WILLIAM C.	University of Minnesota, Minneapolis, Minnesota
REED, ROBERT C.	Michigan Geological Survey, Lansing, Michigan
RENSINK, D. G.	University of Minnesota, Minneapolis, Minnesota
SCHMIDT, ROBERT G.	U.S. Geological Survey, Washington, D.C.
SENDLEIN, L. V. A.	Iowa State University, Ames, Iowa
SPENCER, GEORGE H., JR. ...	Duluth, Minnesota
STAUB, WILLIAM P.	College of St. Thomas, St. Paul, Minnesota
TAMMEMOGI, HANS	University of Toronto, Toronto, Ontario
TRENT, VIRGIL A.	U.S. Geological Survey, Washington, D.C.
VISWANATHAN, S.	University of Minnesota, Minneapolis, Minnesota
WEIS, LEONARD W.	University of Wisconsin-Green Bay, Fox Valley Campus, Menasha, Wisconsin
WOLD, RICHARD J.	University of Wisconsin-Milwaukee, Milwaukee, Wisconsin
WOLOSIN, C. A.	Wisconsin State University, Superior, Wisconsin
WYGANT, THOMAS	Bowling Green State University, Bowling Green, Ohio
YORK, D.	University of Toronto, Toronto, Ontario
YOUNG, GRANT M.	University of Western Ontario, London, Ontario
ZWICKEY, WAYNE	New Jersey Zinc Corp., Platteville, Wisconsin

SHALLOW SEISMIC REFRACTION PROFILES IN WESTERN LAKE
SUPERIOR AND THEIR RELATION TO GEOLOGIC STRUCTURES

Rodolfo Anzoleaga, Leonidas C. Ocola and Robert P. Meyer
Department of Geology and Geophysics
Geophysical and Polar Research Center
University of Wisconsin, Madison, Wisconsin, 53706

The shallow structure of the western half of Lake Superior is interpreted on the basis of four seismic refraction profiles along a line between Knife River (Minnesota) and Otter-Cove (Canada). Five refractors are observed. The first (3.3-3.5 km/sec) is at a depth of 0.3-0.5 km and a thickness of 1.2 km on the average, except for a 50 km wide "depression" centered at about 150 km east of Knife River, where this refractor reaches a thickness of 3.5 km. The second (4.5-4.7 km/sec) is 1.4 km thick east of the depression and 2.5 km under and west of it. This refractor pinches out at about 30 km east of Knife River. The third (5.4-5.6 km/sec) is about 6 km thick east and under the depression wedging out towards Knife River where its thickness is less than one km. The fourth (6.5 km/sec) is found for about 120 km from Knife River to the east with a dip of about 4° . The fifth (6.9 km/sec) is at a depth of 8-10 km under and east of the depression. This refractor is not observed as first arrivals on the profiles between Knife River and the depression.

The model which satisfies the observed gravity requires the 6.9 km/sec material to continue under the 6.5 km/sec refractor towards Knife River. The topography of the 6.9 km/sec upper interface--as required by the gravity--is probably related to the northward continuation of the Mid-Continent Gravity High in the westernmost part of Lake Superior.

HYDROTHERMAL ALTERATION OF A BRECCIA PIPE DEPOSIT,
BATCHAWANA BAY, ONTARIO

George A. Armbrust
Department of Physics and Earth Science
University of Northern Iowa, Cedar Falls, Iowa, 50613

The Tribag mine is situated approximately 45 miles north-northwest of Sault Ste. Marie, Ontario. Precambrian rocks exposed in the area consist of: acid to basic metavolcanics, metasediments and iron formations; granite; diabase dikes and sills; and a series of olivine basalts interlayered with conglomerate and sandstone.

The metavolcanics, metasediments and iron formations represent an accumulation of 30,000 feet of material which was later intruded by granitic batholiths. All of these rocks are faulted and intruded by diabase dikes and sills. Overlying this older rock complex is a thick series of olivine basalts which were extruded into the Lake Superior basin. Conglomerate and sandstone are interlayered with the basalts, which dip southwest at 20 to 40 degrees. Felsite bodies intrude the volcanic and sedimentary layers.

The Tribag mine is in the Breton breccia, one of five breccia pipes near the eastern margin of Township 28, Range 13. The pipe has surface dimensions of 1,400 by 350 feet, and the size increases slightly with depth. The breccia contains angular to sub-rounded fragments of trondhjemite or sodic granite, basic volcanics, felsite, and diabase. These are set in a matrix of quartz, calcite, pyrite, pyrrhotite, chalcopyrite, sphalerite, marcasite and galena. Minor amounts of molybdenite, scheelite, fluorite, laumontite and barite also occur in the matrix.

Secondary effects on the rock fragments include hematization, sericitization, silicification, kaolinitization, chloritization, and minor carbonatization. A small amount of pyrite and leucoxene are associated with sericitized biotite. Hematization of the feldspars preceded brecciation. Quartz, sericite, and kaolinite are abundant near highly mineralized areas. Hydrothermal chlorite bears no special relationship to the mineralized areas.

Hydrothermal alteration and the extrusion of basaltic magma nearby have both been dated at near 1,050 million years by the K-Ar method. An amygdaloidal dike having a similar mineralogic composition to the basaltic lava cuts the breccia at the Tribag mine. This indicates a possible genetic relation between the Middle Keweenaw extrusives and the Tribag copper deposit.

The presence of abundant sericite and quartz in and near the mineralized zone at Tribag, along with the mineralogy and general geologic setting, suggests depositions in a moderate to high intensity environment. The large amount of open space between breccia fragments suggests deposition in a relatively low pressure environment.

GEOLOGY OF THE SOUTHERN PART OF THE
DULUTH COMPLEX, MINNESOTA*/

Bill Bonnichsen
Department of Geological Sciences
Cornell University, Ithaca, New York, 14850

Two groups of intrusive igneous rocks are abundant in the southern part of the Duluth Complex. The earliest group is the Anorthositic Series; it consists primarily of gabbroic anorthosite and troctolitic anorthosite. In general, the mafic minerals (olivine, pyroxenes, oxides) in these rocks are paragenetically later than the plagioclase. The latest group is the Troctolitic Series in which troctolite and augite troctolite are the most common rock types. Plagioclase and olivine generally are contemporaneous in these rocks and are paragenetically earlier than the accompanying pyroxenes and oxides.

The Troctolitic Series is present along the western margin of the southern part of the Duluth Complex and intrudes rocks of the Anorthositic Series that lie to the east. The Anorthositic Series is hypothesized to be genetically related to some of the Keweenawan flows; it is suggested that some flows represent differentiated liquids that were expelled from magma chambers in which rocks of the Anorthositic Series were accumulating by crystal settling. After the Anorthositic Series had been emplaced, troctolitic magma evidently intruded along a widening fracture zone to form the Troctolitic Series between the Anorthositic Series to the east and the Early and Middle Precambrian basement complex to the west.

The sulfide deposits in the southern part of the Duluth Complex that currently are of economic interest for their Cu-Ni potential are believed to be syngenetic segregations within the lower part of the Troctolitic Series.

*/Work done on behalf of the Minnesota Geological Survey.

RUBIDIUM-STRONTIUM AGES OF KEWEENAWAN INTRUSIONS NEAR MELLEN AND SOUTH RANGE IN WISCONSIN

S. Chaudhuri and D. G. Brookins
Department of Geology
Kansas State University, Manhattan, Kansas, 66504
and
G. Faure
Department of Geology
Ohio State University, Columbus, Ohio, 43210

Rubidium-strontium ages were measured on whole rocks and mineral separates from the Mellen Granite and the Mellen Gabbro in Wisconsin. A suite of porphyritic granite chosen for isotopic study of the Mellen Granite was collected from sections 32 and 33, T45N, R3W. Samples of the Mellen Gabbro were obtained from outcrops in the vicinity of Mineral Lake. In addition, a whole-rock rubidium-strontium age was determined on monzonite which cuts the Keweenawan basalts near South Range in Douglas County, Wisconsin. The ages were calculated by using the decay constant for $Rb^{87} = 1.39 \times 10^{-11} \text{ y}^{-1}$.

The calculated age of whole rocks and biotites from the porphyritic granite is $940 \pm 12 \text{ m.y.}$ The Sr^{87}/Sr^{86} ratio of primary strontium is found to be 0.7137 ± 0.0005 . Samples of the Mellen Gabbro range in values of Sr^{87}/Sr^{86} ratio from 0.7057 to 0.7161. The isotopic composition of these samples do not agree with the isochron defined by the porphyritic granite. The Mellen Gabbro appears to be about 1100 m.y. old by assuming it to be related to the intrusion of the Duluth Gabbro.

The whole-rock rubidium-strontium isotopic analyses of the monzonite yield an age of $935 \pm 15 \text{ m.y.}$ The initial Sr^{87}/Sr^{86} ratio is 0.7100 ± 0.0008 .

