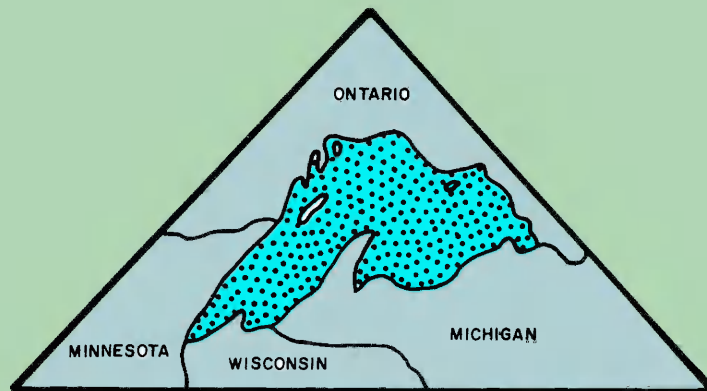


ABSTRACTS & PROCEEDINGS

Twenty Seventh Annual Meeting

INSTITUTE ON LAKE SUPERIOR GEOLOGY



HELD AT THE
KELLOGG CENTER
MICHIGAN STATE UNIVERSITY

EAST LANSING
MICHIGAN

MAY 14-15, 1981

Award Guidelines

SAM GOLDICH MEDAL

Preamble

The Institute on Lake Superior Geology was born on or around 1955, as documented by the fact that the 27th annual meeting will be held in 1981. The Institutes are exemplary in their continuing objectives of dealing with those aspects of geology that are related geographically to Lake Superior; of encouraging the discussion of subjects and sponsoring field trips which will bring together geologists from the academia, government surveys, and industry; and of maintaining an exceedingly informal but highly effective mode of operation.

During the course of its existence the membership of the Institute (that is, those geologists who indicate an interest in the objectives of the I.L.S.G. by attending) has become aware of the fact that certain of their colleagues have made particularly noteworthy and meritorious contributions to the improvement of understanding of "Lake Superior" geology and its mineral deposits.

The exemplary award was made by I.L.S.G. to Sam Goldich in 1979 for his many contributions to the geology of the region extending over about 50 years.

Award Guidelines

- 1) The medal shall be awarded annually by the Board of Directors, I.L.S.G., to a geologist whose name is associated with a substantial sustained interest in, or a major contribution to, the geology of the Lake Superior Region.
- 2) The Board of Directors, I.L.S.G. shall appoint the Nominating Committee. Their annual nominee will be voted on at the annual business meeting. The initial appointment will be of three members, one to serve for three years, one for two, and one for one year, the member with the briefest incumbency to be chairman. After the first year the Board of Directors shall appoint at each spring meeting one new member who will serve for three years. In the third year this member shall be the chairman. The Committee membership should reflect the main fields of interest and geographic distribution of I.L.S.G. membership.
- 3) The Goldich Medal Nominating Committee shall select the medalist and will make its recommendation to the Board of Directors by November 1 of that year.
- 4) The Board of Directors normally will accept the nominee of the Committee, will inform the medalist immediately, and will have one medal engraved appropriately for presentation at the May meeting.
- 5) It is recommended that the Institute set aside annually from whatever sources, such funds as will be required to support the continuing costs of this award.

April 4, 1981

J. Kalliokoski, Chairman
Bill Cannon
Fred Kehlenbeck
Glenn Morey
Greg Mursky

ABSTRACTS and PROCEEDINGS

Twenty Seventh Annual Meeting

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Held at
The Kellogg Center
Michigan State University
East Lansing, Michigan

May 14 - 15, 1981

Sponsored by

DEPARTMENT OF GEOLOGY, MICHIGAN STATE UNIVERSITY
East Lansing, Michigan
and
MICHIGAN DEPARTMENT OF NATURAL RESOURCES, GEOLOGICAL SURVEY
Lansing, Michigan

F. W. Cambray, B. K. Parker, R. C. Reed, J. W. Trow, T. A. Vogel
J. T. Wilband and S. E. Wilson Editors

Gerrald Bennett
Field Trip Coordinator and Director
MINISTRY OF NATURAL RESOURCES, SAULTE STE. MARIE MINING DIVISION
Saulte Ste. Marie, Ontario

Thursday May 14, 1981

Session Chairpersons
T. A. Vogel and J. Kalliokoski

The sessions will begin each day with one hour devoted to a discussion of the programs of the Decade of North American Geology and their implementation with respect to the Precambrian of the Lake Superior Region.

Coffee will be available from 8:00 a.m.

8:20 to 9:20	Workshops on the Decade of North American Geology, General Approach. A. R. Palmer, Geological Society of America Centennial Science Coordinator. Synthesis of the Precambrian geology of the Lake Superior region, perspective and problems. P. K. Sims Major questions in interpretation of Early Proterozoic Crystal Evolution in the Great Lakes Region. R. W. Van Schmus Outstanding Geophysical and Tectonic Problems Associated with the Keweenaw Rift System. H. Halls
9:20 to 9:30	break
9:30 to 9:50	STRATIGRAPHIC EVOLUTION OF APHEBIAN SUPRACRUSTAL ROCKS OF THE LYNN LAKE AREA, NORTHERN MANITOBA H. Paul Gilbert
9:50 to 10:10	DELINEATION OF ARCHEAN AND EARLY PROTEROZOIC ROCKS IN NORTHERN WISCONSIN P. K. Sims and Z. E. Peterman
10:10 to 10:30	THE PENOKEAN OROGENY Samuel S. Goldich
10:30 to 11:00	Coffee Break
11:00 to 11:20	MIDDLE PROTEROZOIC DEFORMATION IN NORTHERN AND CENTRAL WISCONSIN B. A. Brown and J. K. Greenberg
11:20 to 11:40	EVIDENCE FOR MULTIPLE DEFORMATION IN THE MIDDLE PRECAMBRIAN THOMSON FORMATION Timothy B. Holst
11:40 to 12:00	RB-SR DATING OF PRECAMBRIAN BASEMENT FROM ILLINOIS DEEP HOLE PROJECT CORE UPH-3 Carla W. Montgomery
12:00	Lunch

Thursday May 14, 1981

Session Chairpersons
S. S. Goldrich and G. Laberge

1:30 to 1:50	A GEOCHEMICAL RECONNAISSANCE STUDY OF GROUNDWATER FROM AN EIGHTEEN COUNTY AREA OF NORTHWESTERN OHIO Mohr, Eileen T., Deering, Mark F., and Carlson, Ernest H.
1:50 to 2:10	THE DISTRIBUTION OF LITHIUM, RUBIDIUM AND CESIUM IN LAKE MUDS NORTH OF LAKE SUPERIOR M. A. Vos and R. J. Stevenato
2:10 to 2:30	THE SIGNIFICANCE OF THE DISTRIBUTION OF CLASTIC LENSES WITHIN THE NEGAUNEE IRON FORMATION AT THE EASTERN END OF THE PALMER BASIN, MARQUETTE SYNCLINORIUM, NORTHERN MICHIGAN *Mark S. Breithart and F. William Cambray
2:30 to 3:00	Coffee Break
3:00 to 3:20	PRELIMINARY ASSESSMENT OF RARE EARTH ELEMENT GEOCHEMISTRY OF VARIOUS IRON FORMATIONS OF THE LAKE SUPERIOR DISTRICT Elaine L. Slaughter, Susan E. Tituskin, and John T. Wilband
3:20 to 3:40	LITHOLOGIC AND SEDIMENTOLOGIC CHARACTERISTICS OF THE COPPER HARBOR CONGLOMERATE, NONESUCH SHALE AND FREDA SANDSTONE FORMATIONS OF NORTHERN MICHIGAN AND WISCONSIN Paul A. Daniels, Jr.
3:40 to 4:00	THE ROLE OF HYDROTHERMAL ALTERATION AND TECTONISM IN WISCONSIN MOLYBDENITE OCCURRENCES J. K. Greenberg
4:00 to 4:20	RETROGRADE PREHNITE-PUMPELLYITE FACIES METAMORPHISM IN THE SOUTHERN VERMILION GRANITIC COMPLEX, NORTHERN MINNESOTA Robert L. Bauer
6:00 pm	Cash Bar Big Ten Room
7:00 pm	Banquet Big Ten Room

