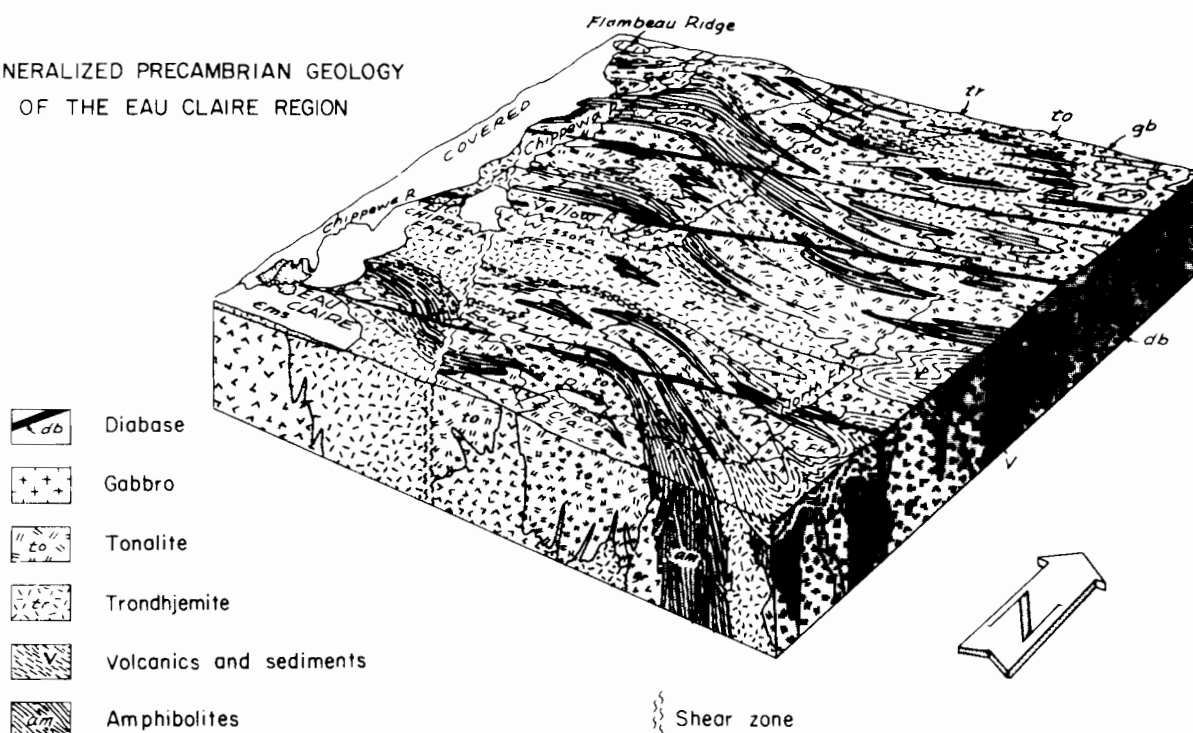


26th Annual
Institute on Lake Superior Geology



PROCEEDINGS & ABSTRACTS

GENERALIZED PRECAMBRIAN GEOLOGY
OF THE EAU CLAIRE REGION



Davies Center
University of Wisconsin-Eau Claire
May 6-10, 1980

Sponsored by:
THE UNIVERSITY OF WISCONSIN-EAU CLAIRE
Program Chairman & Editor: Paul E. Myers
Geology Department UW-Eau Claire

PROCEEDINGS AND ABSTRACTS
for the
26th ANNUAL
INSTITUTE ON LAKE SUPERIOR GEOLOGY



held at
THE DAVIES CENTER
UNIVERSITY OF WISCONSIN - EAU CLAIRE
May 6 - 10, 1980

sponsored by

The University of Wisconsin - Eau Claire

Program Chairman and Editor, Paul E. Myers
Activities Chairman, Nancy Jo Pickett
Geology Department
University of Wisconsin - Eau Claire

SALES

Proceedings and Abstracts and field trip guidebooks may be purchased (@ \$5.00 each U.S.) from the Department of Geology, University of Wisconsin-Eau Claire, Eau Claire, WI 54701. Make checks or money orders payable to 26th Annual Institute on Lake Superior Geology.

Field trip guide books may also be purchased from the Wisconsin Geological and Natural History Survey, Publications Sales Division, 1815 University Avenue, Madison, WI 53706.

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DEDICATION

Ralph W. Marsden will retire this month, May 1980, as Professor of Geology at the University of Minnesota, Duluth. Duluth has been only his most recent stop in a long career devoted to mining and geology. Because Ralph has long been a staunch supporter of the Institute on Lake Superior Geology since its inception in 1955, and because he is a friend of every geologist in the Lake Superior region, this volume is dedicated to him.

Ralph received his geology degrees from the University of Wisconsin, completing his graduate work in 1939. He then went to the Philippines as a geologist and served as Chief of the Geological Survey Division of the Philippine Bureau of Mines from 1940 to 1945. Unfortunately, the last three years in this role were served in civilian internment camps under the guidance of the Japanese.

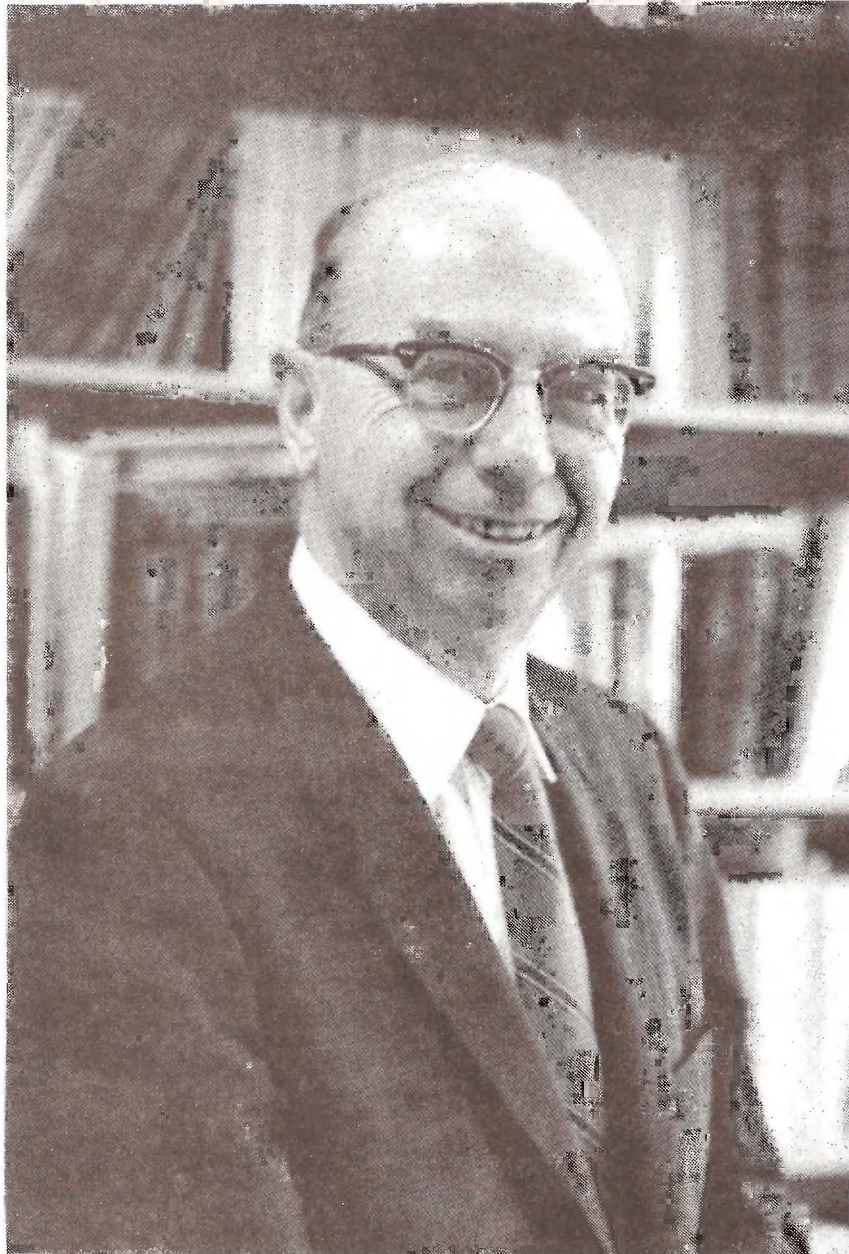
After a few years with the Jones & Laughlin Steel Corporation, he moved to the United States Steel Corporation. He became manager of Geological Investigations in 1953, a post he retained for 11 years until he became manager of U.S. Steel's iron ore operations.

Ralph has long had a love for academia, having taught at Wisconsin while a graduate student, at the University of Oklahoma for one year, and even in the Internment Camp School in the Philippines. In 1967 the University of Minnesota, Duluth, was able to entice him back to the university environment. He served as head of the Geology Department for 7 years, leading it along a path of specialization in Precambrian studies.

Ralph has a reputation as one of the most knowledgeable "iron men" in the world, and is widely traveled. Foreign governments, the United Nations and several foreign companies have sought his advice. His knowledge of iron ores, and especially those of the Lake Superior region, is encyclopedic. His latest major undertaking was a review of the iron ore reserves of Minnesota and Wisconsin for the U.S. Bureau of Mines, a project recently completed. Yet, everyone who knows Ralph realizes that his expertise is far, far broader than his specialization, for he is indeed a geologist in all respects.

He has long served the AIME and SEG, as well as other professional organizations, in a number of capacities. His broad perspective, his unimpeachable integrity, and his steady hand are appreciated by all.

The ILSG has been fortunate to have had the benefit of Ralph's presence and support for its entire existence, and we know we shall enjoy that benefit for many more years to come. Remember, Ralph, that with an ILSG volume dedicated to you, you cannot easily forget this unique organization of which you have long been an important part. We thank you!



Dr. Ralph W. Marsden

GENERAL INFORMATION AND ACKNOWLEDGEMENTS

We welcome you to Eau Claire. This is our first, but hopefully not last attempt at playing host to ILSG. We hope you enjoy yourselves and return with others to help us continue our studies of the Precambrian geology of the region.

We have attempted to make your stay here as convenient as possible. The excellent conference facilities of the Davies Center have been generously provided by the University of Wisconsin - Eau Claire.

All arrangements for space, food, and transportation were handled by Nancy Jo Pickett. Students and faculty of the Geology Department have donated much time and effort to assure the success of the conference. Manuscripts were typed by Penny Hoitomt and Gail Wirz. Coordinator of visual aids is Dr. James Wilson.

Conference vehicles have been provided by the University of Wisconsin - Oshkosh, the Wisconsin Geological and Natural History Survey, the University Center System, Fox Valley, at Menasha, and by the University of Wisconsin - Eau Claire. Special thanks are due to the field trip leaders: Michael Cummings, Randy Maas, Manmohan Sood, Randy Van Schmus, and Stephanie Wurdinger.

I have had the enthusiastic support of colleagues and ILSG friends throughout the state and region. You have helped make the job easier.

Thank you all!