Our data indicate that (1) the porphyritic granite west of Mellen is much younger than the Mellen Gabbro, and the cognate relationship of these two rocks is unlikely, (2) the emplacement of the porphyritic granite near Mellen was contemporaneous with that of the monzonite near South Range. The data also demonstrate that the granite and the monzonite have significantly high initial Sr^{87}/Sr^{86} ratios, which point to their origin in a rubidium-rich environment and may indicate a previous crustal history for these rocks.

FELSIC ROCK ASSOCIATIONS OF THE
DULUTH COMPLEX

Donald M. Davidson, Jr.
Department of Geology
University of Minnesota, Duluth, Minnesota, 55812

Field research has been supported by the Minnesota Geological Survey in Kawishiwi Lake, Lake Polly and Kelso Mountain quadrangles, Lake and Cook Counties, Minnesota. This research and subsequent laboratory investigation have revealed the presence of several felsic rock types spatially associated with anorthositic and gabbroic rocks of the Duluth Complex.

Rock types thus far delineated are: granite, granodiorite, grano-gabbro, granophyre, and diorite(?). These rocks are genetically younger than rocks of the gabbro complex with at least two separate intrusive periods. Petrographic evidence indicates the diorite(?) may be a hybrid rock type derived from intrusive contamination of gabbroic rocks.

RELATIONSHIPS OF REGIONAL MAGNETICS TO THE
BEDROCK GEOLOGY OF THE SOUTH RANGE QUADRANGLE,
DOUGLAS COUNTY, WISCONSIN

A. B. Dickas

and

E. W. Frodesen, B. A. Kososki and C. A. Wolosin (Students)

Department of Geology

Wisconsin State University, Superior, Wisconsin, 54880

Bounded by latitudes $46^{\circ} 33'$ to $46^{\circ} 37.5'$ and longitudes $91^{\circ} 52.5'$ to 92° , the South Range quadrangle lies in central Douglas County, approximately five miles southeast of Superior, Wisconsin. During the Fall and Winter of 1968-69, one hundred and forty station readings employing a Schmidt type vertical magnetometer were recorded along all primary and secondary roads within the northern thirty-six square mile sector of this quadrangle. This spacing yields a density of four stations per square mile. A centrally located station was used for base and drift analysis. As the magnetometer was initially zeroed at this position, all other station data, after proper corrections, are relative to the base point.

The purpose of this study was to determine the degree to which surface magnetics would reveal the structure and trend of the northern Wisconsin bedrock when buried under several tens to hundreds of feet of Pleistocene till. Outcrops are not at all common in this region.

As outlined by Johnson and Mengel (these proceedings), this quadrangle is subdivided by the Douglas Fault into two petrologic provinces. North of the fault the Pleistocene till and Recent lake sediments overlie sandstones interbedded with shale, the latter all of Keweenaw (Cambrian?) age. The thickness of these clastics is estimated by the Wisconsin Geological Survey to be in excess of twenty thousand feet. In this province the magnetic trend is non-uniform. Regionally, a northeast-southwest strike is observed increasing in magnitude to the northwest at a rate of 400 to 600 gammas per mile. Scattered and apparently non-related magnetic noses and closures interrupt this weak regional trend as they range in orientation from north-south to east-west. These anomalies, which have a residual magnitude of 100 to 200 gammas, might be attributed to mineralogic irregularities either in the subclastic basement complex or within the surficial till. The latter is the more probable cause due to the very great thickness of the Keweenaw (Cambrian?) sandstones overlying the basement complex.

South of the Douglas Fault is found a strong and uniform regional magnetic fabric striking $N 75^{\circ} E$. As many as seven separate trends, marked by related closures, are present forming a "wash-board" effect. Each trend averages one-half mile in width, has a residual amplitude of 800 to 1600 gammas and can be traced across the entirety of the study area. Station control suggests these trends possess on their northwest flank a magnetic gradient

that is two to three times as steep as that found on the opposing flank. These differing gradients are in agreement with the known southerly dip of the basaltic flows erratically exposed in the region. Assuming a 30 to 40 degree dip within the flows (various sources) and magnetic trends averaging one-half mile, basaltic flows up to three thousand feet in thickness associated with each trend would be expected. In studies on the North Shore Volcanic group, J. C. Green (1968) lists the "common" thickness for flows similar in composition to the South Range quadrangle group to be ten to fifty feet. From the geophysical point of view, it would thus seem logical that each magnetic trend is recording the effects of multiple rather than single layer conditions. Considering the petrography of this quadrangle as outlined by Johnson and Mengel (these proceedings), the magnetics are recording either basalt-basalt or intrusive-extrusive sequences.

The trend centered in section 15, T 47 N, R 13 W is marked by a gabbroic outcrop, while that trend centered in section 11, T 47 N R 13 W is closely associated with basaltic exposures. In the latter area a magnetic reversal is located on the axis of a positive closure, suggesting supporting evidence for arenaceous units lying between flows as found northeast along strike by Johnson and Mengel. It thus seems that this "wash-board" pattern is related to a more complex situation than a simple layered basalt sequence.

While magnetic trends can be traced throughout this area, their continuity is interrupted. In the center of the South Range quadrangle an apparent left-lateral off-setting is noted. This trace is remarkably coincident with the western border of the large gabbro mass seen in sections 31, 32 and 33 of T 48 N, R 12 W. The gabbro mass appears to be associated with a true offset rather than a cancellation of the magnetic trends. It would thus seem logical that this off-setting is a result of left-lateral transform faulting. Possibly at a later date the gabbro was activated and conceivably partially used the fault plane as an avenue of intrusion. Final analysis of this faulting-intrusion relationship will have to await eventual age dating of the local basement rocks.

This transform fault, with a strike of N 30 to 40° W is parallel to other similar fault patterns known in the Lake Superior area. Each of these faults strike at right angles to the regional structural grain. While the apparent amount of off-setting in the South Range area measures approximately one mile, it is postulated this fault is part of the very extensive transform fault system portrayed by Thiel (1956) and Coons, Woollard and Hershey (1967).

References

- Coons, R. L., Woollard, G. P., and Hershey, G., (1967), Structural Significance and Analysis of Mid-Continent Gravity High, Bull. Amer. Assoc. Pet. Geol., 51, December, pp. 2381-2399.

- Green, J. C., (1968), Varieties of Flows in the North Shore Volcanic Group, Minnesota (abstract), Proc. Institute on Lake Superior Geology, pp. 52-53.
- Johnson, R. W. and Mengel, J. T., (1969), Economic Implications of the Geology of the South Range Quadrangle, Douglas County, Wisconsin (abstract), Proc. Institute on Lake Superior Geology.
- Thiel, E., (1956), Correlation of Gravity Anomalies with the Keweenawan Geology of Wisconsin and Minnesota, Bull. Geol. Soc. Amer., 67, p. 1079.

ISOTOPIC DATING OF THE BARABOO AND WATERLOO QUARTZITES

R. H. Dott, Jr.

Department of Geology and Geophysics
University of Wisconsin, Madison, Wisconsin, 53706

The Baraboo Quartzite long has been assumed to be correlative with Huronian and/or Animikean rocks (i.e. between about 2.5 and 1.6 b. y. old). This correlation, however, was based only upon similarities of lithology and sequence of quartzite, iron formation, dolomite and slates between the Baraboo region and northeastern Wisconsin and adjacent Michigan.

Isotopic dating suggests that both the Baraboo and its inferred equivalent near Waterloo, Wisconsin (25 miles east of Madison) are younger than Animikean. $\text{Rb}^{87}\text{-Sr}^{87}$ dating of five samples of dark rhyolite that underlies the Baraboo Quartzite yields an isochron of $1.54 \pm 0.04 \times 10^9$ years (assuming a Rb^{87} decay constant of $1.47 \times 10^{-11} \text{ yr.}^{-1}$ and an initial $\text{Sr}^{86}/\text{Sr}^{87}$ ratio of 0.705 ± 0.005). A K-Ar date was attempted for a phyllite zone near the top of the quartzite in the hope of dating metamorphism of the formation, but the potassium content was too low to provide a meaningful result ($760 \pm 50 \times 10^6$ yrs.). The younger age limit of red, Baraboo-type quartzite seems to be provided near Waterloo, however. Bass (in Tuve, 1959) reported a Rb-Sr date of 1.44 b. y. for muscovite from a coarse pegmatite that cuts the "Waterloo Quartzite", and Goldich, et al (1966) reported a K-Ar date of 1.41 b. y. from muscovite in a schistose zone within that quartzite.

It appears that the Baraboo-Waterloo type quartzites of southern Wisconsin originally were deposited as sands in a subsiding mobile belt between about 1.4 and 1.5 billion years ago, thus the quartzite probably is both post-Animikean and post-Penokean. This strengthens the possibility that the Baraboo is a southern, thicker equivalent of the Sioux Quartzite, which is known only to be from 1.2 to 1.7 billion years old (Goldich, et al, 1966). Rb-Sr dating of three samples of the Baxter Hollow Granite (on the south side of the Baraboo Syncline) allow a total range of 1.36 - 1.67 b. y., so does not indicate if the granite is older or younger than the quartzite.