POST PRANDIAL

Presentation of the Sam Goldich Medal
by
Dr. Samuel S. Goldich
to
Dr. Carl E. Dutton

ADDRESS
by
F. B. Van Houten
entitled

PHANEROZOIC OOLITIC IRONSTONE - A FACIES MODEL

(See abstract by F.B. Van Houten and D. Bhattacharyya)

Friday May 15, 1981

Session Chairpersons
J. T. Wilband and G. Anderson

Coffee will be available from 8:00 a.m.

8:20 to 9:20	Decade of North American Geology - Open Discussion
9:20 to 9:30	break
9:30 to 9:50	WISCONSIN GRAVITY BASE STATION NETWORK--1980 C. Patrick Ervin
9:50 to 10:10	PALEOMAGNETISM OF THE MEMESAGEMASING AND CARIBOU LAKES NORITES, GRENVILLE PROVINCE, ONTARIO * S. Oey, O. T. A. Symons, and M. Stupavsky
10:10 to 10:30	GEOPHYSICAL INVESTIGATIONS OF THE SLATE ISLANDS CRYPTOEXPLOSION STRUCTURE M. E. Bengtson, and R. P. Meyer, H. C. Halls, and J. H. Karl, and O. Oushek
10:30 to 11:00	Coffee Break
11:00 to 11:20	JOINT ORIENTATION ANALYSIS IN THE NORTHERN MICHIGAN BASIN Timothy B. Holst
11:20 to 11:40	IMPACT AS A POSSIBLE ORIGIN FOR SUBSIDED BASINS Jack B. Hartung
11:40 to 12:00	PRELIMINARY RESULTS OF A GRAVITY SURVEY IN THE EASTERN HALF OF THE IRON RIVER-CRYSTAL FALLS DISTRICT, IRON COUNTY, MICHIGAN * O. R. Paddock, K. Fujita, F. W. Cambray, and H. F. Bennett
12:00	Lunch

Session Chairpersons
Friday afternoon J. W. Trow and J. J. Mancuso

1:30 to 1:50	SUBAQUEOUS PYROCLASTIC FLOW DEPOSITS IN THE VICINITY OF THE HELEN MINE, WAWA, ONTARIO Mark Osterberg and R. L. Morton
1:50 to 2:10	PRE- AND POST-OORE SEQUENCES IN THE WAWA VOLCANIC BELT, ONTARIO K. Attoh
2:10 to 2:30	PETROGENETIC MODELS OF KEWEENAWAN BASALTIC ROCKS, UPPER MICHIGAN John T. Wilband and Pipob Wasuwanich
2:30 to 3:00	Coffee Break
3:00 to 3:20	PETROCHEMISTRY AND STRUCTURE OF THE MIDDLE PROTEROZOIC KEWEENAWAN VOLCANIC SUCCESSION, HURLEY-TO-MINONG, WISCONSIN * Hassan Ali and Campbell Craddock
3:20 to 3:40	EARLY PROTEROZOIC GABBROIC, DIORITIC, AND QUARTZ MONZONITIC INTRUSIONS IN THE MINNESOTA RIVER VALLEY: PETROLOGY AND SIGNIFICANCE M. DeWitt Oaggett
3:40 to 4:00	THE PETROLOGY AND PETROGENESIS OF THE GAMITAGAMA IGNEOUS COMPLEX, WAWA, NORTHERN ONTARIO * Abdul Choudhry and T. E. Smith

27th Annual
INSTITUTE ON LAKE SUPERIOR GEOLOGY
Annual Banquet

PHANEROZOIC OOLITIC IRONSTONE - A FACIES MODEL

Address by delivered by

F. B. Van Houten

(Abstract by Van Houten & D. Bhattacharyya follows)

PHANEROZOIC OOLITIC IRONSTONE - A FACIES MODEL

F. B. Van Houten and D. Bhattacharyya

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Almost all of the Phanerozoic ferric oxide-chamosite oolitic ironstones are associated with detrital deposits that accumulated in low energy, nearshore marine environments, commonly along a broadly embayed coastline. Processes and products were like those on the chenier coast of southwestern Louisiana and the front of the low-energy, wave-dominated Rhone Delta. There were no well-developed tidal features or large, well-winnowed shoreface sandbodies. A subdued, deeply weathered source supplied mature fine-grained sediment composed mostly of quartz, kaolinite, and iron and aluminum oxide.

The detrital deposits are arranged in a succession of asymmetrical, upward-shoaling sequences produced by small-scale regressions. Each sequence commenced with muddy open shelf deposits locally associated with bioclastic debris, and culminated in either a prograding front of a small delta or a shoreline complex of bars and lagoons. Waning of detrital influx was accompanied by development of abundant ooids.

Specific control of the prograding sequences has not been established in many cases. Some may reflect diversion of a major river to a more distant part of the coastal plain while the abandoned muddy shelf continued to subside and was inundated by renewed transgression. Other sequences may reflect more regional control such as tectonic pulses of subsidence or repeated eustatic rise of sealevel.

Ferruginous ooids formed on detritus-starved mudflats that supported abundant micro-organisms and burrowers. These sites were either mudflats along microtidal coasts protected by breaker bars remote from a prograding delta, or on delta-front and interdistributary coastal flats following delta abandonment. Most of the plastic ooids were carried from their place of origin by coastal currents, and concentrated in accreting, cross-bedded bars. Repeated interruptions in accumulation of ooids permitted increased burrowing that commonly destroyed the bedding fabric, as well as precipitation of ferric oxide cement. Locally, lapses in bar building led to deposition of laminated marine mud.

Commonly ooid bars graded laterally into, or were succeeded by a thin ferruginous phosphatic intraclast lag deposit developed when waves and currents of renewed transgression encroached on the detritus-starved mudflats and crests of ooid bars. Each mound of ooids and associated lag deposit was then buried by marine mud that accumulated during an early stage of rapid transgression and renewed supply of sediment.

This facies model emphasizes the role of repeated upward-shaling sequences, of abrupt waning of sediment supply, and of renewed rapid rise of sea level as the local framework of accumulation of most oolitic ironstones. A similar sequence of facies dominated the less common development of oolitic ironstone along carbonate coasts. Within this framework both the iron-rich oolites and associated phosphatic intraclast lenses developed at or near the lithofacies discordance between successive sequences.

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Annual Goldich Medal Award for 1981
Will be presented to

Carl E. Dutton

at the Banquet Thursday evening

Dr. Carl E. Dutton was born in Dunkirk, Ohio on January 24th 1904. He received his B.A. from DePauw University in 1926, his M.A. from the University of Illinois in 1928 and his Ph.D. from the University of Minnesota in 1931.

He was a teaching assistant at the University of Illinois, an Instructor at Minnesota and an Assistant Professor at Wayne State University and The University of Michigan. He joined the U.S. Geological Survey in 1943, becoming regional geologist in 1948 and Research Geologist in 1962 and has been based in Madison, Wisconsin where he participated in the Mineral Resources Cooperative Program of the Wisconsin Geological and Natural History Survey and the USGS in addition to teaching some classes at the University.