A handwritten signature in dark ink, appearing to read "Paul E. Myers". The signature is fluid and cursive, with a small dot at the end.

Paul E. Myers
Conference Director

26th ANNUAL
INSTITUTE ON LAKE SUPERIOR GEOLOGY

sponsored by
University of Wisconsin - Eau Claire
Eau Claire, WI 54701

May 6 - 10, 1980

INSTITUTE BOARD OF DIRECTORS

D. M. Davidson, Jr., Department of Geological Sciences
University of Texas, El Paso, El Paso, Texas (1979)

M.F. Kehlenbeck, Department of Geology
Lakehead University, Thunder Bay, Ontario (1977)

G. Mursky, Department of Geological Sciences
University of Wisconsin, Milwaukee, Wisconsin (1978)

P.E. Myers, Department of Geology
University of Wisconsin, Eau Claire, Wisconsin (1980)

R. C. Reed, Geological Survey Division
Dept. of Natural Resources, Lansing, Michigan (Permanent Member)

M. Walton, Minnesota Geological Survey
University of Minnesota, Minneapolis, Minnesota (1976)

TWENTY-SIXTH ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY - 1980

TECHNICAL SESSION CHAIRMEN

Dr. Bruce Brown
Wisconsin Geological and Natural History Survey
1815 University Avenue
Madison, WI 53706

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Department of Plant and Earth Sciences
University of Wisconsin
River Falls, WI 54022

Dr. Eugene I. Smith
Division of Science, Earth Science Program
University of Wisconsin - Parkside
Kenosha, WI 53141

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Dr. Gene LaBerge
Department of Geology
University of Wisconsin
Oshkosh, WI 54901

Dr. Michael Mudrey
Wisconsin Geological and Natural History Survey
1815 University Avenue
Madison, WI 53706

Dr. Richard Ojakangas
Department of Geology
University of Minnesota
Duluth, MN 55812

TWENTY-SIXTH ANNUAL INSTITUTE ON LAKE SUPERIOR GEOLOGY

ACTIVITY SCHEDULE

- TUE, MAY 6 8:00 a.m. FIELD TRIP #1, CHIPPEWA VALLEY: Departure from north entrance, Davies Center, University of Wisconsin-Eau Claire. Overnight in Eau Claire (accommodations not included in fee).
- WED, MAY 7 8:00 a.m. FIELD TRIP #1, CHIPPEWA VALLEY--DAY 2: Departure from north entrance, Davies Center. Return at 5:30 p.m.
- 7:00 a.m. FIELD TRIP #2, BLACK RIVER VALLEY: Departure from front entrance, Midway Motor Lodge, Eau Claire. Return by 6:00 p.m.
- 4:00 p.m. REGISTRATION BEGINS: Willow Lounge, Davies Center, UW-Eau Claire. Registration closes at 10:00 p.m.
- 7:00 p.m. SMOKER: Ojibwa Room, Davies Center, UW-EC to 10:00 p.m.
- THU, MAY 8 8:15 a.m. TECHNICAL SESSIONS I AND II: Council Fire Room, Davies Center, 8:15 a.m.-12:00, and 1:40-5:00 p.m.
- 8:45 a.m. POSTER SESSIONS: Alumni Room, Davies Center, to 5:00 p.m.
- 7:00 p.m. CASH BAR: Blackhawk Lounge, Davies Center, until 7:00 p.m.
- 8:00 p.m. ANNUAL INSTITUTE BANQUET: Council Fire Room, Davies Center. Speaker, Dr. Ralph Marsden, University of Minnesota - Duluth.
- FRI, MAY 9 8:00 a.m. TECHNICAL SESSIONS III AND IV: Council Fire Room, Davies Center, 8:00-12:00 and 1:20-5:00 p.m.
- 8:45 a.m. POSTER SESSIONS: Alumni Room, Davies Center to 3:00 p.m.
- 12:15 p.m. SYMPOSIUM LUNCHEON FOR AUTHORS AND COORDINATORS: President's Room (\$2.00)
- 3:20 p.m. PRESENTATION OF BEST STUDENT PAPER AWARD: Council Fire Room, Davies Center.
- 6:00 p.m. CARAVAN DEPARTURE FOR WAUSAU--FIELD TRIPS 3 AND 4: North Entrance, Davies Center, UW-EC
- SAT, MAY 10 7:30 a.m. FIELD TRIP #3, WAUSAU SYENITE: Departure from Big Boy Restaurant near intersection of Routes 29 and U.S. 51. Return to the restaurant for lunch at noon. Participants will return to the restaurant upon completion of the trip.
- 8:00 a.m. FIELD TRIP #4, MARATHON COUNTY: Departure from Holiday Inn, Wausau, WI. Return there at end of trip. Shuttle bus will be available to take participants to Central Wisconsin Airport at Mosinee.

SCHEDULE OF PAPERS

SESSION I

Thursday, May 8, 1980

Morning Session

PRECAMBRIAN GEOLOGY

Co-chairmen: D.M. Davidson, Jr. and R. Ojakangas

- | | | |
|-------|--|--|
| 8:15 | P.E. Myers | Opening remarks |
| 8:20 | * <u>B. Van de Voorde & P. Ervin</u> | Geophysical study of a Precambrian boundary in Minnesota |
| 8:40 | M.M. Kehlenbeck | Regional structure, metamorphism and stratigraphy of the Quetico Gneiss Belt, Thunder Bay, Ontario |
| 9:00 | * <u>R.S. Maass, L.G. Medaris, Jr. & W.R. Van Schmus</u> | Archean and Early Proterozoic tectonic history of north-central Wisconsin |
| 9:20 | *J.W. Goodge | Migmatites from the Vermilion Granitic Complex, Minnesota |
| 9:40 | A. Fleming,
* <u>D. Heinz, R. Lee & H. Woodard</u> | Geology of the southeastern contact zone of the Vermilion batholith, Minnesota |
| 10:00 | * <u>K.H. Poulsen & M.M. Kehlenbeck</u> | Overtuned Archean successions and their significance |
| 10:20 | Coffee Break | |
| 10:40 | * <u>C.N. Brandon, E.I. Smith & F.R. Luther</u> | The Precambrian Waterloo quartzite, southeastern Wisconsin: evolution and significance |
| 11:00 | E.I. Smith | Rare earth element distribution in the Precambrian rhyolites and granites of south-central Wisconsin |
| 11:20 | M.L. Cummings | Geochemistry and volcanic stratigraphy of west-central Marinette County, Wisconsin |
| 11:40 | <u>W.F. Cannon & M.G. Mudrey</u> | Where is the source of Wisconsin drift diamonds? |

There will be a luncheon meeting of the Board of Directors in the Heritage Room, Davies Center

* student paper

SESSION II

Thursday, May 8, 1980

Afternoon Session

PRECAMBRIAN GEOLOGY

Co-chairmen: J. Greenberg and G. LaBerge

- | | | |
|------|--|--|
| 1:40 | V.W. Chandler | Correlation of gravity and magnetic anomalies in east-central Minnesota and northwestern Wisconsin |
| 2:00 | *R.S. Maass &
L.G. Medaris, Jr. | Metavolcanic rocks at Eau Claire Dells, Marathon County, and an evaluation of the "shear zone" hypothesis in Wisconsin |
| 2:20 | G.L. LaBerge | Were there two Middle Precambrian orogenies in the Lake Superior region? |
| 2:40 | M.L. Cummings | Volcanic and plutonic rocks of the Jump and Yellow River Valleys, north-central Wisconsin |
| 3:00 | Coffee Break | |
| 3:20 | *T. Ernst,
J. Markert &
M. Montz | Heavy mineral analysis of Precambrian rocks in Rusk County, Wisconsin |
| 3:40 | P.A. Daniels &
D.R. Elmore | Depositional setting of a stromatolite-polite facies on a Keweenawan alluvial fan |
| 4:00 | R.J. Shegelski | Stratigraphy of the Gunflint Formation, Current River area, Thunder Bay |
| 4:20 | N.W. Jones | Petrology of some Logan diabase sills from Cook County, Minnesota |
| 4:40 | *P. Morton | Differentiating ultramafic flows from sills in the Shebandowan Mine area, northwestern Ontario, Canada |
| 5:00 | Adjourn | |

SESSION III

Friday, May 9, 1980

Morning Session

SYMPOSIUM - TECTONIC HISTORY OF THE LAKE SUPERIOR BASIN - A REVIEW

Coordinator: Richard J. Wold

Co-chairmen: W. Cordua and E. Smith

- | | | |
|-------|--|---|
| 8:00 | <u>D.M. Davidson, Jr.</u> | Geological evidence relating to the interpretation of the Lake Superior basin structure |
| 8:20 | <u>J.S. Klasner,</u>
<u>W.F. Cannon &</u>
<u>W.R. Van Schmus</u> | The Pre-Keweenawan tectonic history of the north-central United States and central Canada and how it influenced formation of the Mid-Continent Rift |
| 8:40 | <u>J.C. Green</u> | Keweenawan volcanism and the nature of Keweenawan rift tectonics |
| 9:00 | <u>R.W. Ojakangas,</u>
<u>G.B. Morey,</u>
<u>P.A. Daniels &</u>
<u>J. Kalliokoski</u> | Upper Precambrian sedimentary rocks of the Lake Superior region |
| 9:20 | <u>W.R. Van Schmus,</u>
<u>J.C. Green &</u>
<u>H.C. Halls</u> | Geochronology of Keweenawan rocks: a review |
| 9:40 | Coffee Break | |
| 10:00 | <u>W.J. Hinze,</u>
<u>R.J. Wold &</u>
<u>N.W. O'Hara</u> | Gravity and magnetic anomaly studies of Lake Superior |
| 10:20 | <u>V.W. Chandler,</u>
<u>P.L. Boman,</u>
<u>W.J. Hinze &</u>
<u>N.W. O'Hara</u> | Long wavelength gravity and magnetic anomalies of the Lake Superior Region |
| 10:40 | <u>J.H. Luetgert &</u>
<u>R.P. Meyer</u> | Seismic refraction studies of Lake Superior crustal structures |
| 11:00 | <u>R.J. Wold,</u>
<u>D.R. Hutchinson &</u>
<u>T.C. Johnson</u> | Topography and surficial structure of Lake Superior bedrock based on seismic reflection profiles |
| 11:20 | <u>J.H. Karl,</u>
<u>M.P. Bernardin,</u>
<u>R.P. Meyer,</u>
<u>M.E. Bengtson &</u>
<u>H.C. Halls</u> | Geophysical studies of the Slate Islands, Lake Superior |

SESSION III (CONTINUED)

- 11:40 J.T. Mengel & Lake Superior red clay mineralogy: correlation with mechanical behavior
 B.E. Brown
- 12:00 H.C. Halls & Paleomagnetism of Keweenawan rocks
 L.J. Pesonen
- 12:15 Adjourn for lunch

There will be a Symposium Luncheon for authors and coordinators at 12:20 p.m. in the Presidents Room of the Davies Center (\$2.00)

SESSION IV

Friday, May 9, 1980

Afternoon Session

GENERAL

Co-chairmen: B. Brown and M. Mudrey

- 1:20 *T.J. Grundl, Stable isotope tracer studies in the Cambro-
 E.C. Perry, Jr. & Ordovician aquifer of northern Illinois
 R.H. Gilkeson
- 1:40 *L.I. Kelley & Kaolinitic weathering zone on Precambrian
 F.R. Karner basement of southeastern North Dakota and
 western Minnesota
- 2:00 W.R. Rehfeldt Hydrogeologic investigations at a landfill
 site in the red till (Valderan) region of
 eastern Wisconsin
- 2:20 T.D. Vick Seismic survey of a buried river channel
- 2:40 *W.M. Lucko & The pegmatites of the Quetico gneiss belt,
 S.A. Kissin northwestern Ontario, and their uranium
 potential
- 3:00 Coffee Break - also BEST STUDENT PAPER AWARD \$200 CASH PRIZE

SYMPOSIUM - URANIUM IN WISCONSIN AND THE UPPER MIDWEST
CONTINUED ON NEXT PAGE

SYMPOSIUM - URANIUM IN WISCONSIN AND THE UPPER MIDWEST

Coordinator: M.G. Mudrey, Jr.