GEOLOGY OF THE SAGANAGA-NORTHERN LIGHT LAKES AREA
MINNESOTA-ONTARIO

S. S. Goldich
Division of Geology
Northern Illinois University, DeKalb, Illinois, 60115
and
G. N. Hanson
Department of Earth and Space Sciences
State University of New York at Stony Brook, New York, 11790

The Early Precambrian rocks along the Minnesota-Ontario boundary are of special interest because they were involved in two orogenies giving rise to granites of two ages. The older granite, defined geologically as post-Keewatin and pre-Knife Lake, is typified by the Saganaga Granite (tonalite) which was emplaced in folded Keewatin rocks and was eroded to supply cobbles and boulders to the Knife Lake sediments. The younger Algonian granite was defined geologically as post-Knife Lake and pre-Animikie. Examples are the Giants Range Granite and the Snowbank Granite.

The Keewatin rocks in the Saganaga-Northern Light Lakes area are basaltic volcanics with some intermediate to silicic pyroclastic rocks and graywacke. The Northern Light Gneiss is a fine-grained leucocratic rock of trondhjemitic composition that represents a synkinematic intrusive in the Keewatin volcanic pile. The NW-SE structure developed during the Laurentian orogeny is well exposed along Trafalgar Bay of Northern Light Lake. By contrast the Algonian orogeny which resulted in the folding of the Knife Lake Group developed NE-SW structures mapped by J. W. Gruner west and southwest of Saganaga Lake.

The Saganaga Granite was emplaced in the Keewatin metavolcanics and Northern Light Gneiss in a late kinematic stage of the Laurentian orogeny. It was followed by the intrusion of quartz dioritic plutons in the vicinity of Icarus Lake east of Northern Light Lake. The latter were referred to as "younger syenites" by F. F. Grout.

In our interpretation of the structural development of the region, the Northern Light Gneiss and the Saganaga Granite formed a massif that rose diapirically along faults. F. R. Harris has recently mapped the granite-greenstone contact along the north shore of Saganaga Lake as a fault. On the west side the displacement was accomplished by downfolding of the Knife Lake beds and along faults. Thus the Laurentian massif was rising throughout the time of deposition of the Knife Lake, and the conglomerate which rests on the Saganaga Granite and which is the basal Knife Lake unit in the vicinity of Cache Bay occupies a higher position in the Knife Lake succession as a whole, as earlier determined by J. W. Gruner.

The present interpretation does not require the large amount of erosion and avoids the structural problems inherent in F. F. Grout's earlier interpretation in which the Saganaga batholith was emplaced in a vertical position and was later tilted to the west during the Algonian orogeny.

ELECTRICAL ANISOTROPY STUDIES OF
MICHIGAN PRECAMBRIAN ROCKS

Donald G. Hill

Department of Geology

Michigan State University, East Lansing, Michigan, 48823

Alternating current dielectric constant and electrical conductivity measurements were made on selected rock samples collected from the Precambrian of Michigan's Northern Peninsula. The directional variation (anisotropy) of these properties was studied with variations in rock fabric, lithology, and signal frequency, in the range from 20 to 300,000 cps. Measurements were made using both two and four electrode methods.

Theoretical methods of interpreting geoelectrical data generally assume that earth materials do not exhibit significant tri-axial anisotropy. The results of this study to date indicate that some rocks, particularly those with pronounced lineation or banding are characterized by strongly anisotropic electrical properties. This anisotropy is increasingly evident at lower frequencies, in the range of those used in E. M. and I. P. prospecting. This study has confirmed the theoretical prediction that the electrical anisotropy symmetry is related to rock fabric symmetry. Thus laboratory and/or field electrical anisotropy measurements may be used to predict rock fabric symmetry.

A REGIONAL GRAVITY SURVEY OF SOUTHWESTERN MINNESOTA*/

Rodney J. Ikola
Minnesota Geological Survey
University of Minnesota, Minneapolis, Minnesota, 55455

Approximately 2500 gravity stations have been established by the Minnesota Geological Survey in southwestern Minnesota. The majority of the stations are located on a two mile grid with wider spacing where vertical control is limited. The results are presented as a Bouguer gravity map contoured at 2 and 10 milligals.

The area underlain by the Morton Gneiss, which is exposed at Morton in the Minnesota River valley, is represented on the gravity map as a generally smooth featureless area. The contact between the Morton Gneiss and more mafic gneisses represented by exposures at Granite Falls is marked by a sharp gravity gradient. Within the area of the mafic gneisses there are two positive gravity anomalies, one south of Dawson and the other north of Granite Falls, which are thought to represent mafic intrusive rocks.

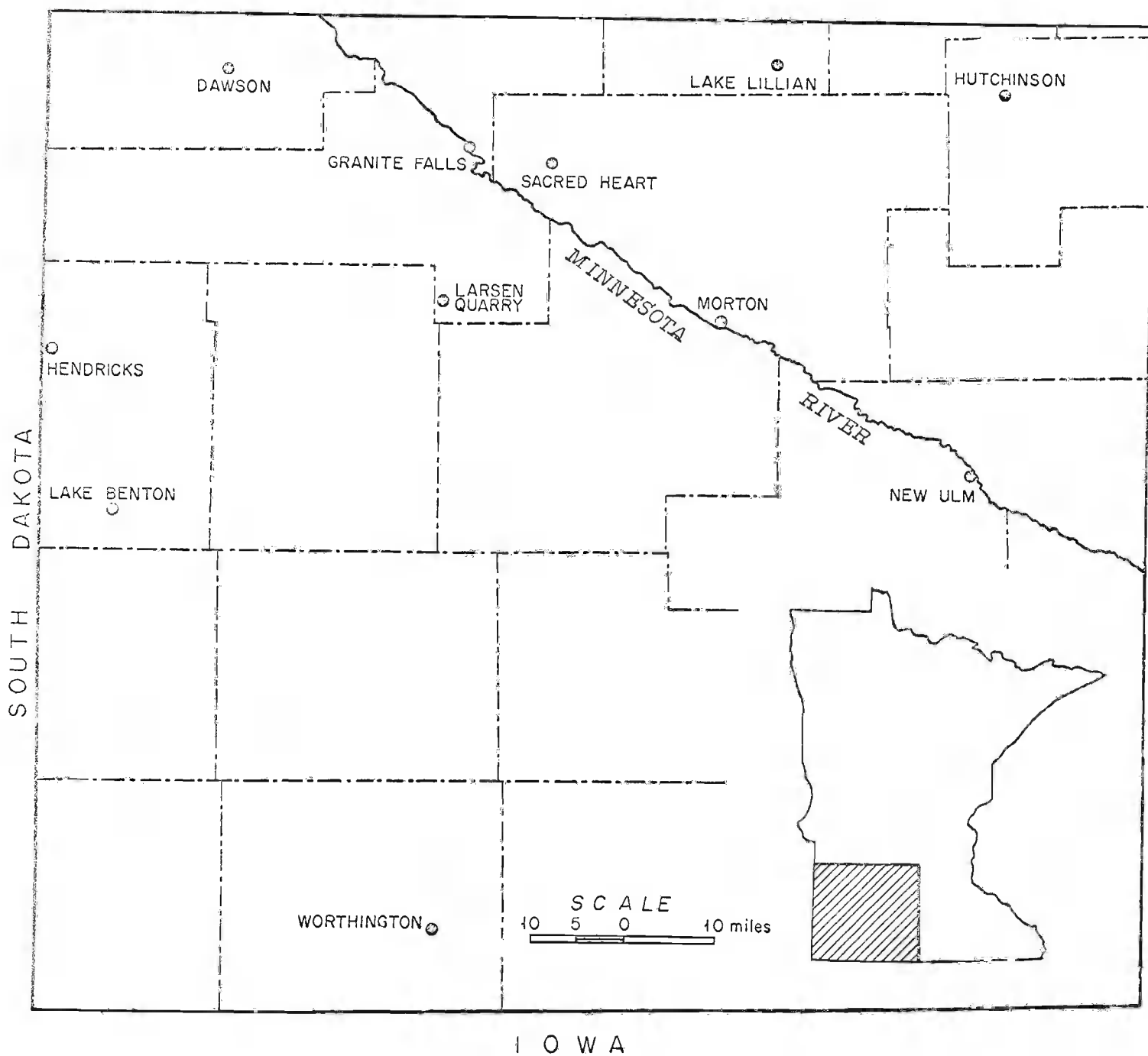
Granitic intrusive bodies are indicated by gravity lows on the map. A gravity low at New Ulm corresponds to known outcrops of granite in the Minnesota River valley. A much larger gravity low extends from south of Granite Falls in the valley westward to the South Dakota border. Outcrops of the Sacred Heart Granite and the granite at the Larsen quarry are present within this low.

Areas of possible mafic volcanic rocks with associated sediments are delineated by the gravity survey. One example is an elongate positive anomaly at Hendricks, in the extreme western part of the state. A series of anomalies extending from Lake Benton southeastward to Worthington also are thought to be caused by mafic volcanics and associated sediments.