Carl Dutton has had a lifelong interest in the geology of the Precambrian, and particularly in the Great Lakes area. He is widely regarded as an authority on iron formations, he has served on the United Nations Committee on Iron Resources in Geneva in 1953-54 and studied iron ore deposits in Yugoslavia with the AID program in 1961.

He is perhaps best known to us for his work in the Menominee District of Michigan and Wisconsin (USGS Prof. Paper 573 and Map I-466, the Cuyucera District, Minnesota (USGS Maps MF-99 & MF 181 the Iron River, Crystal Falls District, Michigan) (USGS Prof. Paper 570 & Map MF-225 and for his series of lithologic, geophysical and mineral commodity maps of the Precambrian Rocks of Wisconsin (USGS Map I-631).

He has written many other papers and particularly field guide books which have opened an understanding of the region for those of us who now try to follow in his footsteps.

The members of the Institute are proud to recognize the achievements of one of their distinguished colleagues in the awarding of the 1981 Sam Goldich Medal to Dr. Carl E. Dutton.

PRE- AND POST-DORÉ SEQUENCES IN THE WAWA VOLCANIC BELT, ONTARIO

K. Attah
Hope College
Holland, Michigan 49423

An unconformity at the base of Doré Fm and equivalent sedimentary rocks marks a significant stratigraphic break on the basis of which the volcanic-sedimentary succession in the Wawa greenstone belt can be subdivided into pre- and post-Doré Sequences. The pre-Doré Sequence includes at least two cycles of mafic-felsic volcanism, each containing an iron formation unit, but only the lower mafic-felsic volcanic cycle which is terminated by an extensive siderite deposit

is completely preserved. Two post-Doré Sequences have been identified; an older Sequence represented by a mafic flow unit, which directly overlies sedimentary rocks equivalent to the Doré and a younger Sequence, which is structurally discordant with the underlying mafic flow, is characterized by a distinct breccia unit interpreted as a debris flow. Post-Doré Sequences do not contain iron formation units.

RETROGRADE PREHNITE-PUMPELLYITE FACIES METAMORPHISM IN THE SOUTHERN VERMILION GRANITIC COMPLEX, NORTHERN MINNESOTA

Robert L. Bauer

Department of Geology, Macalester College, and Minnesota Geological Survey
St. Paul, Minnesota 55105

Regional prehnite-pumpellyite facies metamorphism (M2) overprinted middle amphibolite facies (M1) assemblages in the rocks of the southern Vermilion Granitic Complex, but pre-dated dynamic metamorphism (M3) associated with strike-slip displacement on the Vermilion fault. The M2 event is defined on the basis of the occurrence of various combinations of the Ca-Al silicates, prehnite, pumpellyite, epidote, and grandite garnet along with chlorite, adularia, albite, sericite, sphene, $\pm$ calcite in the biotite schists, lamprophyres, and granitic rocks exposed in the area. The M2 phases may pervade a given sample, but are more commonly concentrated adjacent to thin quartz or adularia veins or fractures in the rocks.

The prehnite and grandite occur most commonly as lenses or barrel-shaped grains aligned parallel to the cleavage traces in biotite or chlorite after biotite. Adularia has a similar mode of occurrence, but also occurs in thin veins $\pm$ prehnite. M2 epidote and rare pumpellyite may occur as lenses in biotite or chlorite, but are more commonly associated with sericite or rare calcite as alteration products of plagioclase. M2 sphene occurs as fine-grained granular clusters in chlorite after biotite and is pseudomorphic after rutile needles in chlorite in some of the lamprophyres.

Most previous studies describing prehnite lenses in biotite do not ascribe this occurrence to reactions involving biotite, but rather to the introduction of all the prehnite components along biotite cleavage traces. Observations made during the present study, including the albitization of plagioclase and the occurrence of prehnite, adularia, and sphene within a single chlorite pseudomorph after biotite, are consistent with the following prehnite-forming reaction:

anorthite (component) + biotite + H_2O =

prehnite + chlorite + adularia + sphene $\pm$ sericite

The other Ca-Al silicates occurring as lenses in biotite or chlorite may also have formed by similar reactions involving the breakdown of biotite.

No regional variations in the observed assemblages have been found which might indicate systematic spatial variations in the conditions of M2 metamorphism. Comparison of the coexisting mineral assemblages with experimental data on the stability of the Ca-Al silicates indicate a probable range of conditions for the metamorphism of 250 to 350 degrees centigrade and 2 to 4 kilobars at $P(\text{fluid}) = P(H_2O) = P(\text{total})$.

GEOPHYSICAL INVESTIGATIONS OF THE SLATE ISLANDS CRYPTOEXPLOSION STRUCTURE

M. E. Bengtson, and R. P. Meyer
Geophysical and Polar Research Center, Department of Geology and Geophysics
University of Wisconsin, Madison, Wisconsin 53706

H. C. Halls
Department of Geology, Erindale College, University of Toronto
Mississauga, Ontario, Canada L5L 1C6

J. H. Karl, and O. Dushak
Department of Physics and Astronomy, University of Wisconsin
Oshkosh, Wisconsin 54901

A survey of the underwater crater area (defined by an irregular arcuate bathymetric rise) surrounding the Slate Islands of northern Lake Superior is now nearly complete. A close order aeromagnetic survey (1000yd spacing, 425m above lake level) and a set of marine magnetic and high resolution 3.5kc bottom and subbottom profiles taken under flight lines has been acquired. These have revealed several short wavelength anomalies on the east side of the islands. The sources of these anomalies appear to be 1/2 km to 1 km below lake level and none seem to have any bathymetric expression. To the west a longer wavelength anomaly trending NW-SE

has been delineated. This feature correlates well with a previously predicted igneous-sedimentary contact. The islands seem to be centered about a roughly defined arcuate magnetic high. Short wavelength anomalies have been found over the islands.

A set of marine refraction and reflection records was also obtained. Data was recorded digitally. Large thicknesses (Up to 1 km) of a ~ 3.5 km/sec layer underlain by a ~ 5.5 km/sec refractor have been detected exterior to the crater. Inside the crater rim, the 3.5km/sec layer is absent. Here, only a 4.8km/sec refractor, lying directly beneath recent sediments, has been detected. All layers appear to have a gentle southerly dip.

THE SIGNIFICANCE OF THE DISTRIBUTION OF CLASTIC LENSES WITHIN THE
NEGAUNEE IRON FORMATION AT THE EASTERN END OF THE PALMER BASIN,
MARQUETTE SYNCLINORIUM, NORTHERN MICHIGAN

* Mark S. Breithart and F. William Cambray

Department of Geology, 206 Natural Science, Michigan State University
East Lansing, Michigan 48824

The vertical and horizontal distribution of clastics found within the Negaunee Iron Formation in the eastern end of the Palmer Basin, T47N-R26W sections 26, 27, and 28, was studied to determine the geometry of the region at the time of deposition of the sediments.

Previous work by Gair (1975), Davis (1965) and Mengel (1956) has suggested that the Palmer Basin is a relict sedimentary basin. Their conclusions were based upon qualitative sedimentary and textural descriptions. This study has attempted to test this concept with a quantitative approach based upon the vertical and horizontal variation in amount, type, and grain size of clastics observed in the subsurface. The data indicates that the earlier models are correct and that the Palmer Basin is a relict sedimentary basin.