3:20	G. Mursky	Relationship of Canadian uranium deposits to the geologic setting of Wisconsin
3:40	J.K. Greenberg	Uranium provinces: enrichment in granitic rocks and relations to Wisconsin
4:00	W.B. Coker & J.M. Franklin	Regional geochemistry and metallogeny north shore of Lake Superior, Ontario
4:20	J.J. Mancuso & R.H. Motten	Geology of the McCaslin Range, northeastern Wisconsin
4:40	T.J. Evans, J.K. Greenberg & M.G. Mudrey, Jr.	Wisconsin interest in radiological impacts resulting from uranium exploration (drilling)
5:00	Adjourn	

This page has no number in original. Appears between 8 and 9

ABSTRACTS

GEOPHYSICAL STUDY OF A PRECAMBRIAN BOUNDARY
IN MINNESOTA

Barbara VanDeVoorde and C. Patrick Ervin

Department of Geology
Northern Illinois University
DeKalb, Illinois 60115

West-central Minnesota is divided by a northeasterly trending boundary separating two Early Precambrian terranes: an older gneiss terrane to the south and a younger granite-greenstone terrane to the north. The nature, location, and origin of this boundary is a matter of conjecture.

During the summer of 1979, COCORP ran a deep-crustal, seismic reflection profile across the boundary. The Minnesota Geological Survey conducted a concurrent gravity survey utilizing the elevation points surveyed by the seismic crew. A corresponding aeromagnetic profile should be completed before this meeting.

This paper will discuss only the modeling of the gravitational field, which is being done using a two-dimensional modeling algorithm.

REGIONAL STRUCTURE, METAMORPHISM AND STRATIGRAPHY OF THE
QUETICO GNEISS BELT, THUNDER BAY, ONTARIO

M.M. Kehlenbeck

Structurally the rocks form a complex domical feature. Fold axes plunge gently to the east or west, and axial surfaces trend parallel to the long axis of the dome.

Metamorphic minerals are distributed in zones which parallel the dominant planar structures, and metamorphic grade increases from greenschist facies on the margins to granulite facies near the center of the dome.

In several places near the center of the structure evidence indicates that rocks become younger toward the north and south.

Boundaries with the Wabigoon Belt to the north and Shebandowan Belt to the south are transitional.

ARCHEAN AND EARLY PROTEROZOIC TECTONIC HISTORY OF NORTH-CENTRAL WISCONSIN

R.S. Maass and L.G. Medaris, Jr.
Department of Geology and Geophysics
University of Wisconsin
Madison, WI 53706

W.R. Van Schmus
Department of Geology
University of Kansas
Lawrence, Kansas 66044

Four field seasons of reconnaissance and detailed structural studies coordinated with geochronologic investigation have been undertaken in portions of Waupaca, Portage, Wood, Jackson, Clark, Eau Claire, Chippewa, Marathon, Lincoln, and Price counties in an attempt to decipher the Archean and Early Proterozoic tectonic history of north-central Wisconsin.

Archean gneisses and migmatites have been identified so far in Portage, Wood, Jackson, and Clark counties. Gneisses containing similar structures in Waupaca and Eau Claire counties are also believed to be Archean in age, although zircons from the Eau Claire county locality yield an Early Proterozoic age. This unit is one of the most thoroughly recrystallized rocks in the terrane and we are therefore considering the possibility that the zircons have been reset. The Archean gneisses are of volcanic, plutonic, and sedimentary origin, and generally exhibit structures indicative of polyphase deformation.

The oldest recognized Early Proterozoic rocks in Wisconsin are mafic to felsic volcanics which were extruded at the beginning of the Penokean Orogeny, about 1860 m.y. ago. Compressional deformation followed shortly thereafter resulting in vertical and near vertical dips for these rocks. Medium-grained granitic to tonalitic plutons were emplaced throughout the terrane between 1840 and 1830 m.y. ago, followed by the finer-grained granitic to tonalitic plutons along the southern margin of the terrane between 1830 and 1820 m.y. ago. The vast majority of these plutonic rocks contain a pronounced lineation which is commonly, but not always, accompanied by a weak to moderate foliation. Cataclastic textures are present in all deformed rocks, but they are subordinate to recrystallization textures. Cataclasis occurred simultaneously with recrystallization during Penokean deformation and amphibolite facies metamorphism of regional extent, rather than being restricted to localized zones of shearing.

The plutonic rocks are generally synkinematic to late kinematic, but a few are post kinematic. On the basis of radiometric ages it appears that some of the undeformed units are older than deformed units elsewhere, thus deformation may have terminated at different times in different parts of the terrane. However, this conclusion must be viewed with caution in light of the level of precision of the radiometric ages, especially when attempting to distinguish events so closely spaced in time.

Penokean deformation had ended prior to the emplacement of 1760 m.y. old granites and rhyolites in southern Wisconsin. Subsequently these rocks were folded, whereas rocks of the same age in the northern half of the state were

(Maass, Medaris and Van Schmus, continued)

not. Throughout the Lake Superior region, Rb-Sr systematics have been reset at approximately 1630 to 1615 m.y. It appears likely that this event is responsible for the folding and metamorphism of the southern Wisconsin granites, rhyolites, and quartzites, but had only a thermal expression in northern Wisconsin.

MIGMATITES FROM THE VERMILION GRANITIC COMPLEX, MINNESOTA

John W. Goodge

Carleton College
Northfield, Minnesota 55057

Archean migmatitic rocks dated at 2.7 b.y. from the Big Falls, Minnesota area were investigated in order to further knowledge of the Vermilion Granitic Complex, particularly in those western portions which have been less extensively studied. The Vermilion Granitic Complex lies in north-central Minnesota and is comprised primarily of pink leucogranite with substantial portions of migmatite throughout. Volcanogenic rocks of the Vermilion District of Minnesota are believed to be the metamorphosed parent rocks for the migmatites in the Vermilion Granitic Complex. On a regional scale rocks in the Big Falls area are grouped as migmatites, but locally distinct differences in structure and fabric permit the subdivision of the rocks into four units: tonalite, garnet-biotite gneiss, mixed tonalite and gneiss and granitic dikes. Structurally, the gneissic portions appear as rafts up to 20m in size which are enclosed by both the tonalite and mixed rock. Orientations of foliation and banding in the gneiss are consistent from one raft to another, which indicates that they have not been extensively moved during migmatization. The tonalite exhibits compositional inhomogeneities in the form of nebulitic structures shown by differences in biotite concentrations. The majority of migmatite appears to be a mixture of tonalite and gneiss, displaying a variety of structures including complex folds and swirls, boudinage, dilation and schlieren to nebulitic structures indicative of high-grade metamorphism and severe plastic deformation. Several pegmatitic dikes cutting both the tonalite and gneiss represent the youngest rocks in the area. The dikes are up to 1 meter in cross section, straight and in sharp contact with the gneiss,

The tonalite is composed of medium- to coarse-grained (3-7mm) plagioclase, quartz and biotite with minor microcline and muscovite, and accessories of zircon, sphene, apatite and an opaque mineral. In several samples, plagioclase contains small patches of microcline. The gneiss is well-foliated, medium-grained (0.5-2.0mm) and is composed of plagioclase, quartz and biotite with minor garnet and microcline. Plagioclase, biotite and cordierite (?) have replaced subhedral garnet to form fine-grained aggregates, and replacement grades from minor to complete. The granitic dikes contain coarse-grained (4-6mm) microcline, quartz and muscovite with minor plagioclase and biotite. Plagioclase composition in both tonalite and gneiss is oligoclase. The gneissic fabric of the rocks and composition of the plagioclase indicate that metamorphism reached amphibolite facies, and the biotite, garnet and microcline content is consistent with this metamorphic grade. Modal mineral analysis of these rocks reveal that the tonalite and gneiss are similar in composition, despite a significant difference in the biotite content (average 15% in tonalite; 28% in gneiss).

(Goodge, continued)

Models for the genesis of the migmatites near Big Falls must consider the following: the strong fabric of the gneiss, complex structures in the mixed rock, mixing of the tonalite and gneiss, a late-stage injection of granitic material, compositional similarities between the tonalite and gneiss and consistencies in the plagioclase composition. Further petrographic and geochemical analysis will lead to an interpretation of the relationship between the tonalite and gneiss.

GEOLOGY OF THE SOUTHEASTERN CONTACT ZONE
OF THE VERMILION BATHOLITH, MINNESOTA

Anthony Fleming, Dion Heinz,
Robert Lee and Henry Woodard

Department of Geology
Beloit College
Beloit, Wisconsin

Detailed geologic mapping in the Fourtown Lake quadrangle and reconnaissance mapping in the Friday Bay, Iron Lake and Anglemorm Lake quadrangles was carried out during the 1978 and 1979 field seasons in order to better understand the complex nature of the southeastern contact zone of the Vermilion Batholith. The oldest rock units are layered amphibolites, biotite schist and a complex unit which may have originally been a volcanic agglomerate. These rocks are intruded by hornblende adamellite sills and migmatized by an early episode of anatexis. These processes have obscured the stratigraphic relationships between the earlier rock units.

This entire assemblage was regionally folded to produce the northeast-trending outcrop belts that are now observed. The detailed mapping in the Fourtown Lake quadrangle confirms that most of the area lies on the southern limb of a major synform. The southern half of the Friday Bay quadrangle probably is underlain by the northern limb of this same structure. The entire region was subjected to passive emplacement of the Vermilion Batholith and the contact zone, which is several miles wide, appears to be the result of a second stage of intense migmatization and anatexis.

The region was then cut by a giant horsetail-like splay of left lateral faults extending northeastward from the Vermilion fault zone to the south. The episode of faulting was accompanied by hydrothermal alteration of the fault zone rocks and by the development of quartz and epidote veins.

Future detailed structural mapping will extend both north and east from the Fourtown Lake quadrangle. Petrologic studies of the contact zone rocks are now in progress. Many important questions concerning the origin of these rocks remain to be answered by these continuing studies.