A positive gravity feature extending westward from Hutchinson to Lake Lillian may represent the southern edge of a sedimentary sequence of Middle Precambrian age, which lies unconformably on the older Precambrian.

The areal extent of the Sioux Formation is not readily delineated by the gravity method. In many areas there appears to be little or no density difference between the Sioux Formation and the older rocks on which it was deposited.

*/Work done on behalf of the Minnesota Geological Survey.



MAP SHOWING LOCALITIES MENTIONED IN
ABSTRACT OF
GRAVITY SURVEY OF SOUTHWESTERN MINNESOTA

THE GEOLOGY OF THE SOUTH RANGE QUADRANGLE,
DOUGLAS COUNTY, WISCONSIN

Rudolf W. Johnson (student) and Joseph T. Mengel, Jr.
Department of Geology
Wisconsin State University, Superior, Wisconsin, 54880

Copper shows are found wherever Keweenawan lavas outcrop in northwestern Wisconsin. Douglas County contains a substantial percentage of the known outcrop and a majority of the Pleistocene subcrop of the lava sequence, all of which must be looked on as prospective for copper. No detailed mapping of the bed rock geology of this county has been published since the turn of the present century. The Wisconsin State University (Superior) Geology Department, in cooperation with the State Geological Survey has recently begun mapping along the Douglas Copper range near the City of Superior to provide basic information on bed rock geology. The purpose of this mapping is to determine the nature and geometry of the bed rock units present and to establish the character of their geophysical responses to serve as a guide to systematic copper prospecting in the drift-covered areas. The South Range, Wisconsin 7-1/2 minute quadrangle is the first area to be mapped.

The South Range quadrangle is located about 5 miles southeast of Superior, Wisconsin, on the south flank of the Lake Superior basin. It lies near the middle of the Douglas Copper Range and exhibits geology representative of that of the entire Range. The quadrangle straddles the steeply south-dipping Douglas fault which brings the Keweenawan lava flow sequence in contact with younger sandstones to the north. The flows are typically tholeiitic basalts with medium grained ophitic interiors and amygdoloidal margins. Individual flows are typically less than 100 feet thick and dip SSE at 35-40°. A horizon marked by basaltic cinders and fine-grained quartz sandstone occurs near the middle of the exposed sequence in the southwest corner of T47N-R12W.

Medium to coarse grained gabbro is widely distributed in the South Range quadrangle. The typical rock consists of equal percentages of plagioclase and pyroxene, together with a few per cent of ilmenite or titaniferous magnetite.

A gabbro body, centering in 32-48N-12W underlies about four square miles of the northeastern part of the quadrangle. Anorthositic portions of this body are exposed in the NW 1/4 of 32-48N-12W; reddish portions crop out along the Amnicon River south of Bardon State Park and finer grained portions occur within the Park. The gabbro body is not noticeably layered in character. The Douglas fault cuts off the gabbro to the north in the SE 1/4 of 29-48N-12W, but elsewhere it is bounded by the lava sequence. No lava-gabbro contact exposures are known, but the suspected position is marked by magnetic anomalies.

Outcrops of gabbro extend S70W from the main body across the S 1/2 of 1-47N-13W in a zone about 500 feet wide. These outcrops are bounded by lavas both to the north and south. A body of reddish granodiorite outcrops in 15-47N-13W. Its boundaries are covered, but the high mafic mineral content of the border portions, and the occurrence of lavas immediately to the west suggest that the country rock is basaltic lava. A basaltic dike with excellent columnar joint development has intruded the granodiorite body. Magnetic relations suggest that other intrusives are present in the southern half of the quadrangle, but a thick cover of Quaternary sands and clays cover the entire area.

Minor native copper and copper sulfide mineralization is found in amygdules and along fractures in amygdaloidal lavas. The best of the observed mineralization occurs at about the horizon of the fragmental materials and close to the western boundary of the principal gabbro mass. Exposures of the gabbro are too limited to permit evaluation of the possibility of sulfide segregations within it. Local introduction of sulfides into the lava sequence can be noted to the southeast of the gabbro in the Poplar quadrangle.

HIGH RESOLUTION SEISMIC PROFILING IN GREEN BAY

Robert P. Meyer
Department of Geology and Geophysics
Geophysical and Polar Research Center
University of Wisconsin, Madison, Wisconsin, 53706

Several thousand miles of high resolution--high frequency seismic reflection profiling in Green Bay, Lake Michigan, have provided both a test for this technique and a surprising amount of data on the sediments under and structural history of the Bay. Eutrophic sediments, characterized by low reflectivity, have been consistently found when predicted from the acoustic data. The converse is not true, for sediments of this type have been found where the reflectivity is high and, in this case, entrapped gas bubbles are thought responsible. Underlying the eutrophic muds, are seen, yet unsampled, finely layered sediments, themselves greatly contorted and resting on what dimly appears as a reflective conformable layer.

Resolution of the single cycle, 7 kc, pulse used is about one foot. Maximum penetration achieved was about 150 feet.

The method appears to have great promise in combined and detailed geological-geophysical studies of the immediate sub-bottom including programs in eutrophication and mineral search.

A RECONNAISSANCE PALAEOMAGNETIC STUDY OF THE SOUTH RANGE
LAVA SERIES IN THE WESTERN UPPER PENINSULA OF MICHIGAN

R. Middleton, J. Murray, G. Aho (Graduate Students)
Department of Geology and Geological Engineering
Michigan Technological University, Houghton, Michigan, 49931

A total of eleven block samples of the South Range Lava Series were collected at Silver Mountain, Bond Falls, and Wakefield in the western part of the Upper Peninsula of Michigan. Forty core specimens of one inch diameter were obtained from the samples. Remanent Magnetism was measured using a Permali spinner magnetometer. A-C demagnetization studies were carried out to test the remanence stability. The results of the survey were compared with previously published palaeomagnetic studies of the Lake Superior region.

REJUVENATED PRECAMBRIAN FAULTS AS A CAUSE
OF PALEOZOIC STRUCTURES IN
SOUTHEASTERN MINNESOTA

G. B. Morey and D. G. Rensink
Minnesota Geological Survey and
Department of Geology and Geophysics
University of Minnesota, Minneapolis, Minnesota, 55455

The upper midwest is part of a tectonically stable province characterized by large sedimentary basins and arches in Paleozoic rocks. It is known that the large basins and arches overlie equivalent features on the Precambrian surface, and that a close correlation commonly exists between small-scale structures in Paleozoic rocks and inferred older structures in the basement rocks. The detailed relationships between basement features and Paleozoic structures seldom have been established, however, because the basement is covered and integrated data on subsurface geology and geophysics rarely are available. Such an integrated study has been completed of a recently recognized Paleozoic structure--called the Vermillion anticline--in Dakota County, Minnesota.

The Vermillion anticline is a northeast-trending structure about six miles long and two miles wide. It is doubly plunging and asymmetrical in cross-section; the northwest limb dips about 20 feet/mile, whereas the southeast limb dips about 40 feet/mile. The anticline is modified by at least two northwest-trending cross-faults and one northeast-trending fault that parallels and is slightly southeast of the anticlinal axis. The faults are interpreted as having steep dips and reverse movements; the apparent vertical displacement does not exceed 100 feet on any of the faults.

Concurrent Paleozoic deposition and vertical movements in the vicinity of the anticline are indicated by: (1) displacement on the cross-faults apparently decreases upward in the section, (2) thinning of several stratigraphic intervals in Cambrian strata occurs over the fold crest, and (3) an erosional unconformity separates Cambrian and Ordovician rocks at the fold crest.

An analysis of structural and isopach contour maps for various intervals within the Paleozoic section indicates that warping in a northwesterly direction took place prior to movement along the cross-faults, and was sufficient to modify the depositional pattern during the middle part of late Cambrian time. That movement along the northeast-trending fault took place during the last phase of Cambrian deposition or before the first phase of Ordovician deposition is indicated by the Cambrian-Ordovician unconformity, where approximately 30 feet of Cambrian strata are missing.

Combined drilling and geophysical data in this area indicates that the Vermillion anticline in part overlies an uplifted block of Middle Keweenaw basalt called the Hudson-Afton horst. The basalt

is in fault contact with Upper Keweenawan sedimentary rocks on three sides; apparent vertical displacement on these faults is on the order of 8,000 to 12,000 feet. Two of the three Paleozoic faults geographically coincide with the Precambrian faults, suggesting that they have resulted from minor isostatic readjustments in the basement. Other nearby Paleozoic structures, such as the Hudson-Afton anticline, also are geographically coincident with the Hudson-Afton horst, suggesting a similar origin for them.