The Palmer Basin is located on the south limit of the Marquette synclinorium in the Upper Peninsula of Michigan. It contains over 2,000 feet of middle Proterozoic age sediments and has been down-faulted along the E-W trending Palmer Fault relative to the main synclinorium.

This study utilized 84,000 feet of core made available by the Cleveland-Cliffs Iron Company. The clastics were divided into two main types based upon matrix composition (chloritic vs. iron oxide). The size distribution was divided into coarse ($1.05 \pm .15 \phi$), medium ($1.82 \pm .28 \phi$) and fine ($2.80 \pm .46 \phi$).

From petrographic analysis of over 100 thin sections of the clastics could best be

classified as immature sediments of the lithic-quartz wacke clan. The quartz is subangular and is supported by a variable matrix of chlorite and iron oxides with minor cryptocrystalline quartz (chert) and carbonate. The majority of lithic fragments were either rounded chert or chloritic clasts. Feldspar was rarely noted. Most bedding contacts between clastics and iron formation are sharp.

The vertical and horizontal variation indicates that: 1) the south margin of the Palmer Basin has a consistently higher percentage of coarse clastics with a chloritic type matrix dominating, 2) depositional centers of clastics varied with vertical position throughout the basin, and 3) the source areas for the clastics is indicated to be to the SW, S or SE. All of this supports the idea of the Palmer Basin being a relict sedimentary basin.

The best model for the deposition of the sediments is one involving mass flows and/or submarine fans with migrating feeder channels and depositional centers. This would account for the high percentage of matrix, the immaturity of grains, the wide horizontal and vertical distribution and the sharp bedding contacts. A source area for the clastics low in feldspar is also inferred.

The pattern is consistent with the concept of a basin which was progressively subsiding during deposition. The periodic supply of clastics by mass flow being perhaps controlled by disturbances associated with fault movements controlling the subsidence.

* Presentation eligible for the Student Award

MIDDLE PROTEROZOIC DEFORMATION IN NORTHERN AND CENTRAL WISCONSIN

B. A. Brown and J. K. Greenberg

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Recent mapping and compilation by the Wisconsin Geological Survey has pointed out the compelling need for reinterpretation of the Proterozoic tectonic history of northern and central Wisconsin. Tectonic structures observed in this region were predominantly formed during the Penokean deformational event, and have been modified locally and possibly on a regional scale by later events.

In central Wisconsin, the Wolf River granitic complex of 1500 m.y. age represents a major plutonic event, covering over 3600 km². A plutonic event of this magnitude would be expected to produce at least locally intense deformation as well as thermal metamorphism. Mapping in the Wisconsin Northeast sheet (Greenberg and Brown, 1980) has revealed various metamorphic and deformational features associated with the Wolf River complex, including: (1) amphibolite-grade metamorphism and intense folding near the northern margin of the Wolf River complex in Langlade and Lincoln Counties; (2) recrystallization and refoliation of the 1850 m.y. Athelstane granitic complex in southwestern Marinette County; (3) thermal metamorphism in the Mountain (Lahr, 1972) and Thunder Mountain areas; (4) crenulation and chevron folding of metavolcanic rocks in the Mountain area where earlier fabrics impinge at high angles to the granite's contact; (5) tectonic reorientation in Marathon and Portage Counties, as shown by aeromagnetic trends; (6) intense deformation observed in metavolcanic units caught between the Wolf River complex and a major Penokean pluton in eastern Marathon County (LaBerge, 1980).

Deformation related to the emplacement of the Wolf River complex is restricted to the rocks south of the major structural boundary proposed by Brown and Greenberg (1980) and Greenberg and Brown (1980). Structures to the north of this boundary trend to the northeast in Lincoln County, gradually arching eastward until trends are

east-west to slightly southeast in central Marinette County.

In south-central Wisconsin, broad, open folding is preserved in widely scattered exposures of quartzite and underlying 1760 m.y. old rhyolites. If the interpretation of Dott and Dalziel (1972) is correct, and the quartzites are correlative over a wide area, considerable strain has been superimposed on the basement rocks of central Wisconsin between the 1760 m.y. plutonic-volcanic episode, and the intrusion of the 1500 m.y. anorogenic Wolf River complex. Deformation appears to increase in intensity from west to east. This is exhibited in contrasting the minor structural modification of the Sioux and Barron quartzites (west) with the obvious folding and metamorphism evident in McCaslin, Thunder Mountain, Baraboo, and Waterloo quartzites (east). The deformation is closely related in time to the resetting of Rb-Sr ages (1600 m.y.) observed widely in northcentral Wisconsin (Van Schmus, 1980; Sims and Peterman, 1980). The 1500 m.y. intrusive episode itself may be envisioned as a result of the 1600 m.y. event, just prior to (and during?) intrusion.

Confirmed Archean rocks are known only in northernmost Wisconsin and as limited exposures surrounded and intruded by Proterozoic rocks in Central Wisconsin. Current data indicate no Archean rocks exposed in the main part of the Proterozoic volcanic belt. The complexity of deformation observed in this belt is probably due to multiple deformation and intrusion during the Penokean event, with local, and possibly widespread overprinting by younger events at 1600 m.y. and associated with the 1500 m.y. Wolf River complex.

The apparent absence of Archean ages in the volcanic belt of northeastern Wisconsin better supports this interpretation than alternative interpretations which appeal to Penokean deformation overprinting Archean structures in this region.

THE PETROLOGY AND PETROGENESIS OF THE GAMITAGAMA IGNEOUS COMPLEX, WAWA, NORTHERN ONTARIO

* Abdul Choudhry and T. E. Smith
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The Gamitagama Lake Complex is a plug-shaped, elliptical gabbroic complex of Archean age (Rb/Sr 2642 Ma), approximately 7 x 10 km in dimensions. It outcrops in the metasedimentary-metavolcanic rocks of the Shebandowan Greenstone Belt of the Superior Province, approximately 40 km south of Wawa.

Five intrusive phases are recognized in the complex, four of which are sub-alkaline. They include an olivine-bearing inner gabbroic series, partly surrounded by a middle zone of less basic, gabbroic rocks, and an outer group of dioritic rocks. The dioritic group includes hornblende-gabbro, diorite, quartz-diorite, quartz-monzodiorite, and tonalite. Arcuate outcrops of leucocratic granodiorite and granite occur within the diorite zone. The granites and diorites are cut by a large dyke-like body of quartz-monzonite which has alkaline affinities.

In the olivine-bearing inner gabbroic series, olivine gabbro and gabbro dominate, and troctolite, norite, and andesine anorthosite are subordinate. In the middle zone of gabbroic rocks, gabbro and amphibole gabbro occur with lesser amounts of norite and pyroxene diorite. Late dykes of fine-grained gabbroic rocks with porphyritic amphibole and phlogopite intrude the inner and outer gabbroic series.

In the inner gabbroic series olivine + plagioclase + titaniferous magnetite + clinopyroxene + orthopyroxene, and in the middle gabbroic series plagioclase +

orthopyroxene + clinopyroxene + titaniferous magnetite, crystallized out of the respective parent magmas, at pressures less than 5 Kb, to give calc-alkalic differentiation trends within each series.

Many of the rocks of the complex are cumulative in origin, and their major and trace element chemistry is not representative of the liquid line of descent. However, their incompatible element contents may be compared to those of other complexes considered to be cumulate rocks produced during calc-alkaline fractionation.

The most basic rocks of each discrete, intrusive event are successively less basic in composition indicating that fractionation was occurring in the source magma chamber, at deeper levels. The late fine-grained gabbroic intrusions in the complex contain amphibole and phlogopite phenocrysts. This suggests that the differentiation was controlled by the separation of amphibole and phlogopite at more than 10 Kb pressure (~35 km depth).