OVERTURNED ARCHEAN SUCCESSIONS AND THEIR SIGNIFICANCE

K.H. Poulsen and M.M. Kehlenbeck

Lakehead University
Thunder Bay, Ontario

Numerous examples of overturned Archean successions from widely separated cratons have been reported in the recent literature. Recognition of these phenomena in North America is still limited to two such examples from the Superior structural province; one near Red Lake, Ontario, the other at Rainy Lake, Ontario. In the latter example, the overturned succession includes strata which have been the subject of a long standing controversy: the Coutchiching and Keewatin Groups of A.C. Lawson. At Rainy Lake it can be demonstrated that the stratigraphic succession is overturned for distances of 15 km and that the deformation which produced the inversion took place relatively early in the deformational history of the region.

The fact that the sequence at Rainy Lake is overturned had not been recognized previously. The reason for this is that two fundamentally different approaches to structural and stratigraphic interpretation have been applied in the past. A.C. Lawson mapped large antiformal folds which he assumed to be anticlines. As a result, he interpreted the Coutchiching metasedimentary rocks near the cores of these antiforms to be the oldest strata in the region. Observations of younging using primary sedimentary and volcanic features at key localities indicate this stratigraphic interpretation to be incorrect. F.F. Grout, on the other hand, interpreted the stratigraphy from observations of younging in graded beds near stratigraphic contacts. As a result, he placed the Coutchiching metasedimentary rocks much higher in the stratigraphic column. In addition, however, Grout used the younging criteria to interpret the structure. Anticlines and synclines mapped in this manner conflict with observed minor structures such as fold symmetry and bedding-cleavage relationships. It is only by the integrated application of both structural and primary younging data that an extensive inverted sequence can be recognized.

Widespread overturning in Archean terranes has mainly been attributed to the existence of large foldnappes. Such structures are normally associated with the concept of compressional tectonics generally related to the closing of primitive volcano-sedimentary basins. On the other hand it has been proposed that gravity driven tectonics might also result in the development of nappes, either due to crustal instability near the boundaries between sub-provinces or to the buoyant emplacement of gneissic diapirs. Each of these models may in part be supported by data from the Rainy Lake region. Further documentation on the lateral extent and timing of the deformation will be required before a critical appraisal of these models will be possible.

THE PRECAMBRIAN WATERLOO QUARTZITE, SOUTHEASTERN WISCONSIN: EVOLUTION AND SIGNIFICANCE

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The Waterloo Quartzite forms a broad asymmetric eastward-plunging syncline that is a prominent structural and topographic feature of the Precambrian basement of southeastern Wisconsin. If the Paleozoic and Pleistocene overburden were stripped from the Waterloo area, the quartzite would stand as an arcuate ridge 150 to 275 m above the surrounding Precambrian surface.

A detailed structural study of quartzite exposures reveals two important joint directions: N 60 E with variable dip, and N 30-40 W, vertical. The N 60 E joint set is interpreted as the axial plane direction for the syncline; the variable dip is probably due to stress refraction in the quartzite. The N30-40 W direction is roughly perpendicular to the hinge line of the fold. These joint directions are similar to those described by Dalziel and Dott (1970) for the Baraboo Quartzite (which crops out 60 km to the northwest). The coplanar attitude of the axial planes of the Baraboo and Waterloo synclines suggests that both structures formed during the same tectonic event.

Andalusite porphyroblasts were identified by petrographic and X-ray diffraction studies in beds of schist interbedded with quartzite (near the nose of the syncline at Glasgow's Farm). This is the first reported occurrence of a medium grade metamorphic index mineral in outcrop in the Waterloo area (Haimson, 1978, identified andalusite in core from deep wells drilled into the quartzite). The assemblage andalusite-muscovite-quartz suggests that the quartzite was metamorphosed to the upper greenschist facies or to the lower amphibolite facies. In contrast, the metamorphism of the Baraboo Quartzite only reached the lower greenschist facies (pyrophyllite is found in phyllite beds interbedded with the quartzite). This suggests that either the thermal event responsible for andalusite growth was restricted to the Waterloo area or that the heat source (intrusive body?) was at a deeper level in the Baraboo region.

We suggest the following scenario involving three episodes of metamorphism for the development of the Waterloo area: (1) Deposition of the Waterloo sediments on an eroded volcanic-plutonic terrain between 1760 and 1630 m.y. ago. (2) Folding and metamorphism 1630 m.y. ago forming the syncline and major joint directions. (3) An intrusive event affecting the Waterloo

(Brandon, Smith and Luther, continued)

Quartzite. The andalusite porphyroblasts probably formed at this time. This event may have occurred soon after the folding episode or possibly as late as 1500 m.y. ago (related to the Wolf River intrusive event). The pegmatite dike on Rocky Island and the amphibolite identified in a well core probably formed during this stage. (4) A retrograde metamorphic event producing a weak penetrative foliation that is revealed by aligned sericite grains within the andalusite porphyroblasts.

RARE EARTH ELEMENT DISTRIBUTION IN THE PRECAMBRIAN RHYOLITES AND GRANITES OF SOUTH-CENTRAL WISCONSIN

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The rhyolites and granites of south-central Wisconsin resulted from anorogenic igneous activity 1760 ± 10 m.y. ago. This event occurred after the magmatic activity of the Penokean Orogeny (1850 m.y.) but before the emplacement of the Wolf River Batholith (1500 m.y.). Rare earth and trace element data suggest that two major magma types formed during this event, but preclude a comagmatic relationship between the type types. The magma types are: a peraluminous suite characterized by low Ba/Sr, Rb/Sr and high CaO and Al_2O_3 (the Marcellon and Marquette rhyolites-groups 2 and 4 of Smith, 1978); a metaluminous suite characterized by higher Ba/Sr, Rb/Sr and lower CaO and Al_2O_3 (the quartz-alkali feldspar rhyolites at Utley, Berlin, Endeavor, Observatory Hill, and Taylor Farm; the granophyric granites at Montello and Redgranite; and a porphyritic granite dike at Flynn's Quarry-group 3 of Smith, 1978). Both suites show light REE enrichment (La/Yb-4.7-8.6) and prominent negative Eu anomalies ($Eu/Eu^* = 0.15-0.4$), but the metaluminous suite displays uniformly higher REE abundances. The rhyolite and granite of the metaluminous suite occur to the northwest of the rhyolite of the peraluminous suite. These suites in general correspond to those proposed by Anderson, Van Schmus and Cullers (1978).

Within the peraluminous suite the Marcellon rhyolite may have formed from the Marquette rhyolite by the fractional crystallization of plagioclase, orthoclase and biotite. Within the metaluminous suite the quartz-alkali feldspar rhyolites and granophyric granites may have formed from a magma having the composition of the Flynn's Quarry granite by fractional crystallization involving two feldspars, biotite and hornblende.

Even though there is wide compositional variation due to fractional crystallization, the two suites remain compositionally distinct. This indicates differences in crustal source materials. Model studies suggest that the peraluminous suite was generated by 21% nonmodal fractional melting of a crustal source having an intermediate composition (quartz dioritic or andesitic). The model source is remarkably similar in composition to the andesite and dacite dikes that cut the rhyolite exposures. The source for the metaluminous suite was difficult to model, since the undifferentiated member of this suite could not be identified with confidence. However, the source is most probably an intermediate rock, but with higher REE abundances than the source for the peraluminous suite. The major igneous suites of south-central Wisconsin probably formed by partial fusion of different parts of a heterogeneous crust. The crust was probably tectonically thickened during the Penokean Orogeny.

GEOCHEMISTRY AND VOLCANIC STRATIGRAPHY OF WEST-CENTRAL
MARINETTE COUNTY, WISCONSIN

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The volcanic pile in west-central Marinette County, Wisconsin, includes mafic to felsic flow and pyroclastic units, and clastic sedimentary, massive sulfide and iron formation units. The volcanic belt is approximately 8 km wide and is bounded on the north by the Dunbar gneiss and on the south by the Athelstane quartz monzonite. North of Coleman Lake the belt is approximately 2 km wide where the Twelve Foot Falls quartz diorite occurs to the north and the Athelstane quartz monzonite to the south. Contacts between volcanic units are steeply dipping and strike north to northwest.

A felsic center north of Coleman Lake contains interlayered andesite and massive rhyolite flows. Fragmental units have not been observed. Plagioclase phenocrysts occur in the andesite flows and abundant quartz and plagioclase or sparse plagioclase phenocrysts occur in rhyolite flows. The rhyolite flows contain 70 to 77% SiO_2 and the andesite flows contain 57 to 60% SiO_2 .

The northwestern portion of the volcanic pile is underlain by porphyritic dacite and rhyodacite flows. Basalt and rhyolite flows are present locally. The southeastern portion of the area is underlain by clastic metasediments, iron formation, massive to semi-massive sulfide, and basalt and dacite flows.

The composition of the flows define a distinct calc-alkaline differentiation trend. All units are subalkalic. The composition of the volcanics suggests island arc volcanism.

The volcanic units of westcentral Marinette County are chemically distinct from the volcanic units in eastern and northeastern Marinette County including the Quinnesec, Beecher, and Pemene Formations. The flows in the study area in general are higher in TiO_2 , K_2O , Al_2O_3 and CaO , and lower in Na_2O and FeO than Quinnesec, Beecher and Pemene Formations. The volcanic pile in westcentral Marinette County should not be considered part of the Quinnesec Formation.

WHERE IS THE SOURCE OF WISCONSIN DRIFT DIAMONDS?

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Between 1876 and 1903, diamonds were found in at least seven localities in southern and central Wisconsin. All were found in Pleistocene glacial deposits or Holocene river gravel. The bedrock kimberlite source for the diamonds is unknown but has been presumed to be in northern Canada, the only area north of Wisconsin previously known to contain kimberlites. Recently, a kimberlite pipe has been found in Iron County, Michigan. That find caused us to consider the possibility that Wisconsin drift diamonds have come from a more local source--kimberlites in northern Michigan and Wisconsin.

The Iron County kimberlite is very poorly exposed, but a strong positive magnetic anomaly indicates that it is roughly circular in plan and 200-300 meters in diameter. Although the kimberlite is entirely surrounded by Precambrian rocks, it contains abundant inclusions of fossiliferous limestone, probably from the Ordovician Black River Group that overlaid the area when the kimberlite was intruded. The post-Ordovician age of the kimberlite leads us to suspect that other possible cryptovolcanic structures in Paleozoic rocks in the region were formed over kimberlite pipes that are not yet exposed by erosion. Such structures include Limestone Mountain and Sherman Hill in Houghton and Baraga Counties, Michigan; Glovers Bluff in Marquette County, Wisconsin; and possibly an area along the Brule River south of Iron River, Michigan.

No diamonds are known in the Iron County kimberlite, but it has not been adequately sampled. The cryptovolcanic structures could not be the source of the Wisconsin diamonds because even if they are caused by kimberlites, those kimberlites have not yet been exposed by erosion.

Elsewhere in the world, kimberlites rarely occur as a single isolated body; clusters of bodies are more common, and the presence of one kimberlite makes us suspect that others exist nearby.