FORMATION OF LONGSHORE-BARS AND TROUGHS,
LAKE SUPERIOR, ONTARIO

John S. Mothersill
Department of Geology
Lakehead University, Port Arthur, Ontario

Grain size analyses of 186 samples from the axes of longshore-bars and troughs along the lake shelf at Batchawana Bay and Pancake Bay, Lake Superior, Ontario, show the longshore-bar sands to be better sorted and finer grained than the adjacent shoreward longshore-trough sands. In addition the longshore-bar sands are unimodal and tend to be positively "skewed" whereas the longshore-trough sands may be either unimodal or bimodal and show a tendency towards negative skewness. This would suggest that the longshore-troughs were formed by the action of breaking waves that preferentially set the finer grained particles into motion. These finer grained particles were then moved lakeward by the undertow to form the longshore-bar areas.

STATISTICAL STUDY OF THE PORTAGE LAKE LAVA SERIES

Stephen C. Nordeng

Department of Geology and Geological Engineering
Michigan Technological University, Houghton, Michigan, 49931

The frequency of occurrence of conglomerates in the Portage Lake Lava Series fits a Poisson distribution, implying that such events occur at random intervals.

The frequency distribution for thickness of the different types of lava flows and for the conglomerates fall in the impossible region for the Pearson Type Curves. The single exception was ophitic (coarse-grained) flows with a cellular amygdaloidal top which have a Type I (Beta "J" shaped) distribution. This type of distribution can result from a random variable operating over an interval with definite upper and lower limits. The failure of other types, including the overall thickness distribution, to fall in a similar class is reflected in their standard deviations being commonly equal to the mean. This shows an overabundance of thin flows suggesting a high degree of fluidity for the lavas.

Treating the flow type transitions as a Markov process gives an expected sequence of textural and flow top combinations as follows:

- 1) melaphyre with cellular top; 2) melaphyre with fragmental tops;
- 3) ophites with cellular top; 4) ophites with fragmental tops;
- 5) glomerophorphyrates with cellular tops; 6) glomerophorphyrates with fragmental tops; and 7) conglomerate. This is accompanied by a tendency toward greater flow thickness.

Plotting the flow types as a time series and smoothing shows four incomplete cycles of this type in the Portage Lake Lava Series.

THE RAINY LAKE "GREENSTONE" BELT*/

Richard W. Ojakangas
Department of Geology
University of Minnesota, Duluth, Minnesota, 55812

The Rainy Lake "Keewatin Greenstone Belt" of A. C. Lawson (1887, 1913) has been restudied in detail on the United States side of the International Boundary. The belt, 2 to 3 miles wide in this area, trends ENE and is bounded on both sides by Lawson's "pre-Keewatin Couthiching Series" of biotite schists. The dominant rocks within the belt are chloritic schists, massive "tuffaceous" greenstones, and meta-arkoses; minor rock types include pillowed greenstones, conglomerates, and "felsic tuffs". These rocks are generally interbedded and gradational.

Most of the metasedimentary rocks in the area are vertical or nearly vertical and lineations generally plunge to the ENE at angles of 30° to 50°. Lawson interpreted the regional structure here as a syncline composed of Couthiching biotite schists on the outside, Keewatin greenschists and greenstones nearer the center, and Huronian (Seine) meta-arkoses and conglomerates at the center. In light of this study, a different structural interpretation seems more probable. Graded beds in the biotite schists and cross-beds in the meta-arkoses provide information on stratigraphic tops. Tops in the meta-arkoses are consistently towards the south, ruling out any syncline within the unit. The belt appears to be in fault contact with the biotite schists to the North and South; shear is evident and the structure based on top directions within the "greenstone belt" and the adjacent biotite schists is difficult to resolve without the presence of these faults.

A unit composed of intimately interbedded biotitic and chloritic schists appears to form a gradational unit between the "greenstone belt" and the biotite schists. Apparently the assemblage of the "greenstone belt" is gradational with and overlain by the biotite schists. The entire sequence of the region thus represents a thick accumulation which resulted from relatively continuous deposition; volcanoclastic sediment, clastic sediment, and minor volcanics grade upward into dominantly clastic (terrigenous?) sediment.

Sulfides are quite commonly disseminated in these rocks and small gossans were noted at several localities. Rocks from the Little America Mine which produced some gold in the 1890's from the shear zone at the south edge of the "greenstone belt" contain gold and silver, and rocks from a few other localities contain anomalous values of gold, silver, and copper.

*/Work done on behalf of the Minnesota Geological Survey.

PETROLOGY OF THE REARING POND INTRUSION,
MELLEN, WISCONSIN

J. F. Olmsted
Department of Physics and Earth Sciences
State University College of Arts and Science
Plattsburgh, New York, 12901

The Rearing Pond Intrusion is part of the Keweenaw igneous complex which lies along the south limb of the Lake Superior syncline in Wisconsin. The intrusion is roughly elliptical in plan and displays graded banding which dips toward the center from all directions, suggesting that it has a funnel-like shape. The intrusion lies directly north of, and in contact with, the Mineral Lake anorthositic unit of the complex. These two units are mineralogically and texturally in strong contrast with one another and are readily recognizable in the field as well as under the microscope. The Rearing Pond Intrusion is emplaced into what appears to be South Range type Middle Keweenaw volcanics, but probably earlier than the Mineral Lake Intrusion.

The Rearing Pond Intrusion contains three major rock units that are readily distinguishable in the field. The three types are best described by listing the cumulus minerals in order of abundance, according to the practice of L. R. Wager and co-workers. The earliest unit is an olivine cumulate (peridotite) which forms an outer shell, followed by a plagioclase-olivine cumulate (picritic gabbro), which in the latest part of the intrusion gives way to a plagioclase-pyroxene-olivine cumulate (gabbro). The latter two units combined form the core or inner zone of the intrusion. The second unit (picritic gabbro) also contains fairly large amounts of what appears to be intercumulus pyroxene which actually may also be cumulus. This thesis is developed on the basis of the fact that the banding noted above is largely due to the variation of the content of these poikilitic pyroxene crystals. The fact that these crystals could not have developed in a pile of plagioclase and olivine crystals lying on the bottom of the magma chamber can be reasonably well shown on textural grounds.

Mineral compositions in each of the three units show small changes but fractionation is not strong. Plagioclase varies from about An. .80 (cores) in the picritic gabbro to about An. .60 (cores) in the latest gabbro. Normal zoning is very common and in any crystal the change from core to rim is from 10 to 15 percent, in either rock type. Olivine and orthopyroxene both have compositions in the range of 80 percent Mg end-member in the peridotites to about 65 percent Mg end-member in the gabbros. Little difference is seen in the mineral compositions between the peridotite and the picritic gabbro. Intercumulus myrmekite is common in the latest gabbros indicating the extent to which fractionation has proceeded.

RARE EARTHS IN ROCKS AND MINERALS OF THE
DULUTH COMPLEX

T. P. Paster, E. B. Denechaud, and L. A. Haskin
Department of Chemistry
University of Wisconsin, Madison, Wisconsin, 53706

Rock samples of all principal types from the Duluth Gabbro complex in Gabbro Lake quadrangle, Lake County, Minnesota, have been analyzed for rare earths. As a first approximation, the relative rare-earth abundances of the whole rocks appear to reflect only the mineralogical compositions of the rocks. Separated minerals from a troctolite, a gabbro, and a pegmatite are now being analyzed.

MAFIC DIKES IN THE PRECAMBRIAN ROCKS
OF GOGEBIC COUNTY, MICHIGAN*/

Robert G. Schmidt and Virgil A. Trent
U. S. Geological Survey, Washington, D. C., 20242

Dark, sulfide-bearing, mafic dikes of two ages are common in the older Precambrian rocks of the Gogebic area. Although there is a considerable range in the dimensions, composition, age, texture, and degree of metamorphism, the most abundant dikes are hornblende-rich, contain disseminated pyrite, and are moderately metamorphosed. The youngest dikes are mostly unmetamorphosed and at least some are younger than the oldest "South Range Traps". Detailed study of the dikes provides information useful in solving the geology of the enclosing rocks.

The same general field relations have been found in the Marenisco area and in the area south of Ironwood and Ramsay, 10 to 20 miles to the west. Most older dikes trend northeast, but some trend eastward; younger dikes trend northeast and northwest; and both types appear to be joint controlled. Many well-defined younger dikes were found within the older dikes in both areas, and in exposures near McDonald Lake young dikes seem more abundant in the old dikes than in the adjacent granitic rocks.

Old dikes are particularly abundant and thicker in a northeast-trending 3-mile-wide belt 2 miles south of Ironwood and Ramsay. Some are at least 600 feet wide, and others can be traced intermittently for several miles; thick glacial drift on the south prevents us from determining the full width of this dike swarm. Furthermore, no hornblendic dikes were identified in the Ironwood-Ramsay area within rocks of Animikie age, and these older dikes are rare or perhaps absent in the northernmost 2-mile-wide band of pre-Animikie granitic rocks.

Most dikes cropping out in the central part of the Marenisco quadrangle which intrude metasedimentary rocks and derived gneiss and schist are young, diabasic types. Both older and younger dikes are common in the Presque Isle Granite to the south. Although the old dikes near Ironwood and Ramsay are essentially undeformed, many in the Marenisco area are strongly sheared.