The complex is compared to several well described hornblende-bearing gabbroic plutons occurring in the Cordilleran batholiths of North and South America. It is concluded that the Gamitagama Complex is most similar to the Guadalupe Complex in California. Within the Gamitagama Complex there is a complete range of rock types from troctolites, through amphibole gabbros and diorites, to quartz-diorites and granitoid rocks. It is considered to represent an excellent illustration of the fractionation of gabbroic melts to ultimately yield granitoid rocks.

* Presentation eligible for the Student Award

EARLY PROTEROZOIC GABBROIC, DIORITIC, AND QUARTZ MONZONITIC
INTRUSIONS IN THE MINNESOTA RIVER VALLEY:
PETROLOGY AND SIGNIFICANCE

M. DeWitt Daggett

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Three, small, early Proterozoic plutons intrude the Archean gneiss terrane of the Minnesota River Valley south of Franklin, Redwood County, Minnesota. The largest is the Cedar Mountain Complex, a composite intrusion consisting of a chilled margin of diabase and microgabbro, a main body of flow-layered hornblende diorite, and a quartz monzonite core. This complex is 600 meters in diameter. Two smaller plugs consisting of 1) diabase and gabbro, and 2) granodiorite, crop out five kilometers east of Cedar Mountain. Cross cutting relationships between rock types identify three distinct stages of intrusion: 1) gabbro, 2) diorite and granodiorite, and 3) quartz monzonite.

Petrographic and mineral chemistry data from these rocks suggest that the dioritic, granodioritic, and monzonitic melts differentiated from a common gabbroic parent magma by fractional crystallization of olivine, clinopyroxene, and calcic plagioclase. Feldspar compositions range continuously from An_{80} in diabase and gabbro to An_2 in quartz monzonite. Olivine in the diabase is Fo_{53} to Fo_{60} . Clinopyroxene from diabase, gabbro, and hornblende diorite is diopside or diopsidic augite. The restricted range of clinopyroxene compositions and the lack of an overall iron enrichment trend for clinopyroxene phenocrysts are evidence for an original melt with calc-alkaline affinities. High modal abundances of biotite

and orthoclase in diabase indicate that the parent melt was potassic.

Assimilation of sialic crust during magma intrusion affected the final mineralogies and chemistries of the Franklin-area plugs. Xenoliths of Archean gneiss occur throughout the Cedar Mountain diorite and the gabbro plug to the east; emplacement of the plugs to a fairly shallow depth proceeded in part by stoping of the country rock.

These early Proterozoic intrusives may be a part of a limited but widespread shallow level igneous event which occurred in the southern Lake Superior region about 1,760 m.y. ago. The Minnesota River Valley plugs are lithologically somewhat similar to the Fox River rhyolites and related granites of south-central Wisconsin, and to the Amberg quartz monzonite and related intrusions of northeast Wisconsin. These rocks all occur as small, isolated, epizonal intrusions or extrusive flows; they all possess a calc-alkaline chemical character. The presence of rare rhyolite clasts in conglomerate units of the middle-Proterozoic Sioux quartzite indicates the former existence of additional similar rocks in Minnesota.

This 1,760 m.y. old igneous event followed the Penokean orogeny but preceded the more voluminous igneous activity which accompanied crustal extension in middle- and late-Proterozoic time.

LITHOLOGIC AND SEDIMENTOLOGIC CHARACTERISTICS OF THE
COPPER HARBOR CONGLOMERATE, NONESUCH SHALE AND FREDA SANDSTONE
FORMATIONS OF NORTHERN MICHIGAN AND WISCONSIN

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The Keweenaw Age Copper Harbor Conglomerate, Nonesuch (Shale) Formation, and Freda Sandstone formations comprise the Oronto Group and are found in outcrop over some 200 kilometers in northern Wisconsin and western Upper Michigan. These formations are part of a volcanic-clastic sequence created in response to the formation of the Midcontinent Rift System. Although intercalated volcanics are found in the lower one-third of this group, the sedimentary depositional regime was dominant. Along the Keweenaw Peninsula paleocurrent indicators for all three formations show that the predominant paleoflow directions were generally in northerly directions. In contrast, sedimentary structures in the Copper Harbor Conglomerate on the opposite side of the rift (i.e., Isle Royale) indicate stream flow was to the south and east.

Depositionally, the Copper Harbor Conglomerate is a basinward-thickening wedge of volcanogenic clastics and subordinate volcanics that decreases in average grain-size upsection. Various facies comprise the Copper Harbor and these have been interpreted collectively as representing a prograding alluvial fan complex. Maximum thickness is on the order of 1830 meters. Principal lithologies are red-brown, oxidized, lithic graywacke and volcanogenic conglomerates. The conglomeratic facies are predominantly clast-supported and comprised of volcanic clasts with an overall compositional ratio of mafic to silicic plus intermediate clasts of about 2:1. The heavy-mineral suite for the Copper Harbor (as well as for the Nonesuch and Freda) mainly consists of ilmenite plus similar opaque minerals, and epidote.

Interfingering with the Copper Harbor Conglomerate is the Nonesuch (Shale) Formation, an unoxidized sequence of gray-black siltstone, shale, and sandstone with a maximum thickness of 215 meters. The Nonesuch contrasts with the redbed sequences, both above and below, by: 1) having been deposited in a reducing environment, 2) increased textural maturity, and 3) hydrocarbon, sulfide and chlorite content. The Nonesuch is interpreted as having been deposited in a rift-flanking lacustrine environment of varying depth. Initiation of lacustrine conditions probably occurred through disruption of existing drainages by alluvial, volcanic, and/or tectonic processes. As with the underlying Copper Harbor, a gradational contact exists with the overlying Freda Sandstone.

The Freda Sandstone is a ferruginous, lithic sequence of cyclic sandstone and mudstone exceeding 3660 meters in maximum thickness. Although similar in appearance to some sandstones of the Copper Harbor Conglomerate, the Freda, overall, is of greater compositional maturity and conglomerate facies are uncommon. The Freda is dominantly fluvial in origin and appears to have "overridden" the Nonesuch environments.

Although complex in detail, the overall depositional model for the three formations is one of simple transgressive-regressive relationships between alluvial fan/lacustrine/fluvial environments (Elmore and Daniels, 1980b). Important aspects of such a model are that: 1) all the formations are genetically related with no major unconformities between them, and 2) the intervening Nonesuch Formation is, at least in part, equivalent in age to the upper Copper Harbor and the lower Freda.

PALEOMAGNETISM OF THE MEMESAGEMASING AND CARIBOU LAKES NORITES, GRENVILLE PROVINCE, ONTARIO

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The Memesagemasing and Caribou Lake layered norites outcrop as oval, 20 km² stocks intruding the high rank granitic gneisses in the Grenville Province about 60 km S of the Grenville Front. Five cores yielding 10 specimens were drilled in the stocks at each of 24 and 26 sites respectively. Low-field magnetic susceptibility measurements show that both stocks have a central phase with a high magnetite content. This explains their airborne magnetic anomaly pattern rather than invoking a funnel-shape. Anisotropy of magnetic susceptibility measurements show that the norites are strongly layered even though most outcrops appear unbanded, and that the plutons have not been structurally compressed or tilted as previously suggested. AF, thermal, and chemical step demagnetization and general AF cleaning all isolate a stable remanence component with 95 percent confidence of $\sim 310^\circ$, -51° in the Memesagemasing stock using conventional tiered statistical analysis. This component

resides in titanomagnetite with numerous exsolution lamellae. The same component is isolated in the Caribou Lake stock by point density stereonet contouring only after AF cleaning. Its less stable remanence resides in coarser unexsolved titanomagnetite grains. Eight baked contact tests using more than 100 additional specimens and including 2 profiles show that: 1) the norite remanence predates emplacement of the crossing cutting ~ 1250 Ma Sudbury olivine diabase dikes and ~ 1100 Ma granite pegmatite dikes, and 2) the norite was cooled to $\sim 20^\circ\text{C}$ when the dikes were emplaced. The norite pole lies on the ~ 1760 Ma position of the North American APW path implying: 1) emplacement during the terminal stages of the Hudsonian Orogeny dated by Rb-Sr at $\sim 1800 \pm 100$ Ma ago; 2) possibly comagmatic emplacement with the Sudbury Irruptive which is ~ 90 km NW in the Southern Province; and 3) the juxtaposition of the Grenville and Southern Provinces as far back as 1760 Ma.