The discovery of additional kimberlites may be very difficult because of the extensive cover of glacial drift and the probable small size of kimberlite bodies. If all are magnetic, they might be found by detailed aeromagnetic surveys. However, the magnetism of the Iron County kimberlite appears to be caused by secondary magnetite formed during serpentinization of olivine, so an unserpentinized kimberlite may not be strongly magnetic.

We suggest that one or more diamond-bearing kimberlites may exist in northern Michigan or Wisconsin, but the discovery of such bodies is unlikely unless a very thorough search is undertaken.

CORRELATION OF GRAVITY AND MAGNETIC ANOMALIES IN EAST-CENTRAL MINNESOTA AND NORTHWESTERN WISCONSIN

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Similarities in gravity and magnetic anomaly patterns in east-central Minnesota and northwestern Wisconsin imply that several Precambrian rock units may be correlative between the two areas. A broad magnetic maximum that is bounded to the south by east-trending linear magnetic maxima is an anomaly pattern that exists in both central Aitkin County, Minnesota, and northern Sawyer County, Wisconsin. Both areas are characterized by regional gravity maxima. In Aitkin County, Minnesota, the broad magnetic maximum is associated with the Archean McGrath Gneiss whereas the linear magnetic maxima are apparently related to belts of early Proterozoic metavolcanic and meta-sedimentary rocks. Similarly, in Sawyer County, Wisconsin, the broad magnetic maximum is associated with Archean granitic and gneissic rocks and the linear magnetic maxima are believed to be related to belts of early Proterozoic metavolcanic and metasedimentary rocks. An east-trending belt of irregular magnetic minima and maxima in Mille Lacs and Kanabec Counties, Minnesota, resembles a magnetic terrane in Barron and Rush Counties, Wisconsin. Both regions are characterized by regional gravity maxima. This magnetic terrane in Minnesota corresponds to early Proterozoic granites and minor volcanic rocks of similar age. In Wisconsin, the corresponding magnetic terrane is associated with exposures of middle Proterozoic Barron Quartzite and early Proterozoic granites and volcanic rocks.

In order to shift the discussed magnetic terranes of east-central Minnesota to match corresponding terranes in northwestern Wisconsin, a southeastward transposition of at least 60 km is required. This distance is consistent with some estimates of crustal separation during Keweenawan rifting but loss of typical magnetic signatures near the rift zone, where the Keweenawan clastic rocks are thick, make this estimate somewhat tentative. Clearly, quantitative analysis of gravity and magnetic anomalies combined with further geologic studies is required before the model presented in this paper can be fully tested. The results of this paper, however, demonstrate the potential utility of gravity and magnetic data in unraveling and correlating complex geologic features now separated by the Keweenawan rift system.

METAVOLCANIC ROCKS AT EAU CLAIRE DELLS, MARATHON COUNTY, AND
AN EVALUATION OF THE "SHEAR ZONE" HYPOTHESIS IN WISCONSIN

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In recent years the interpretation as mylonites of rocks at the Dells of the Eau Claire River (sec. 7, T29N, R10E) in Marathon County Wisconsin has gained wide acceptance among geologists working in the Precambrian of the Lake Superior region. Based on this interpretation and geophysical data, numerous authors have drawn a major N25E to N30E trending "shear zone" through this locality. The rocks at the Dells are a mafic to felsic metavolcanic sequence, probably Early Proterozoic in age, which was deformed and metamorphosed to amphibolite facies during the Penokean Orogeny. The inequigranular textures in these rocks represent relict porphyritic features and are not the result of cataclasis. The metavolcanics, trending N35E to N45E with vertical dips, are bounded on the west and north by the Kalinke quartz monzonite, which was emplaced and deformed during the later stages of the Penokean Orogeny, and on the east by the undeformed 1500 m.y. old Wolf River Batholith.

The volcanic sequence at the Dells ranges from basaltic to rhyolitic; the latter including feldspar porphyries, quartz porphyries, and lapilli tuffs. In the feldspar porphyries many of the feldspar phenocrysts remain subhedral to euhedral, and a significant number have not been rotated into the plane of the foliation. Some of the quartz phenocrysts in the quartz porphyries have been flattened, but others have not, and none are as granulated as would be expected in a mylonite. In addition, some contain relict embayment features. Basaltic units are now amphibolites containing subhedral to euhedral hornblende, while compositionally intermediate units contain subhedral garnet.

Compositional layering varies in thickness from millimeters to tens of meters. Numerous distinctive lithologies down to the millimeter scale can be traced across the outcrop with little or no change in thickness. Cross-cutting mafic and felsic veinlets are tightly folded, but there is no evidence of isoclinal folding, and attenuation of fold limbs is minor. Both the microscopic and mesoscopic features of these rocks were produced by deformation associated with middle grades of metamorphism without substantial transposition of layering.

Throughout Wisconsin, rocks older than the 1765 m.y. old granites and rhyolites have been subjected to a widespread brittle deformation event during the Penokean Orogeny. This deformation was regional in nature rather than localized in zones of intense cataclasis. We suggest that many of the localities previously described as mylonites, are either metavolcanics, or rocks affected by this regional event, and should be reevaluated with these alternatives in mind.

WERE THERE TWO MIDDLE PRECAMBRIAN OROGENIES IN THE LAKE SUPERIOR REGION?

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Precambrian rocks in Central Wisconsin occur as large, discrete areas of gneisses, amphibolites and migmatites, and areas of greenschist facies volcanic and plutonic rocks. Marathon County is underlain mainly by greenschist facies volcanic and plutonic rocks in fault contact with gneissic rocks on the north, west and south. Radiometric ages suggest that both the gneisses and greenschist facies rocks are Middle Precambrian.

Fold axes, mineral lineations and elongated fragments in the gneisses plunge to the west at 20° - 60° over most of the region. However, comparable lineations in the greenschist facies volcanic rocks in Marathon County plunge east to northeast at 50° to near vertical. Near the fault boundary between gneissic and greenschist facies rocks, the lineations are nearly vertical. Lineations in greenschist(?) facies volcanic rocks in Rusk, Price and Oneida Counties also plunge to the east. Therefore, there appears to be a consistent relationship between direction of lineations and metamorphic grade. This suggests that the rocks have been subjected to different stresses, and these stresses may be of different age.

Myers (1978) reports greenschist facies volcanic rocks folded about east-plunging axes resting unconformably on gneisses in western Clark County. Thus, a period of erosion must have occurred between formation of the gneisses and deposition of the volcanic rocks.

If the gneisses (and the deformation in them) are Middle Precambrian and the greenschist facies rocks are also Middle Precambrian, then there must be two periods of Middle Precambrian deformation in the region. These two postulated deformations may be recognized elsewhere in the Lake Superior region. Mild flexuring and erosion occurred on the iron ranges after deposition of the Chocoma Group of the Marquette Range Supergroup. Conceivably the gneissic rocks in Central Wisconsin represent a more intense metamorphism associated with this unconformity. The "Penokeyan Orogeny," which occurred after deposition of the Menominee and Baraga groups, would then be represented by the greenschist facies metamorphism and widespread intrusion of granitic rocks in much of northern Wisconsin.

VOLCANIC AND PLUTONIC ROCKS OF THE JUMP AND YELLOW RIVER VALLEYS, NORTH-CENTRAL WISCONSIN

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Metavolcanic rocks are exposed along the Jump River in southeastern Rusk County and locally along the Yellow River near Gilman, Wisconsin. Plutonic rocks crop out south of the Jump River and along the Yellow River. The metavolcanics and some plutonic rocks have been deformed and metamorphosed under upper greenschist to lower amphibolite facies conditions. Schistosity is weakly to strongly developed and is subparallel to bedding in the volcanics. Stratigraphic tops indicate that the volcanics are overturned to the south and appear to have been folded about northeast trending fold axes.

Quartz monzonite plutons crop out south of the Jump River and locally can be shown to intrude the volcanics. The plutons are weakly foliated and locally display cataclastic textures. A quartz monzonite pluton also crops out along Main Creek north of the Jump River. The pluton displays a granophyric texture and euhedral quartz crystals occur as inclusions in feldspar crystals.

A strongly foliated pluton crops out 2½ miles south of the Jump River and similar plutonic rocks crop out along the Yellow River. The composition of the plutons is granodiorite.

An intermediate composition volcanic center crops out east of the village of Jump River. Volcanic blocks to one foot diameter form massive units associated with fine-grained bedded tuffs and massive porphyritic flows. Crystal-lithic tuffs and intermediate to basic flows crop out at apparently similar stratigraphic levels east and west of the volcanic center. A porphyritic felsite with plagioclase phenocrysts occurs to the south of the main fragmental units of the volcanic center and is believed to be stratigraphically above the volcanic center.

The geologic evolution of the area suggests volcanism followed by or associated with, intrusion of granodioritic plutons. Deformation of the area produced recumbent folds about Northeast trending axes. Quartz monzonite intrusives were emplaced along the axial zones of the folds producing linear plutonic belts. The metamorphic grade may increase to the south toward the Yellow River. This interpretation suggests that the proposed northern boundary of the Chippewa Amphibolite complex and the Jump River Fault Zone need to be reconsidered.

HEAVY MINERAL ANALYSIS OF PRECAMBRIAN ROCKS IN RUSK COUNTY

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The bedrock in Rusk County consists mainly of granitic and metavolcanic rocks of middle Proterozoic age. Several quartzite bodies are believed to unconformably overlie the middle Proterozoic rocks. The age of the various quartzites is not known, but they have been correlated with the middle Proterozoic Baraboo Quartzite by Dott and Dalziel (1970) and with the late Proterozoic Sioux Quartzite of Minnesota by Craddock (1972).

The study was undertaken to try to determine whether the various siliceous rocks have the same origin and whether they may be correlative. Four units were sampled for study, the Barron and Flambeau Quartzites and two unnamed units informally referred to here as the Bruce and Broken Arrow units.

The Barron Quartzite is nearly flat-lying and forms a ridge in the northwestern part of the county. Petrographic studies show well-rounded, well-sorted grains with quartz overgrowths. To the south, the Flambeau Quartzite forms another resistant ridge. In contrast to the flat-lying Barron, the Flambeau Quartzite occurs as a steeply dipping tightly folded unit. Thin section analysis reveals a lithology similar to the Barron although sorting is not as complete. Heavy minerals common to both bodies include apatite, zircon, corundum, and ubiquitous hematite and magnetite. In addition the Barron Quartzite has some siderite, while the Flambeau Quartzite contains sphene.

Between the two quartzite ridges lie the Broken Arrow and Bruce units. These massive units are both fine-grained splintery cherts. Examination of thin sections shows small serrated quartz grains that have undergone some metamorphism but show no evidence of a detrital origin. Heavy minerals of the Broken Arrow unit include grossularite, zoned hematite and possibly spessartite. The Bruce unit is very ferruginous and contains zircon (malacon), analcite and schorl.

We have established that the metacherts are not detrital and thus may be related to the older volcanic sequence rather than the younger quartzites. Petrographic and heavy mineral studies indicate a separate origin for the respective quartzites and the metacherts.