All dike contacts we have seen are chilled. Even though a particular contact is not exposed, we interpret the abrupt diminution of grain size to represent a chilled margin. Most dikes have relatively uniform compositions and grain sizes, but several large ones are notably inhomogeneous. Rhythmic color banding of unknown origin and local segregations of "gabbroic pegmatite" were found. Diabasic textures predominate but equigranular gabbroic textures are common in the coarse-grained bodies.

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

The older dikes owe their present mineralogical assemblage to metamorphism under conditions of the upper greenschist facies (Turner and Verhoogen, 1960), followed by a very unevenly distributed retrograde metamorphism. The fresher rocks contain mainly hornblende and plagioclase, but chlorite, epidote, clinozoisite, and calcite are also present in most places, depending upon the extent of retrograde metamorphic effects.

The younger dikes are augitic, with strongly zoned plagioclase laths; locally these dikes are considerably altered, perhaps deuterically. The possibility that a late period of metamorphism has affected some of the young dikes in this area must still be tested. In both types of dikes either the retrograde or deuteric effects, or both, principally affected the mafic mineral, but locally the plagioclase is preferentially altered. Our work to date does not permit us to say anything regarding direction of metamorphic gradients.

The old hornblendic intrusives may be contemporaneous with sills that cut the Ironwood Iron-Formation east of Wakefield and are truncated by lower Keweenawan strata as mapped by W. C. Prinz (1967). The younger augitic dikes intrude lower Keweenawan quartzite and some of the "South Range Traps" both at Bessemer and, according to C. E. Fritts (written communication, 1966), just west of the Cisco Branch of the Ontonagon River.

Appreciable magnetic variations are rarely found associated with the old mafic rocks observed, but a very notable exception is the magnetite-rich rock in the northern part of the metamorphosed sill described by W. C. Prinz (1967). The augitic dikes contain enough magnetite to be detected with a small hand magnet and generally have strong magnetic anomalies associated with them. Near Ironwood and Ramsay the anomalies are probably all of positive sign, in contrast to the consistently negative anomalies associated with dikes of Keweenawan age farther east in northern Michigan as described by J. R. Balsley, H. L. James, and K. L. Wier, (1949). Near Marenisco one diabase dike anomaly was determined to be of negative sign.

A special interest in the dikes developed when it was noted that many of the large mafic masses contain sulfides. The largest are at least 600 feet wide and perhaps 3000 feet long. Disseminated sulfide generally ranges 0.2-0.4 per cent.

Semi-quantitative spectrographic analyses and atomic absorption spectrometry determinations indicate low copper, nickel, cobalt, and silver contents in all these rocks. An attempt was made to relate age and minor element composition of the mafic rocks, but no significant differences were noted although there is a suggestion of somewhat higher amounts of titanium, beryllium, copper, and strontium in the younger, augitic dikes. For the present we conclude that although sulfide-bearing, neither type of dike is of economic interest for its metal content.

References

- Balsley, J. R., James, H. L., and Wier, K. L., 1949, Aeromagnetic survey of parts of Baraga, Iron, and Houghton Counties, Michigan, with preliminary geologic interpretation: U. S. Geol. Survey, Geophys., Inv. Prelim. Rept.
- Prinz, W. C., 1967, Pre-Quaternary geologic and magnetic map and sections of part of the eastern Gogebic iron range, Michigan: U. S. Geol. Survey Misc. Geol. Inv. Map I-497.
- Turner, F. J., and Verhoogen, John, 1960, Igneous and metamorphic petrology: 2nd ed., New York, N. Y., McGraw-Hill Book Company, 694 p.

SEISMIC REFRACTION SURVEY OF THE AMES ANTICLINE,
AMES, IOWA

L. V. A. Sendlein
Department of Earth Science
Iowa State University, Ames, Iowa, 50010
and
W. P. Staub
Department of Geology
College of St. Thomas, St. Paul, Minnesota, 55101

Ames, Iowa lies astride the mid-continent gravity high. If this important anomaly is to be properly understood, geologic information is essential. The seismic refraction method was selected to investigate the geology of the drift covered Ames region because of its economy and reliability.

There is a remarkable correlation between seismic and gravity data from the Ames region. This correlation suggests that the residual gravitational field is influenced by the thickness of glacial drift as well as geologic structure. Seismic data were used to produce a structure contour map of a high speed Mississippian (Kinderhook) marker horizon. The map illustrates an arched horst that is consistent with the residual gravity map. Evidently the horst is associated with the mid-continent gravity high.

SOLUTION AND DEPOSITION OF IRON IN SEDIMENTS

G. H. Spencer, Jr.
619 First American Bank Building
Duluth, Minnesota, 55802

Sedimentary layers of iron minerals are found in many geologic areas associated with volcanic materials, sandstone, clays, limestones and even coal beds. The theories of origin of these iron bearing beds are often conflicting because of an inability to discover the chemical and sedimentary processes involved in the different environments.

Dissolution of iron in acid waters may be due to either dissolved volcanic gases or to organic acids produced by bacterial action on plant material. In acid volcanic waters, northern lakes, and possibly in Pre-Cambrian seas, iron has been leached from bottom sediments either as chlorides or sulfates or as organic complexes. Organic complexes or chelates of iron are soluble to several thousand parts per million and are as effective solvents for iron as volcanic waters.

Deposition of iron as a carbonate, silicate, sulfide or even as an oxide is due to a gradual or sudden relative increase of alkalies in solution. This may be due to loss of gases from solution by a pressure or temperature change or to actual increase of alkalies ions in solution. A few examples of the various types are discussed.

A MAGNETO-TELLURIC STUDY OF THE
NORTHEASTERN LAKE SUPERIOR AREA

Hans Tammemogi
Department of Physics
University of Toronto, Toronto, Ontario

Results from stations at Port Arthur, Marathon, Chapleau and Michipicoten Island will be presented. These include polarization and anisotropy studies, as well as geomagnetic depth sounding and magneto-telluric resistivity profiles. Preliminary results indicate anisotropy and unusually high apparent resistivities.

GEOLOGIC EXAMINATION OF PIPELINE TRENCH
THROUGH THE EAST GOGEBIC RANGE, MICHIGAN*/

Virgil Trent

U. S. Geological Survey, Washington, D. C., 20242

Bedrock and surficial deposits exposed along 16 miles of a natural gas pipeline trench through the Wakefield-Marenisco area were mapped prior to backfilling. Thirty-five samples were collected for hand specimen and laboratory study. The location of the pipeline on standard topographic base maps was facilitated by pipeline survey maps supplied through the courtesy of Williams Bros. Co. of Tulsa, Okla.

Geologic data obtained from the trench across the southern half of the Marenisco 7-1/2 minute quadrangle were compared with data from previous geologic mapping. The 8- to 10-foot-deep trench exposed shallow ledges in many places, and numerous cuts were made into bedrock.

Near the center of the Wakefield NE quadrangle in the SW 1/4 of sec. 28, T. 47 N., R. 44 W., 1 to 2 feet of white quartzite was exposed for 20 feet along the trench and numerous scattered boulders of thinly laminated siliceous dolomite were found 200 feet to the east. These rocks probably represent Sunday Quartzite and/or Bad River Dolomite. This trench exposure extends the known area underlain by these units southward one mile from exposures mapped by W. C. Prinz (U.S.G.S.). It is the southernmost occurrence of these middle Precambrian rocks.

South of Wolf Mountain in sec. 35, T. 47 N., R. 44 W., the trench exposed a wide belt of gneissic rock striking northeast which appears to be quite similar to rocks which crop out near the center of the Marenisco quadrangle. Recent mapping in sections 28, 21, and 22, T. 47 N., R. 43 W., support the thesis of R. C. Allen and L. P. Barrett that these rocks were derived from metasedimentary rock of their Palms Formation. Paragneiss and paraschist which crops out in the center of sec. 28, T. 47 N., R. 43 W., can be traced in a series of outcrops to the northeast, where, over a distance of 1/2 mile, their transition to metasedimentary rock of the Palms Formation is evident.

Numerous blasted exposures of the Presque Isle Granite along the trench in the Marenisco quadrangle suggest that many of the transitional lithologic changes in this unit are a result of stress mineral formation and mineral alteration. Rather abrupt transitions from granite porphyry, pegmatitic granite, or equigranular granite to a mottled, "contaminated-appearing" rock containing wisps or lamellae of dark micaceous minerals and which grade from incipient

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

to good foliation are common. No evidence was found along the trench for granite of more than one age, and geologic field mapping to date indicates this granite intrudes the Animikie strata with considerable contact effects as previously reported by R. C. Allen and L. P. Barrett.

Two wide fracture zones were exposed in cuts in granite along the trench east of the Marenisco mine road. Previous mapping gave little indication of the extent of fracturing. Fault traces are marked by mylonitized shear zones from 6 to 24 inches wide within the shattered rock.