* Presentation eligible for the Student Award

WISCONSIN GRAVITY BASE STATION NETWORK--1980

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The Wisconsin Geological and Natural History Survey has embarked upon a regional gravity surveying program. Mapping is being done on a one mile grid insofar as the road system and elevation control permit. The Northeast Wisconsin Sheet is "in press" and was presented at this meeting last year. The rest of the state will be covered in the coming years.

A successful field program is dependent on the existence of a high precision, internally consistent base station network. To facilitate field operations, a base station should be readily accessible by auto, no more than 25-30 feet from a road or drive,

easy to locate, permanent, relatively isolated from foot and vehicular traffic, and have a stable base on which to set the meter. Additionally, no point in the state should be more than about a 45 minute drive from a base station.

A statewide base station network, consisting of 30 stations, was established in the summer of 1980 using two LaCoste-Romberg model G gravimeters. Use of two gravimeters doubles the number of ties between stations and facilitates error detection. The network was designed to include several extant base stations and is in good agreement with the earlier measurements.

THE PENOKEAN OROGENY

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The Penokean orogeny, which occurred in the Lake Superior district approximately 1800 m.y. ago, was a complex event that involved more than mountain building by uplift followed by erosion. As in the development of the more recent mountain chains, igneous and metamorphic activity on a grand scale characterized the Penokean orogeny. Graywacke-argillite sequences with intercalated volcanic rocks were folded, metamorphosed, and intruded by a variety of igneous rocks ranging from gabbroic to granitic in composition.

Published U-Pb zircon ages from Wisconsin and Michigan indicate two pulses of igneous activity. The older, 1835 ± 15 m.y. ago, involved a variety of rock types, whereas the younger pulse, 1760 ± 10 m.y. ago, appears to have been restricted to granite and rhyolite. Unpublished U-Pb analyses of zircon concentrates from a large number of samples representing tonalitic to granitic rocks in east-central Minnesota are closely related in time, 1804 ± 24 m.y.

Rb-Sr isochron ages for the rocks of east-central Minnesota range from 1700 m.y. to 1750 m.y. and are distinctly younger than the corresponding U-Pb zircon ages.

The data available at this time indicate more or less continuous igneous activity in the Lake Superior region between 1850 and 1750 m.y. ago.

The 2600-m.y. old McGrath Gneiss of eastern Minnesota was strongly deformed during the Penokean orogeny. The U-Pb ages on zircons from the gneiss are strongly discordant and reflect the 1800-m.y. deformation. Similarly, old rocks in Wisconsin and in Michigan were severely affected by the Penokean orogeny, and the earlier geologic history, as a result, is difficult to decipher.

The similarity in lithologic types and structural style of the rocks involved in the 1800-m.y., the 2600-m.y., and in older orogenic events in the Lake Superior region is striking. In each case metasedimentary-volcanic accumulations, a variety of igneous intrusive rocks, and migmatitic development were involved. Regional folding gave way to higher grades of metamorphism accompanying igneous activity, and late shearing with recrystallization are characteristic. Emplacement of pegmatite and aplite dikes followed each major orogenic event.

THE ROLE OF HYDROTHERMAL ALTERATION AND TECTONISM IN WISCONSIN MOLYBDENITE OCCURRENCES

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Molybdenite is known to occur in three places in northeastern Wisconsin. These appear to be situated along a north-south region restricted near 88°W longitude. Molybdenum mineralization in Michigan's Upper Peninsula is also concentrated near the same longitude. In all Wisconsin cases, Penokean-age granite plutons are directly associated with the mineralization. The best known occurrence, near Middle Inlet in Marinette County, is in quartz veins within the Mount Tom granite body. The other two occurrences, near Amberg in Marinette County and in southeast Florence County, are pegmatite mineralizations.

Chemically, the granite host rocks are calcalkaline to alkaline, with no "unusual" trace element characteristics. However, near the site of mineralization in veins or

pegmatites, the host rocks show the effects of hydrothermal alteration, especially alkali metasomatism. Dramatic examples of potassium metasomatism are apparent at Middle Inlet and southeastern Florence County. The granite at Middle Inlet has also been albitized and silicified proximal to quartz veins. These alteration effects should be considered as essential guides in exploring for molybdenum in Wisconsin.

Wisconsin occurrences of molybdenum are similar to those in older Precambrian terranes of the world, such as in Ontario and Western Australia. However, these cannot be equated with the extensive ore resources represented by porphyry-type deposits typical of younger plate tectonic environments.

IMPACT AS A POSSIBLE ORIGIN FOR SUBSIDED BASINS

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Subsidence of roughly circular intracontinental basins, such as the Michigan basin, must have a driving mechanism or energy source. Mechanisms directly related to plate tectonics do not operate slowly enough to explain a record of almost continuous subsidence of the Michigan basin throughout the Paleozoic Era. Thermal contraction of the lithosphere underlying the basin is another mechanism, but even proponents of this idea recognize "little direct evidence that an initial heating event actually occurred in the Michigan basin immediately before the start of subsidence." Another energy source which could lead to a subsiding basin is the impact of an asteroid or comet roughly 10 km in diameter.

During such an impact material is excavated from depths of a few tens of km and deposited on the surrounding area. The temporary cavity produced is filled immediately by material that was originally below the cavity. The resulting structure, similar to those observed on the Moon and Mars, is a broad topographic low surrounded by higher rocks capped by ejecta deposits. Of particular importance is the likelihood

that a state of isostatic equilibrium will be established or closely approached after motions directly related to the impact have ceased. The mass deficiency associated with the topographic low may be expected to be compensated for by excess mass related to more dense rocks centrally uplifted below the basin. Basin evolution proceeds with erosion of surrounding highlands and deposition within the basin. If it is required that isostatic equilibrium is maintained, the basin will subside in response to the sediment load and the surrounding highlands will be uplifted. This process will continue until the more dense material underlying the basin is returned approximately to its original level or until no topographic difference exists between the basin center and the surrounding area. A significant characteristic of this process is that the rate of subsidence is controlled entirely by the rate of sedimentation, which may be extremely slow or even nonexistent at times. On the Earth an evolved impact basin may take the appearance of a subsided sedimentary basin, something like the Michigan basin.

EVIDENCE FOR MULTIPLE DEFORMATION IN THE MIDDLE PRECAMBRIAN THOMSON FORMATION

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The Thomson Formation of East-Central Minnesota exhibits numerous structural features which have been interpreted to have formed during the Penokean Orogeny. In the Thomson-Carlton-Cloquet area there are open folds on a scale from centimeters to kilometers. The folds are upright, and fold axes trend about east-west and are horizontal to gently plunging either east or west. An axial-planar cleavage, vertical or nearly vertical, is present.