^{*} Student Paper

DEPOSITIONAL SETTING OF STROMATOLITE-OOOLITE FACIES
ON A KEWEEAWAN ALLUVIAL FAN

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The Copper Harbor Conglomerate (~ 1 B.Y.) predominantly consists of heavily oxidized immature sandstones and boulder conglomerates with subordinate volcanics. The unit is a fining upward and basinward sequence with the volcanics in the lower portions. The sediments were deposited by northerly (basinward) flowing streams creating a classical alluvial fan environment off the basin margin.

Sedimentary structures and associated features, including current crescents, parting lineation, tabular and trough cross-stratification, intraformational conglomerates, mudcracks, oolites, cross-stratified boulder conglomerate, large boulders (~ 70 cm), micro-cross-stratification, extensive oxidation, and calcite pseudomorphs after gypsum; all combine to indicate a probably arid, periodically dessicated, shallow water environment that was subject to large variations in flow regime.

Seemingly enigmatic, in regard to the harshness of such an environment, is the medial fan occurrence of algal stromatolites. The stromatolites are now represented by thinly laminated carbonates intercalated with mudstone and sandstone, and as drapes on conglomerate. These stromatolites are well-preserved with much of the original depositional and early diagenetic fabric being retained. Various micro-structure types and cements can be recognized. Stromatolite morphologies include laterally linked hemispheroids (LLH), horizontal mats, oncoids, and intraclasts. Thin beds containing hematitic single and compound (grapestone) ooids, some exhibiting primary radial cortical fabric, occur interbedded with the stromatolites.

This carbonate depositional environment was cyclic with at least three thin (< 25 cm) biostromes present through a stratigraphic interval of about four meters. Discontinuous exposures encompass a lateral extent of approximately 13 kilometers. Overturned algal encrusted boulders, up to 50 cm in diameter, occur about two meters stratigraphically below the lowest observed biostrome, attesting to the existence of this facies at an earlier time, and in a position still closer to the basin edge.

The existence of the stromatolite/oolite facies indicates some of the complexities that should be addressed in any interpretation of the overall depositional system, in particular, how a cyclic "quiet water" environment related to boulder conglomerates.

STRATIGRAPHY OF THE GUNFLINT FORMATION,
CURRENT RIVER AREA, THUNDER BAY

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A total of fourteen stratigraphic sections of the Gunflint Formation have been measured along the Current River resulting in a section with a lateral extent of 2.6 kilometers. The composite section from this study is 43 meters thick and contains five distinct lithostratigraphic members. The base of the Gunflint Formation has not been observed in these sections and is probably below the level of Lake Superior but there is a conformable contact with overlying fissile black shale interpreted as Rove Formation. The members are, in ascending order: 1. fissile black shale (450 cm, base not exposed); 2. micrite-siliceous grainstone (taconite) association capped by 1 meter of algal chert (1450 cm); 3. fissile black shale (1250 cm); siliceous grainstone (920 cm) and 4. an algal chert-intraformational breccia association (200 cm) which is overlain by the Rove Formation. At least 50% of this composite thickness is fissile black shale because black shale interfingers with and forms a matrix to grainstone lenses as well as occurring as separate members. The remainder is predominantly siliceous grainstone.

Micrite and siliceous grainstone occur as lenticular deposits which exhibit tabular and trough cross bedding. The grainstones contain smooth and pustular algal laminae, fenestrae and pisolites and are locally overlain by flat-pebble conglomerates, intraformational breccias and stromatolite mounds. The grainstone-algal association is a chert-carbonate chemical sediment which was reworked in a littoral-intertidal depositional environment and is analogous to the deposits of Shark Bay, Western Australia. Flat-pebble conglomerates and intraformational breccias are high-energy deposits which formed during periodic storms. The fissile shales associated with these deposits likely represent lagoonal and deeper water deposits of clastic debris which accumulated contemporaneously with the chert carbonate.

PETROLOGY OF SOME LOGAN DIABASE SILLS FROM COOK COUNTY, MINNESOTA

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Four Lower Keweenawan Logan diabase sills between South and Birch Lakes, South Lake quadrangle, northeastern Minnesota, are stratified as shown in Figure 1 (thickness in meters). Although fabric is variable, the following

general sequence of textural zones is recognized: lower chilled, lower fine-grained, medium-grained, coarse-grained (except in sill C), porphyry or porphyritic, upper fine-grained, upper chilled.

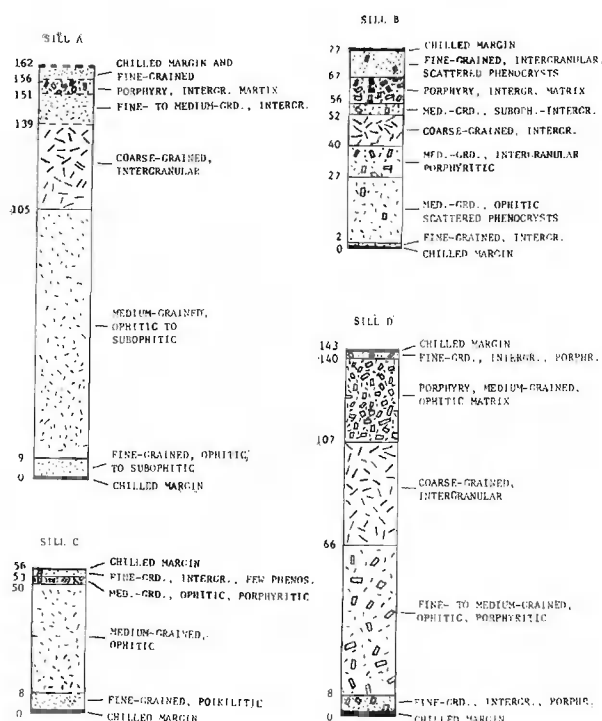


Figure 1

Both chilled margins contain scattered phenocrysts of plagioclase in a matrix of plagioclase, amphibole and/or biotite, quartz, and granular, acicular, or skeletal ilmenite. The fine- and medium-grained zones consist of plagioclase, augite, interstitial quartz, acicular apatite, some K-feldspar, and embayed, skeletal or lath-shaped ilmenite; pegonite (ave. $Wo_{10}En_{52}Fs_{28}$) and partially-resorbed, iron-rich, olivine (2 samples, $Fo_{22.5}$ and $Fo_{33.3}$) are present in some samples. Coarse-grained zones are distinguished by the abundance and variety of inter-growths between quartz and K-feldspar and/or sodic plagioclase; pyroxene is typically more altered than in finer-grained zones. Porphyry zones contain plagioclase phenocrysts which appear to be slightly more calcic than the matrix plagioclase; other aspects of the mineralogy are similar to the medium-grained zones. Deuteric alteration was extensive in all zones, but the intensity, distribution, and exact nature of the alteration are variable, even on the scale of a thin section.

Fourteen rock analyses for major oxides from sills A and B and microprobe analyses of feldspars, pyroxene, and olivine from 13 samples (mostly from sills A and B) show that: (1) there is little variation in bulk or mineral chemistry in the fine- and medium-grained zones; (2) chilled margins are notably richer in SiO_2 and lower in CaO and alkalis than other zones; (3) porphyry zones (based on one analysis) are lower in FeO , MgO , and CaO and richer in alkalis, reflecting the high percentage of plagioclase; (4) coarse-grained zones are enriched in SiO_2 and alkalis, depleted in CaO

(Jones, continued)

and MgO, have high $\text{Fe}_2\text{O}_3/\text{FeO}$ ratios, and contain plagioclase which is notably more sodic than other zones; (5) augite compositions are similar throughout, mostly in the range $\text{Wo}_{30-40}\text{En}_{35-45}\text{Fs}_{20-30}$; (6) the composition of cores of plagioclase crystals (excluding phenocrysts) is An_{45-52} , except in the coarse-grained zones.

These data suggest emplacement of a magma containing plagioclase phenocrysts, minor assimilation of adjacent Rove Formation, crystallization minerals, and migration of silica, alkalis, and water toward the coarse-grained zones, which were the last to solidify.

DIFFERENTIATING ULTRAMAFIC FLOWS FROM SILLS IN THE
SHEBANDOWAN MINE AREA, NORTHWESTERN ONTARIO, CANADA

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Shebandowan Ni-Cu Mine (Inco Metals, Ltd.) is spatially associated with a thin ultramafic sill which is intrusive into volcanic rocks of the Shebandowan-Wawa Belt, Superior Province, northwestern Ontario. A study of the volcanic stratigraphy in the mine area (32 km²) has revealed the presence of conformable lens-like extrusive and intrusive ultramafic rocks. These are now serpentinites and talc-carbonate schists, but in many instances, relict textures have been preserved.

In the field, flows are differentiated from sills on the basis of rock association. Ultramafic flows are spatially and genetically (?) related to black and white, magnetite-chert iron formation and dark green, iron rich basaltic hyaloclastite (17.8% FeO). Younging directions indicate that hyaloclastite sits on top of the iron formation which in turn tops the ultramafic flows. Sills, however, show no such relationship and can be intrusive into either basalts or more felsic pyroclastic rocks.

Typical petrochemical plots (Arndt et al., 1977; Muir, 1979) do not differentiate these ultramafic rocks but disseminated chromites have markedly different chemical affinities. Chromites found in flows are generally lower in Al₂O₃ and MgO contents, higher in TiO₂ and have higher Fe⁺²/Fe⁺²+Mg and Fe⁺³/Fe⁺³+Al+Cr ratios than those chromites found in sills. Analyses of chromites from consecutive samples from a thin sill (every 20 feet) and from a thin flow (10 feet) show that Cr₂O₃ decreases and Fe₂O₃ increases towards the top of both units. But in the case of the sill, chromites from the immediate top and bottom have exactly the same Fe₂O₃ and Cr₂O₃ contents whereas those in the flow are markedly different. This different chemical trend might well be attributed to different cooling histories for flows and sills.

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Muir, T.L., 1979, Discrimination Between Extrusive and Intrusive Archean Ultramafic Rocks in the Shaw Dome Area Using Selected Major and Trace Elements. Can. Jour. of Earth Sci., Vol. 16, pp. 80-90.

GEOLOGICAL EVIDENCE RELATING TO THE INTERPRETATION OF THE LAKE SUPERIOR BASIN STRUCTURE

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The configuration of the Lake Superior Basin coincides with the regional geologic structure and is primarily composed of rock units of Lake Precambrian (Y) age which unconformably overlie older assemblages.

Evidence of basin formation is poorly developed in pre-Keweenawan (late Precambrian) and lower Keweenawan geologic units in the Lake Superior region. However, middle Keweenawan intrusives, lava flows, and associated sediments display primary features such as mineral layering, flow thickness, and cross-bedding, which directly indicate basin development at that time. Upper Keweenawan sedimentational patterns delineate the basin outline.