The radioactivity was continuously monitored along the pipeline trench using a McPhar model T-1 scintillator. Higher than ordinary readings were noted in sections of sheared granite, and mass effect was quite apparent along the bottom of the trench. Thin sections of pegmatitic granite contain sphene, zircon, allanite, and probable monazite as common accessory minerals; biotite enclosing many of these minerals shows radiation halos. A chemical analysis of megascopic sphene crystals from pegmatitic granite in the Presque Isle Granite gives 1500 parts per million (ppm) yttrium, 1000 ppm lanthanum, and 300 ppm niobium, suggesting that the Presque Isle pegmatitic granite has a higher background radioactivity than other intrusive rocks in the area. Radioactive thorium oxide is commonly associated with the rare earth elements and sphene.

Glacial deposits were very well exposed along the 16 miles of pipeline trench. Boulder till made up the bulk of the material but swamp or bog accumulations and stratified sand and gravel deposits were exposed locally. Clearly, an extended profile section such as that provided by a pipeline trench would be of great value in a study of the surficial deposits.

Because pipeline excavations are temporary and progressive, geologists concerned with areas through which they pass should be forewarned about the planned construction. The State Geological Surveys are probably in the best position to provide this important information to interested workers.

PRECAMBRIAN GRANITIC ROCKS AND PRE-KEEWATIN (?) PARA-GNEISSES
OF THE NASHWAUK-BUHL SECTOR, NORTHERN MINNESOTA -
METAMORPHIC OR IGNEOUS COMPLEX?

S. Viswanathan and William C. Phinney
Minnesota Geological Survey
Department of Geology and Geophysics
University of Minnesota, Minneapolis, Minnesota, 55455

Previous knowledge of the geology and petrology of the granitic complex north of the Nashwauk-Buhl sector of the Mesabi iron range, in Northern Minnesota, has been limited to the work of I. S. Allison (1925). Allison regarded this area as being part of an elongate Giants Range batholith (Algoman) extending for some 100 miles from the vicinity of Grand Rapids to a point 15 miles east of Ely and having an average width of 8 miles. He believed that the batholith attained its maximum width, about 18 miles, in a north-south direction in the area of our present study.

Detailed reconnaissance geological mapping of some 500 square miles north of the Nashwauk-Buhl sector of the range during the summer of 1968 has shown that the width of the batholith in this area is substantially less than previously believed, and that it seldom exceeds 8 to 10 miles. Further, our work has revealed that the granitic rocks exposed in this area are mappable as four major northeast-southwest trending conformable zones; from south to north these are: Zone (1) a medium-grained, massive biotite granite (8 miles long and 4 miles wide), Zone (2) a coarse-grained, foliated, porphyritic biotite granite (12 miles long and 5 miles wide), Zone (3) a medium-grained, muscovite- and biotite-bearing gneissic granite which is garnetiferous in places (15 miles long and 4 miles wide) and is associated with several types of inclusions of Knife Lake (Timiskamian) affinities, and Zone (4) a fine-grained, compactly foliated biotite-muscovite granite (15 miles long and 4 miles wide). The evolution of zones (4) and (3) could be ascribed to processes of partial melting and replacement of pre-existing sedimentary country rocks (Knife Lake Group) during metamorphism.

The western half of the area is characterized by thick sequences of presumed Keewatin (Ely) pillowed basalts (massive as well as schistose), ortho-amphibolites, striped (para) epidote-amphibolites, minor intercalated meta-sediments, gabbro dikes and a suite of granitic rocks altogether different from those in the eastern half of the area in that they contain hornblende and are granodioritic in composition. Within this complex, it is possible to map a meta-sedimentary-migmatitic rock unit, measuring at least 10 square miles, that is petrographically diverse. The unit is composed of quartz-plagioclase-biotite-epidote-gneisses, quartz-plagioclase-biotite-muscovite-gneisses, quartz-plagioclase-hornblende-biotite-epidote-gneisses, quartz-plagioclase-biotite-staurolite (?) rock, quartz-plagioclase biotite-epidote-sillimanite (?) -gneisses, layered hornblende-quartz-plagioclase rocks, hornblendites, and granitic mylonites. This unit is tentatively considered to be of pre-Keewatin age for the following reasons: (1) it is stratigraphically below

the presumed Keewatin (Ely) volcanic and meta-volcanic sequence, and (2) it is wholly unlike any known component of the Knife Lake Group. The implications of this find could provide a fresh impetus to the Coutchiching controversy.

In addition to conventional petrographic work, the techniques of oxygen isotope geochemistry and major and trace element analysis by x-ray fluorescence and electron microprobe methods are being used in the study of the rocks discussed herein.

SHALLOW SEISMIC STUDIES IN WESTERN LAKE SUPERIOR

Richard J. Wold
Department of Geology
University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, 53201

A continuous seismic reflection profiling program was begun in Lake Superior in 1965 with an EG&G Boomer, continued in 1966 with an EG&G Sparker. The regional study ended in 1967 with a Bolt air-gun used as the seismic energy source. Altogether some 6000 miles of profiles were obtained in Lake Superior. This paper will report on the profiles obtained west of the tip of the Keweenaw Peninsula.

Sufficient detail was obtained in most areas to correlate from one profile to the next so that an isochron map was constructed of the material above "bedrock". The isochron map shows lines of equal reflection time difference; large numbers indicate thick accumulations above "bedrock" and thin accumulations are indicated by small isochron numbers.

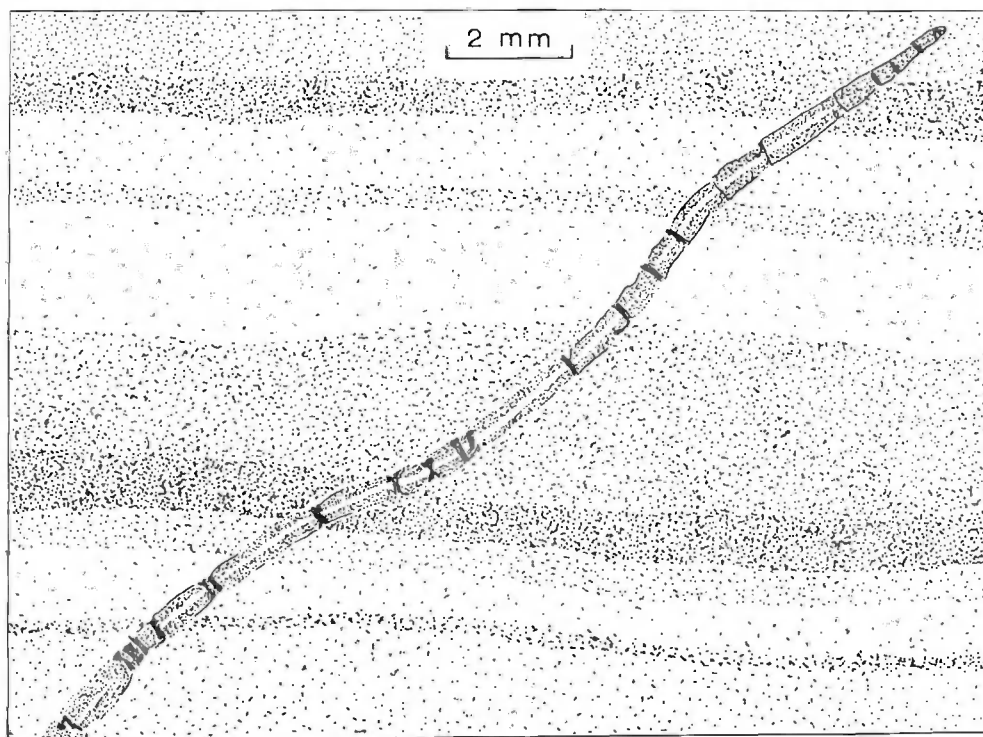
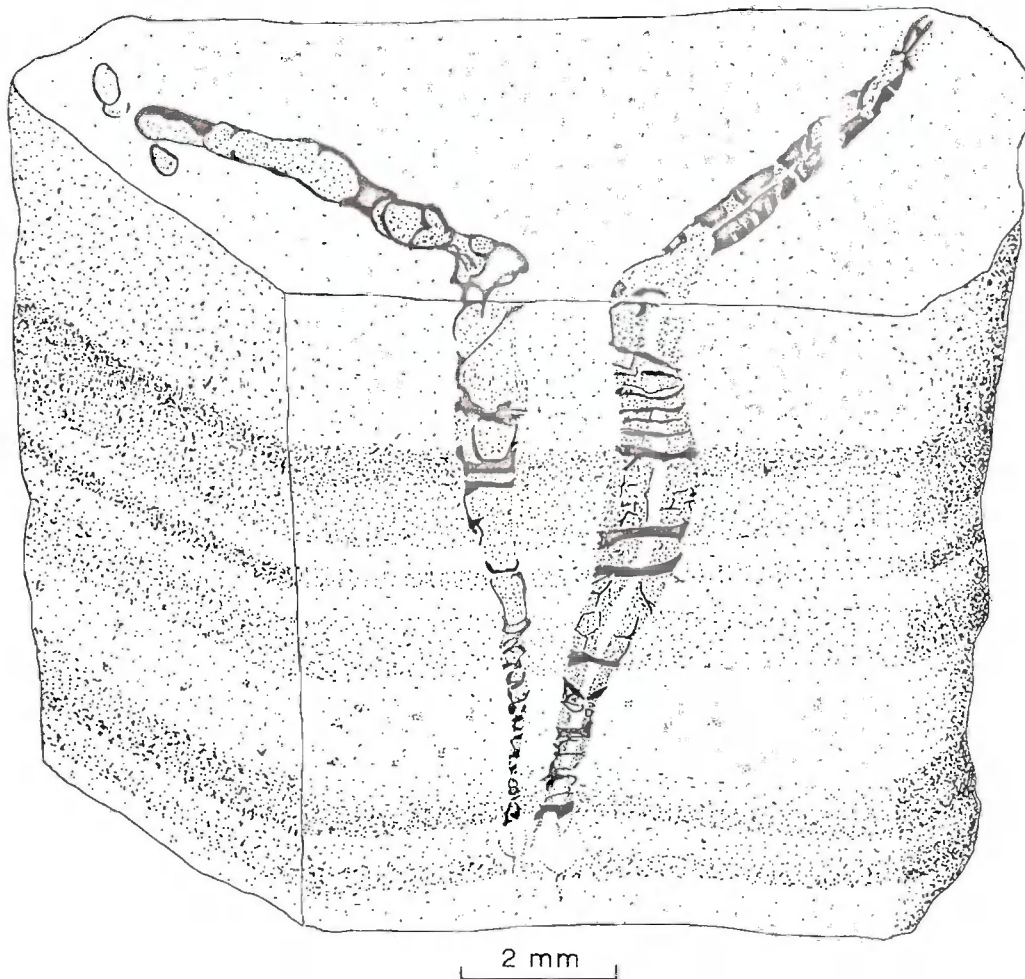
Several buried valleys are outlined on the isochron map. Two impressive valleys parallel the north-shore from Duluth to Isle Royale. It is quite likely that the valley closest to shore is due to differential erosion between volcanics and sediments. Other valleys are observed near the center of the Lake Superior Syncline and seem to outline it. The data also indicate the apparent direction of dip of the underlying bedrock in many areas.