To the south there is a pervasive bedding-parallel foliation which has previously been interpreted as having formed in a metamorphic event which predated deformation. Evidence of the amount of compressional strain associated with foliation (Wood, 1974) as well as abundant extensional features (boudinage) within the foliation plane in this region suggest that the bedding-parallel foliation is associated with a deformation. Folds are present in the southern area, with geometries and attitudes similar to those in the north. A vertical crenulation cleavage, axial-planar to these folds where both are observable, is also present. The crenulation cleavage can be found even where folds are not found, in the area from Denham to

Atkinson. The deformation which caused the bedding-parallel foliation must then pre-date that which caused the open, upright, sub-horizontal folds.

Isoclinal, recumbant folds, to which the earlier foliation is axial-planar, have been found in several localities. These folds vary in scale from centimeters to meters. Fold hinges are fairly rare because of the isoclinal nature of the folds. The pervasive nature of this earlier foliation suggests that isoclinal, recumbant folds of a large scale also may be present.

The deformation history indicated involves an early stage of isoclinal, recumbant folding, with the development of an axial planar foliation. A latter stage of deformation involved the development of open, upright folds, with an axial-planar foliation also, which is a crenulation cleavage where the earlier foliation is present, and a slaty cleavage where the earlier foliation is not present. Evidence for the earlier deformation has been found from Denham to just northeast of Atkinson, whereas evidence for the second deformation can be found in the entire region of Thomson Formation exposure.

JOINT ORIENTATION ANALYSIS IN THE NORTHERN MICHIGAN BASIN

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The orientations of 14,687 joints were measured at 142 locations in the Paleozoic rocks of the Michigan Basin. The data were taken in an area which ranged from Manitoulin Island on the east, the south shore of Lake Superior on the north, the Door Peninsula on the west and the northern portion of the lower peninsula of Michigan on the south. The rocks at the sample localities range in age from Cambrian to Devonian. Most of the localities are in carbonate rocks, but data were taken from outcrops of sandstone and shale also.

Almost all (over 98%) of the joints are vertical or nearly vertical. Four main joint sets are present in the northern Michigan Basin. The largest peak in the data is a joint set with a strike of about 054 degrees (N54°E). The second-largest peak in the data is a set with a strike of about 133 degrees (N47°W). Two peaks of about the same height are joint sets striking 002 degrees (N02°E) and 092 degrees (N88°W). Local mean orientation of any of the sets does vary from location to location, but is relatively consistent over the entire area

for each of the four sets. The local variation could not be correlated with lithology, age of rock, or geographic location.

Joint set orientation is independent of regional strike around the Michigan Basin which varies from about 020 degrees (N20°E) to about 115 degrees (N65°W) across the study area. Possible structural trends in the Precambrian rocks below the Devonian rocks in the area, postulated from geophysical data, do not correlate with any of the joint sets. Trends of axes of folds present in the Paleozoic strata of the lower peninsula average about 135 degrees (N45°W). This suggests that the joint set of nearly the same strike direction may be related to these folds (the b-c joints of Price, 1966). In-situ stress measurements in the Paleozoic rocks of the mid-continent region (summarized in Haimson, 1978) show the maximum principal compressive stress in the horizontal plane to be quite consistent in orientation, averaging 053 degrees (N53°E). This suggests that the joint set with a nearly-identical strike may be extensional, and fairly recent in age.

A GEOCHEMICAL RECONNAISSANCE STUDY OF GROUNDWATER FROM AN EIGHTEEN COUNTY AREA OF NORTHWESTERN OHIO

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A reconnaissance study of groundwater quality in Northwestern Ohio was undertaken in which 100 samples from actively pumping wells were collected. The major supply of groundwater for this area is from carbonate aquifers which locally contain evaporites and epigenetic mineralization that may be the source of natural trace element pollution. Major industrial centers and agricultural areas may also be a prime source of pollution.

On site measurements of static water level, pH (6.85-8.55), temperature, conductivity (100-2500 micromhos), alkalinity (83-580 ppm), F (0.2-2.8 ppm) and Cl (3-230 ppm) were made. Digital titration analyses performed on filtered, acidified samples indicated Ca to be present in concentrations from 27-560 ppm and Mg from 14-192 ppm, while spectrophotometric

techniques showed sulfate and silica to be present in concentrations of 4-1500 ppm and 7.2-29.0 ppm respectively. Fe, also determined by a spectrophotometric technique, ranged from 0.0 ppm to 11.2 ppm. The concentrations of K (1.0-34.4 ppm), Zn (less than 40 ppb-1.7 ppm), Co (less than 300 ppb), and Na (5.5-150.6 ppm) were determined by atomic absorption techniques.

Other trace elements including As, Cd, Cu, Ba, Pb and Sr will be measured by graphite furnace techniques, while Hg concentrations will be determined by a flameless AA method. It will be determined if any of the trace elements present a health hazard and should, therefore, limit water utilization or require special treatment of water supplies.

RB-SR DATING OF PRECAMBRIAN BASEMENT FROM ILLINOIS
DEEP HOLE PROJECT CORE UPH-3

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Illinois Deep Hole core UPH-3 penetrated approximately 840 m of Precambrian granitic basement. Whole-rock samples taken over the full length of the Precambrian portion of the core fit a single Rb-Sr isochron with slope age of 1479 ± 10 m.y. and initial $^{87}\text{Sr}/^{86}\text{Sr}$ of $0.7102 \pm .0025$ (1 σ errors). Mineral isochrons from several core samples yield essentially the same age within the precision of the

measurements, indicating that these rocks have not been affected by any significant thermal event since that time. The initial strontium isotope ratio reflects some contribution of radiogenic Sr from older crust. The 1479-m.y. age is similar to ages reported for granitic rocks in Wisconsin, Missouri, and elsewhere in the midcontinent region, suggesting widespread igneous activity at about that time.

PRELIMINARY RESULTS OF A GRAVITY SURVEY IN THE EASTERN
HALF OF THE IRON RIVER-CRYSTAL FALLS DISTRICT, IRON COUNTY, MICHIGAN

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A gravity survey was conducted in the eastern portion of the Iron River-Crystal Falls district of Iron County, northern Michigan. Measurements were taken on five profiles, three east-west profiles to the south of Crystal Falls and two north-south profiles to the west of Crystal Falls. The stations along each profile were separated by an average of 750 meters. Altitude control was maintained by an altimeter and 1:24,000 topographic maps. Accuracy of the data after reduction to bouguer anomalies is about plus or minus 1.4 milligals. A maximum amplitude of 34 milligals is observed over the Iron-River Crystal Falls district. Our observed data are in agreement with those obtained by Bacon and Wyble (1952). The anomaly is centered to the south and west of the iron formation exposures. The shape of the anomaly indicates that the source is at depth.

Several crustal models were developed to interpret the data. If the stratigraphic section reported in the literature is used, only a 9 milligal anomaly is obtained.

Linear stretching of the stratigraphic succession requires a sedimentary thickness of greater than 40 km to fit the amplitude of the anomaly. With no stretching of the column, and an iron formation density of 3.21 gm/cc, an increase of the iron formation thickness from 200 to 1200 meters is required. An increase in the density of the Riverton Iron Formation to 3.56 gm/cc would reduce the total sedimentary thickness to the reported 12 km with an iron formation thickness of 600 meters. These iron formation thicknesses are greatly in excess of the reported average thickness of 200 meters.

An alternative possibility is that the Paint River group and Badwater Greenstone are directly underlain by basalt. This model postulates a sedimentary thickness of 2800 meters (of which 200 is iron formation) and 1800 meters of greenstone. To fit the observed anomaly, an underlying basaltic layer of between 3200 and 3900 meters is required. This could be caused by the sub-aqueous emplacement of basalts in a rift basin which has subsequently filled with sediments.