Penetrative structures, particularly folds and foliation, are well developed in Archean and Middle Precambrian rocks, but are generally rare in Late Precambrian sequences. Nonpenetrative faults and joints are prevalent in all Precambrian rocks in the Lake Superior region. Curvilinear faults with east-west trends, prevail in Archean and Middle Precambrian units, although other trends are to be noted, particularly in Wisconsin. Northeast-and northwest-trending fractures are common in Late Precambrian units although regional data are incomplete. Faults of late Precambrian age have been reported to occur locally in the region.

In summary, Archean, Middle Precambrian and pre-Keweenawan geologic units render little direct evidence of basin formation over that time interval. The basin structure appears to have been initiated in middle Keweenawan time as a crustal rift. Rifting in the basin proper was very likely enhanced by east-west structural trends within older units.

THE PRE-KEWEENAWAN TECTONIC HISTORY OF THE NORTH-CENTRAL UNITED STATES AND
CENTRAL CANADA AND HOW IT INFLUENCED FORMATION OF THE MIDCONTINENT RIFT

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The Midcontinent rift formed about 1.1 b.y. ago in crust that had a long and complex history but that had been a rigid crustal block for several hundred million years before the rifting. The rift formed at a high angle to the general ENE structural grain of older rocks and crossed a boundary that separates two very different geologic terranes near the southern edge of the Superior Province. North of the boundary, the rift is within crust typical of Superior Province that had been deformed only by faulting and gentle warping after about 2.6 b.y. ago; south of the boundary, the rift is in crust that had a much longer and more complex history. There, rocks as old as 3.8 b.y. have undergone repeated tectonism; major events took place at 2.6 b.y. (Kenoran orogeny), 1.9 b.y. (Penokean orogeny), and 1.5 b.y. (the emplacement of the Wolf River batholith and synchronous volcanism).

The boundary between the Superior Province-type crust and rocks to the south seems to have had a pronounced effect on the nature of the Midcontinent rift. Where the rift is in Superior Province-type crust, it is about 150 km wide and is complex; where it is in rocks of the more complex terrane to the south, it is about 90 km wide and has a simpler shape. Its width changes abruptly at the contact of the two terranes.

Lithologic and/or tectonic boundaries within the Superior Province may have affected the extent of the Midcontinent rift. In the Superior Province, the rift lies entirely within the confines of the Shebandowan granite-greenstone belt except for the poorly defined arm that extends to Lake Nipigon. Changes in composition, structure, or thickness of the crust at the north edge of the Shebandowan belt may have inhibited the northward extension of the rift.

Orientations of the rift arms are probably controlled by older faults or fractures. Lineament analysis of gravity and aeromagnetic maps and Landsat images indicate the presence of linear zones that are more than 1000 km long. Many of the lineaments coincide with known faults or zones of crustal weakness. Geologic data indicate that these features formed before 1.1 b.y. ago. Conspicuous directions are N. 65° W., N. 45° W., N. 35° E., and N. 65° E., the same as those of individual segments of the rift.

(Klasner, Cannon and Van Schmus, continued)

A large elliptical gravity low, more than -60 milligals in amplitude, lies in part above granitic rocks in central Wisconsin. This low suggests the presence of large volumes of subjacent granitic rocks throughout this area. The inferred subsurface granite in Wisconsin may have played a role in localizing the rift because the arcuate shape of the rift symmetrically encircles the gravity low. It may be that the granite formed an area of unusually strong crust through which the rift could not form.

KEWEENAWAN VOLCANISM AND THE NATURE OF KEWEENAWAN RIFT TECTONICS

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Since the early inklings in the '60's of a rift-tectonic origin for the Mid-Continent Gravity High, a number of more detailed concepts have developed. These include that of White (1972) who proposed the existence of several separate basins of accumulation of lavas along a tensional zone, contrasting with modern examples such as the East African Rift with its central graben and relatively thin volcanics. Chase and Gilmer (1973) subsequently proposed a strictly rigid-plate model, in which the rift widens to the north from a pole of rotation in New Mexico and in which mafic mantle-derived rock completely fills the rift to widths of 80-90 km. Weiblen and Morey (in press) have since suggested that the Duluth Complex, and by extrapolation, other parts of the structure, developed through a sequence of normal faulting in which down-dropped, rotated blocks of crust under tension have made way for the great volumes of intrusions leaving an intact, horizontal carapace of volcanic rocks. Green (1977) elaborated on White's model of broad volcanic "plateaus."

The following evidence within the mapped Keweenawan volcanics tends to minimize, though not eliminate, the role of normal faulting, particularly graben formation, and mega-dikes within the Lake Superior district. 1. Nowhere are the lavas seen to be faulted against pre-Keweenawan rocks. 2. With the exception of the Osler Group in Thunder Bay-Nipigon district, the basal Keweenawan lavas are erupted onto an area of low relief that was either an erosion surface or the site of cratonic deposition of water-laid quartz arenite. At the base of the Osler a conglomerate may reflect local fault relief. 3. The stratigraphy of the various Keweenawan plateau lava accumulations is in many cases remarkably continuous, showing both a surface of low relief on which flows could spread out for many tens of kilometers, and the lack of faulting within sequences. The major faults now evident show reverse, not normal displacement. 4. Normal displacement is rarely observed between rocks on either side of Keweenawan basaltic dikes (feeders?) both within and beyond Keweenawan volcanic areas. If normal faults had been prevalent, the feeder dikes could be expected to have followed them preferentially or vice versa. 5. The small percentage (2-3%) of interflow sediments in most of the major plateau-lava sequences argues against large normal-fault displacement during volcanism. 6. The fanning of dips and down-dip thickening of the Portage Lake Volcanics imply warping, not faulting, at the edge of the lava basin. 7. If mafic magma supply to the crustal gravity anomaly were dominated by half-graben faulting leading to intrusions, surely many such faults would have reached the surface through the lavas. Where are they? 8. The gravity anomalies (at least in western Lake Superior where the attempt has been made: White, 1966) can be adequately modeled by the known lava basins without any major crustal separation of many tens of kilometers. 9. Chase and Gilmer's model ignores the thick Osler and Mamainse basalts of Ontario.

This evidence basically supports a view of Keweenawan magmatism in large, oval basins (such as the Columbia Plateau basalts but of smaller extent.

(Green, continued)

and thicker) which gradually subsided by warping while keeping a more-or-less level surface. The models of Chase and Gilmer and of Weiben and Morey do not fit the geology in the Lake Superior area where the rocks actually crop out.

UPPER PRECAMBRIAN SEDIMENTARY ROCKS OF THE LAKE SUPERIOR REGION

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Quartzose sandstone units which represent parts of one or more sand sheets a few hundred feet or less in thickness include the Bessemer Quartzite in Michigan and Wisconsin, the Pass Lake Formation of the Sibley Group in Ontario near Thunder Bay, the Puckwunge Formation in northeastern Minnesota, and the Nopeming Quartzite just west of Duluth. A basal conglomerate is present at each locality above the subjacent unconformity. Lava flows succeed the sandstones except in Ontario where red mudstones and carbonates overlie the sandstone and are in turn overlain by flows and sedimentary rocks of the Osler Formation. The flows immediately overlying the Bessemer and Nopeming are commonly pillowed and the sandstone appears to have been unlithified at the time of initial volcanism whereas the Puckwunge appears to have been lithified (e.g. Mattis, 1972). There is paleomagnetic and radiometric evidence that the lower Sibley is older (1340 m.y.) (Wanless and Loveridge, 1977) than the latter two units which may be closer to 1100 m.y. old. Paleomagnetic evidence (e.g. Books, 1968, 1972; Halls and Pesonen, in prep.) indicates that the Bessemer and the lower Sibley are normally polarized whereas the other units are reversely polarized and thus can be interpreted to be younger. The quartzose sandstones are all pre-tectonic in origin, although the Sibley rocks were deposited upon a down-faulted block which may have been a failed arm of a 1300 m.y. old rift which could have had some effect on sedimentation (Kustra et al., 1977; Franklin et al., in press).

During many pauses in Keweenaw volcanism, compositionally immature gravels, sands, silts, and muds, dominantly derived from intra-basinal volcanic sources but locally from extra-basinal older terranes as well, were moved toward the center of the volcanic basin by streams and deposited in stream valleys, on alluvial plains, in deltas, and in lakes (e.g., White, 1970; Merk, 1972, 1979; Jirsa, 1979, 1980).

When volcanism ceased over most of the area, tectonic activity associated with the rifting-volcanic event continued. In response, dominantly fluvial "red bed" sedimentation began in the tectonic basin which developed on the site of Lake Superior, with streams flowing into the basin from marginal portions of the basin and from adjacent highlands. The oldest sedimentary sequence, the Oronto Group (Copper Harbor Conglomerate, Nonesuch Shale, and Freda Sandstone in ascending order) is present in northern Wisconsin, western Upper Michigan, and on Isle Royale. The Copper Harbor (to 7000 ft thick) is dominantly a fining upward alluvial fan-fluvial clastic wedge. The gray cupriferous, pyritiferous and carbonaceous Nonesuch is an argillaceous siltstone unit (250-750 ft thick) which accumulated under reducing conditions, probably in a lacustrine (and deltaic) environment. The Freda (12,000+ ft thick) is a fluvial and lacustrine(?) unit. The source rocks for the Oronto Group included both Keweenaw volcanics and older basement rocks, with the latter most important in the Freda.

(Ojakangas, Morey, Daniels and Kalliokoski, continued)

In Wisconsin, the more steeply dipping Oronto Group is overlain (unconformably?) by the more mature (e.g., Hite, 1968; Myers, 1971; Craddock, 1972), subhorizontal Bayfield Group which includes, in ascending order, the feldspathic Orienta Sandstone, the quartzose Devils Island Sandstone, and the feldspathic Chequamegon Sandstone. Geophysical evidence suggests the group may be as much as 7000 ft thick (Mooney, et al., 1970). The Devils Island (300 ft thick) is apparently the result of the lacustrine reworking of Orienta fluvial detritus during a significant pause in tectonic activity. The source rocks for the Bayfield Group were dominantly pre-volcanic basement rocks, although reworking of Oronto detritus may also have been important.

In Minnesota three formations are present--the feldspathic-lithic red Solor Church Formation (to 3200 ft thick), the red feldspathic Fond du Lac Formation (400-1200 ft thick), and the buff quartzose Hinckley Sandstone (to 500 ft thick). The Solor Church, found only in the subsurface (Morey, 1972, 1974) was deposited southwest of Lake Superior along the rift zone. In the basins flanking the St. Croix Horst, the Solor Church is overlain unconformably by the Fond du Lac which in turn is gradationally overlain by the Hinckley. In contrast the Solor Church conformably overlies basaltic rocks on top of the Horst and in turn is unconformably overlain by the Hinckley; at places a regolith separates the two formations. The hiatus represented by this regolith may have been of significant duration, for the Solor Church was indurated by diagenetic or very low grade metamorphic processes prior to the deposition of the Fond du Lac. The Solor Church Formation can be correlated with the Oronto Group, the Fond du Lac with the Orienta, and the Hinckley with the Devils Island. The Solor Church and the Fond du Lac were deposited in a meandering stream-floodplain environment, whereas the Hinckley appears to have been formed by the reworking of Fond du Lac detritus in the same lacustrine environment in which the Devils Island Sandstone was formed (Tryhorn and Ojakangas, 1972).