ORGANIC STRUCTURES FROM THE NEGAUNEE (IRON) FORMATION,
MARQUETTE RANGE, MICHIGAN

Thomas G. Wygant and Joseph J. Mancuso
Department of Geology
Bowling Green State University, Bowling Green, Ohio, 43402

In the course of a continuing study of the mineralogy and stratigraphy of the Negaunee (Iron) Formation, curious structures were found which in form and occurrence appear to be organic in origin. These structures are present in specimens taken from the magnetite-chert-silicate unit of the Negaunee Formation which is exposed in the Empire Pit, Palmer, Michigan. The iron formation at this locality has suffered the least amount of metamorphism, structural deformation, and oxidation that is known in the Marquette Iron Range.

If the structures are indeed organic in origin, it would add credibility to the theories which postulate an organic or biochemical control on the deposition of iron formation.



K-Ar DATING OF TWO DYKE-SWARMS FROM THE NORTH SHORE OF LAKE SUPERIOR

D. York and H. C. Halls
Geophysics Division, Department of Physics
University of Toronto, Toronto, Ontario

Whole rock K-Ar dating has been carried out on two geographically distinct sets of dykes from the north shore of Lake Superior. Four dykes from a swarm in the Pukaskwa region, north of Michipicoten Island, give K-Ar ages between 1020 and 1070 m.y. The scatter among the results lies within the range of experimental error and it seems that all the dykes in this group were emplaced about 1050 m.y. ago. Two dykes from the Sibley Peninsula-Grande Portage swarm were each analysed in duplicate and give mean ages of approximately 1150 and 1210 m.y. It appears, therefore, that this set of dykes is measurably older than those from the Pukaskwa region. Whether more than one age of emplacement is represented in the Sibley-Grande Portage dykes remains to be determined. The results in general indicate that the diabase dykes have retained their radiogenic argon extremely well and are evidently satisfactory material for K-Ar dating in this age range.

STRATIGRAPHICAL AND SEDIMENTOLOGICAL COMPARISON OF EARLY
PROTEROZOIC ROCKS OF S.E. WYOMING AND THE GREAT LAKES REGION

Grant M. Young
Department of Geology
University of Western Ontario, London, Ontario

The Huronian rocks of the north shore of Lake Huron were deposited between approximately 2.5 and 2.1 b.y. ago (van Schmus, 1965) and were folded in an orogeny (Penokean?) which was initiated more than 2.1 b.y. ago (Church, 1966). The Animikie "Series" of the Lake Superior region was laid down between 2.0 and 2.5 b.y. ago (Aldrich et al., 1965). A recently suggested stratigraphic correlation of the upper part of the Huronian succession with the lower part of the Animikie (Young, 1966) results in a combined sequence of sedimentary formations which closely resembles that of Early Proterozoic rocks of the Medicine Bow Mountains of S.E. Wyoming.

The Wyoming rocks were deposited between 1.65 and 2.41 b.y. ago (Allan Hills et al., 1967). The stratigraphic succession in the Medicine Bow Mountains area was described by Blackwelder (1926) and has recently been divided into two parts by Houston (1967). The lower part, the Deep Lake Formation, is a highly varied succession of chloritic schists, metaconglomerates, quartzite and siliceous marble. Quartz pebble conglomerates in the basal part of the succession are strongly reminiscent of the basal uraniferous conglomerates of the Ontario Huronian. The Deep Lake Formation is succeeded by the more extensive Libby Group which oversteps the older units and commonly lies directly on basement rocks.

The oldest unit of the Libby Group contains polymictic conglomerates which were interpreted by Blackwelder as tillites. Associated finely laminated argillites contain scattered (ice rafted?) clasts. The overlying Heart Formation is a highly varied succession of meta-siltstones, mudstones and sandstones with ball and pillow structures, ripple marks and cross beds. These two formations correspond very closely with the Gowganda Formation of Ontario (a twofold division of the Gowganda is possible in many areas). Above the Heart Formation of Wyoming occurs the Medicine Peak Quartzite. This unit closely resembles the Lorrain Formation of Ontario in that both become progressively mature upwards, both contain jasper pebbles, kyanite (probably a metamorphic derivative from kaolin) and the chrome mica fuchsite. The overlying Lookout Schist and Sugarloaf Quartzite of the Wyoming area show close similarity to the Gordon Lake and Bar River Formations respectively of Ontario. Thicknesses of the corresponding units are closely comparable in the two areas.

The Early Proterozoic rocks of both regions occur in similar tectonic settings (southern edge of the Superior craton) and display remarkably similar sedimentary structures in corresponding formations. The presence of tillites in such widely separated areas as Wyoming and N. Quebec (Chibougamau) indicates an extensive North American glaciation in Early Proterozoic times and lends support to the idea that these deposits are approximately contemporaneous.

References

- Aldrich, L. T., Davis, G. L. and James, H. L., 1965. Ages of minerals from metamorphic and igneous rocks near Iron Mountain, Michigan. *J. Petrol.*, v. 6, p. 445.
- Allan Hills, F., Gast, P. W., Houston, R. S. and Swainbank, J. G., 1968. Precambrian geochronology of the Medicine Bow Mountains. *Bull. Geol. Soc. Amer.*, v. 79, p. 1757.
- Blackwelder, E., 1926. Precambrian geology of the Medicine Bow Mountains. *Bull. Geol. Soc. Amer.*, v. 37, p. 615.
- Church, W. R., 1966. The status of the Penokean orogeny in Ontario. *Prog. Ninth Conf. on Great Lakes Research*, Chicago, p. 25.
- Houston, R. S., 1967. Geologic map of the Medicine Bow Mountains, Albany and Carbon counties, Wyoming. Plate 1, Mem. 1 (in press), *Geol. Surv., Wyoming*.
- van Schmus, R., 1965. The geochronology of the Blind River-Bruce Mines area, Ontario, Canada. *Jour. Geol.*, v. 73, p. 755.
- Young, G. M., 1966. Huronian stratigraphy of the McGregor Bay area, Ontario; relevance to the paleogeography of the Lake Superior region. *Can. J. Earth Sci.*, v. 3, p. 203.

EXPLORATION OF THE ROUND LAKE ANOMALY,
SAWYER COUNTY, WISCONSIN

Wayne R. Zwickey
The New Jersey Zinc Company
Platteville, Wisconsin, 53818

The Round Lake magnetic anomaly, located on the east side of Round Lake in T41N, R7W, Sawyer County, Wisconsin, was discovered by a Wisconsin Geological Survey dip needle survey in 1914. In 1960 and 1961, The New Jersey Zinc Company investigated this intense negative magnetic anomaly by detailed magnetic and gravity methods, as well as diamond drilling. The results of this investigation will be discussed.