* Student Presentation eligible for the Student Award

PRELIMINARY ASSESSMENT OF RARE EARTH ELEMENT GEOCHEMISTRY OF VARIOUS IRON FORMATIONS OF THE LAKE SUPERIOR DISTRICT

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Several samples of banded iron-formation (BIF) from the Wawa district and the Gunflint, Vulcan, and Negaunee Iron Formations have been analyzed for their rare earth elements (REE) as part of an investigation to determine the use of REE as indicators of depositional environments and to investigate their mobility during metamorphism, oxidation, and leaching.

Our preliminary results cannot be interpreted too literally in terms of genetic modeling because the experimental base, such as exists for magmatic rock-forming minerals, is very weak for BIF sedimentary systems. The carbonate rich sediments of the Negaunee I.F. at the Empire Mine show relatively strong fractionation of the light REE (La/Sm 3-5x chondrite) and have surprisingly uniform total abundances with respect to depth. The clastic lenses are considerably more enriched in total abundances yet show similar distribution

patterns to the carbonate samples. The "jaspilite" and "hard ores" (Cliffs Shaft) of the Michigan formations are most REE enriched, Vulcan samples the least, and Tilden and Empire Mine oxide ores are intermediate to these groups.

We suggest the REE enrichment in the oxides to be a response to solutions migrating through the formations (e.g. Cannon, 1975 - hard ores) or depletions in response to increase in metamorphic grade (Vulcan). In the Empire and Tilden environments where carbonate to oxide reactions are obvious or implied, preliminary data indicate that the abundance of REE in the oxides are similar to that of the carbonates. Cherts, carbonates and oxides do not exhibit a Ce depletion. The Gunflint and Negaunee cherts have "terrestrial" REE patterns similar to other "land exposed" cherts.

* Student Presentation eligible for the Student Award

THE DISTRIBUTION OF LITHIUM, RUBIDIUM AND CESIUM IN LAKE MUDS NORTH OF LAKE SUPERIOR

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A study of the distribution of Li, Rb and Cs in lake muds north of Lake Superior is funded by the Ministry of Northern Affairs under the Northern Industrial Mineral Study program, and is supervised by staff of Mineral Deposits Section, Ontario Geological Survey. Centre-lake samples covering an area of 27,700 sq. km. (NTS 42D, 1/2 of 42E, 52A, 1/2 of 52H), originally collected for the Federal-Provincial Uranium Reconnaissance Program of 1977, were used in this study. The primary purpose is to evaluate the geochemical response of lithium and related trace elemental concentrations in lake sediments and determine its potential as a tool for lithium exploration.

The lake sediment samples were collected at an average density of 1 sample per 13 sq. km. A total of 1782 samples were analyzed for Li, Rb and Cs by Barringer Magenta Ltd. not including randomly inserted control reference and blind duplicate samples. Two hundred and four samples were analyzed for tin and tantalum.

Lithium, rubidium and cesium were analyzed by flame atomic absorption upon reverse HF/HClO₄/HNO₃ digestion. The detection limits were 1 ppm, 10 ppm

and 1 ppm respectively. Tantalum was analyzed by plasma emission upon reverse HF/HClO₄/HNO₃ digestion and a redissolution in 0.5 N HCl/HF. The detection limit was 5 ppm. Tin was analyzed colourimetrically upon fusion with ammonium iodide; the detection limit being 1 ppm.

Control reference, blind duplicate and field duplicate samples were utilized to determine the precision and accuracy of the data. Precision of the four different control samples ranged from 8% to 18% for lithium and from 6% to 10% rubidium. Blind duplicate accuracy was 16% and 20% for lithium and rubidium respectively, while field duplicate accuracy was 7% for Li and 12% for Rb. Cesium was not considered since most concentrations recorded were below the detection limit of the lab equipment.

While high lithium concentrations generally coincide with high rubidium concentrations, no large anomalous regions were detected in a preliminary visual examination except in the area southwest of Thunder Bay. Progress of a detailed computer analysis amalgamating the data with major element and base metal values of the lake muds is discussed.

PETROGENETIC MODELS OF KEWEENAWAN BASALTIC ROCKS, UPPER MICHIGAN

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Lower Keweenawan diabase dikes from Marquette-Baraga Counties, and middle Keweenawan Portage Lake Lavas from upper Michigan, can each be subdivided into two chemically distinct groups: a low TiO_2 - P_2O_5 group characterized by higher Al_2O_3 content, higher Mg ratio, and lower total Fe and REE abundances than a high TiO_2 - P_2O_5 group. Both groups, which are indistinguishable in the field, are enriched in the LREE relative to the HREE, and have similar normalized REE abundance patterns.

Plots of La/Sm vs. La and Yb are linear but nonparallel for each subgroup of the basalt. This correlation can be interpreted to mean that the rocks, regardless of mode of formation, are coeval within their

respective type. The wide gap between the TiO_2 - P_2O_5 contents of each group cannot be resolved by a simple fractionation or mixing model, especially because the $\text{TiO}_2/\text{P}_2\text{O}_5$ ratio remains remarkably constant within each group. We conclude that two sources perhaps from different depths or with separate REE signatures, are required to produce the two groups and suggest each linear trend is indicative of liquids derived by varying degrees of partial melting of these sources. Similar chemical trends within the dikes have been interpreted to mean that the same magmatic processes must have been operative during their emplacement in the early opening stages of the Keweenawan rift in Michigan.

AUTHOR

TIME

H. Ali and C. Craddock	3:00 to 3:20 Friday
K. Attoh	1:50 to 2:10 Friday
R. L. Bauer	4:00 to 4:20 Thursday
M. E. Bengtson, R. P. Meyer, H. C. Halls, J. H. Karl, and D. Dushek	10:10 to 10:30 Friday
M. S. Breithart and F. W. Cambray	2:10 to 2:30 Thursday
B. A. Brown and J. K. Greenberg	11:00 to 11:20 Thursday
A. Choudhry and T. E. Smith	3:40 to 4:00 Friday
M. D. Daggett	3:20 to 3:40 Friday
P. A. Daniels, Jr.	3:20 to 3:40 Thursday
S. Dey, D. T. A. Symons, and M. Stupavsky	9:50 to 10:10 Friday
C. P. Ervin	9:30 to 9:50 Friday
H. P. Gilbert	9:30 to 9:50 Thursday
S. S. Goldich	10:10 to 10:30 Thursday
J. K. Greenberg	3:40 to 4:00 Thursday
J. B. Hartung	11:20 to 11:40 Friday
T. B. Holst	11:20 to 11:40 Thursday
T. B. Holst	11:00 to 11:20 Friday
E. T. Mohr, M. F. Deering, and E. H. Carlson	1:30 to 1:50 Thursday
C. W. Montgomery	11:40 to 12:00 Thursday
M. Osterberg and R. L. Morton	1:30 to 1:50 Friday
D. R. Paddock, K. Fujita, F. W. Cambray, and H. F. Bennett	11:40 to 12:00 Friday
P. K. Sims and Z. E. Peterman	9:50 to 10:10 Thursday
E. L. Slaughter, S. E. Tituskin, and J. T. Wilband	3:00 to 3:20 Thursday
F. B. Van Houten and D. Bhattacharyya	Thursday evening
M. A. Vos and R. J. Stevenato	1:50 to 2:10 Thursday
J. T. Wilband and P. Wasuwanich	2:10 to 2:30 Friday