In Michigan the feldspathic to quartzose Jacobsville Sandstone is a northward-thickening, fault-bordered wedge of regionally variable fluvial sedimentary rocks. The maximum drilled thickness is 2845 ft and the geophysically inferred thickness is 10,000 ft. Most of the conglomerate clasts can be correlated with deeply weathered source areas to the south and southeast, confirming paleocurrent data near the base of the section. Northeast of Houghton a coarse conglomerate (clasts to 36 cm) exposed near the Keweenaw Fault and an interbed of highly angular basalt fragments in the sandstone were derived from the Portage Lake felsic and mafic lavas northwest of the present fault or from basement highs now buried under the sandstone. The Jacobsville is also found on the east end of Lake Superior and is interpreted to be present in a deep drill hole in the middle of the Michigan Basin (Fowler and Kuenzi, 1978). Correlation with the Bayfield Group remains uncertain.

Sedimentological and stratigraphic analysis in progress will expand upon earlier work (e.g., Fowler and Kuenzi, 1978) on the causal tectonic events and the resultant sedimentational events which occurred within the mid-Continent rift system in the Lake Superior region.

GEOCHRONOLOGY OF KEWEENAWAN ROCKS: A REVIEW

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There have been many U-Pb, Rb-Sr, and K-Ar geochronologic studies of Keweenawan rocks. U-Pb data of Silver and Green show that most of the igneous activity (by volume) occurred 1110 ± 10 m.y. ago in the Lake Superior region. This age includes rocks of the upper normal magnetic polarity as well as upper units of the underlying reversed magnetic polarity sequence, thus dating that reversed-to-normal change at 1110 ± 10 m.y. ago.

Many of the Rb-Sr and K-Ar results on the 1110 m.y. old units are concordant, although in many instances there is clear discordance with the Rb-Sr and K-Ar ages being too young. Many other units, not yet dated by U-Pb methods, also give young ages, suggesting that upper Keweenawan igneous activity may have extended to as young as 900 m.y. ago. However, review of paleomagnetic pole positions for such units shows no evidence for such young crystallization ages; the paleomagnetic data are consistent with all younger ages being about 1100 m.y. old.

K-Ar results suggest ages of 1150-1250 m.y. for older units (e.g., Logan Sills) of the reversed sequence and, along with Rb-Sr results, for normal polarity dikes of the Sudbury dike swarm. Paleomagnetic pole positions are also consistent with early Keweenawan igneous activity occurring about 1200 m.y. ago. Thus, we conclude that Keweenawan rifting and associated igneous activity began 1200-1225 m.y. ago, peaked at 1110 m.y. ago, and ceased shortly thereafter.

GRAVITY AND MAGNETIC ANOMALY STUDIES OF LAKE SUPERIOR

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Gravity and magnetic anomalies in Lake Superior are useful primarily in tracing out the extent and near-surface structure of igneous rocks that crop out around the lake or on islands within the lake. The data show that the Lake Superior structural basin generally conforms with the shoreline of the lake. The limbs of the basin are delineated by gravity and magnetic maxima which occur over the outcropping and buried mafic volcanic rock. The limbs coalesce at the southwestern and southeastern ends of the lake into the midcontinent and mid-Michigan geophysical anomalies. These geophysical data indicate several faults that roughly parallel the outline of the basin or transect the basin. However, the anomaly maps provide no indication of an axial graben. Rather, the inferred axis of the basin is generally a magnetic minimum reflecting the increased thickness of sedimentary rocks having low magnetic susceptibility. Gravity and magnetic anomalies locally are caused by structural deformation and variation in thickness of volcanic and sedimentary rock related to pre-Keweenaw topography and Keweenaw fault blocks that strike into the basin from the margins. A major north-northeast trending fault divides the basin into contrasting eastern and western units. By comparison with the western unit, the eastern unit is characterized by relatively subdued gravity and magnetic anomalies due to a combination of less diastrophism, decreased volume of volcanic rock, and more extensive sedimentary cover.

Modeling of the gravity data utilizing constraints provided by the geologic, magnetic, and seismic data indicates that volcanic units overlain by relatively nonmagnetic low-density clastic sedimentary rocks fill the Lake Superior basin. This model shows the entire crust to be abnormally dense beneath both eastern and western Lake Superior. This density is interpreted as the result of extension along an axial zone associated with pervasive intrusions of the mantle. This modeling also indicates a broad thickening of the crust by a few kilometers along the axis of the basin.

W.S. White divided the Lake Superior basin into six overlapping volcanic basins whose boundaries closely follow faults and other structural features identified by geologic and geophysical data. Removing the gravitational effects of the surficial sedimentary rocks of the Bayfield Group and Jacobsville Sandstone from a smoothed Bouguer gravity anomaly map results in an anomaly map that shows only minor variations from the original map. The maxima of the anomaly map correlate with the lava basins of White. The basins of eastern Lake Superior are smaller and have a lesser thickness of volcanic rocks than the basins in the western part of the lake. These differences reflect a major division in the midcontinent rift system. The pattern of anomalies extending from central Lake Superior southeast into Michigan is subdued compared to that of the western limb. This may represent a fundamental difference in the degree of extension in the limbs with the eastern limb subjected to lesser extension, igneous activity, and diastrophism.

(Hinze, Wold and O'Hara, continued)

These interpretations of the gravity and magnetic anomaly data in the Lake Superior basin are consistent with the concept that mid-America was subjected to tensional forces in Keweenawan time concurrently with the Grenville orogeny. These forces caused extension of the crust which caused a range of igneous activity and diastrophism that today is observed in a more dense and perhaps thickened crust overlain by volcanic and sedimentary rock basins that have been disturbed primarily by minor vertical movements.

LONG WAVELENGTH GRAVITY AND MAGNETIC ANOMALIES OF THE LAKE SUPERIOR REGION

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Gravity and particularly magnetic anomaly maps of the Lake Superior region are dominated by short wavelength anomalies that originate from near-surface sources which have strong physical property contrasts with the country rock. As a result anomalies which have broad, deep sources with limited physical property contrasts can be difficult to discern in the anomaly pattern. This problem can be alleviated by upward continuation of gravity and magnetic data to emphasize long wavelength anomaly components. Gravity and magnetic data compiled over the Lake Superior region were upward continued to levels of 50, 150, and 350 km and the resulting long wavelength anomalies were investigated for significance to crustal structure.

The long wavelength gravity anomalies of the 50 (Figure 1), 150 and 350 km level data define a continuous, arcuate belt of maxima that extends along the St. Croix Horst, into the Lake Superior Syncline, and southward across the Michigan Basin. This arcuate belt reflects the extensive emplacement of mafic rocks into the crust during the Keweenaw rifting event. The 50 km level gravity data indicates that primary mass concentrations along the arcuate rift occur in slightly offset segments along the St. Croix Horst, the Minnesota shore of Lake Superior. The Keweenaw Peninsula, northeastern-most Lake Michigan, and the central Michigan Basin. The intense gravity minima which commonly flank the central rift anomaly in low-level data are not apparent at least as a continuous zone in the upward continued data. There are no long wavelength anomalies which directly connect with either the Nipigon Plate or the Kapuskasing feature. In addition, the long wavelength gravity maxima along the rift zone do not display a change in character upon crossing the Great Lakes Tectonic Zone. Other long wavelength anomalies occur in the Lake Superior region that are apparently not related to Keweenaw rifting. Among these anomalies are a northeast-trending maximum over northern Wisconsin, a northeast-trending maximum across the southern Michigan Basin, and north-trending maxima over the Kapuskasing feature and the Moose River Basin. Long wavelength gravity minima reflecting a thickening of felsic crustal rocks occur over the Wisconsin Arch and over the Superior Province adjacent to the Grenville Front.

Upward continuation of the magnetic data to levels of 50 (figure 2) and 150 km reveals several long wavelength anomalies that locally show a relationship to the corresponding gravity data. The 50 km level magnetic data reveal an arcuate belt of maxima along the rift zone which in gross form corresponds to the arcuate gravity maxima. However, in the Lake Superior Syncline, the axis of the magnetic maxima lies approximately 100 km north of the gravity maxima. The 50 and 150 km level magnetic data reveal several long wavelength anomalies that are believed to be unrelated to Keweenaw rifting. Among these anomalies are a regional maximum in northern Minnesota and maxima along a belt extending from northern Lake Huron to southern Wisconsin. Upward continued gravity values are low to intermediate in these areas implying the crust in these areas is dominated by felsic, but highly magnetic, rocks. Long wavelength magnetic minima generally correspond to regional gravity minima over the eastern Superior Province and over the

(Chandler, Boman, Hinze and O'Hara, continued)

Wisconsin Arch.

The 50 km level gravity and magnetic data were subjected to quantitative correlation and modeling. Correlation analysis indicated that the majority of anomalies in the long wavelength gravity data are directly related to long wavelength magnetic anomalies, although exact spatial correspondence between anomaly peaks is not commonly observed. Poisson analysis along the Keweenaw rift zone yields magnetization to density contrasts consistent with mafic igneous rocks emplaced into felsic to intermediate rocks. Modeling results of long wavelength anomaly data along the Keweenaw rift zone are consistent with emplacement of mafic igneous rocks into all levels of the continental crust.

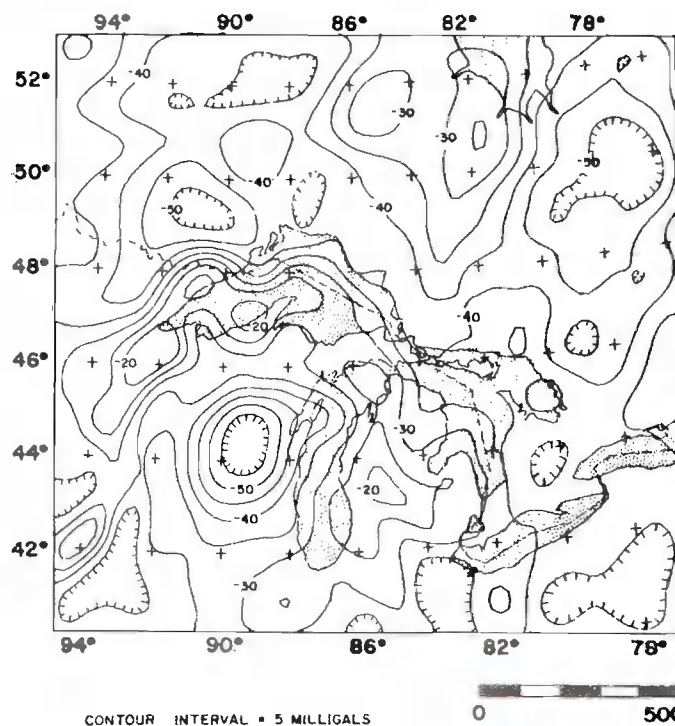


Figure 1. Central North America Bouguer gravity anomaly upward continued to 50 km, data interval = 20 km (flat earth assumption).

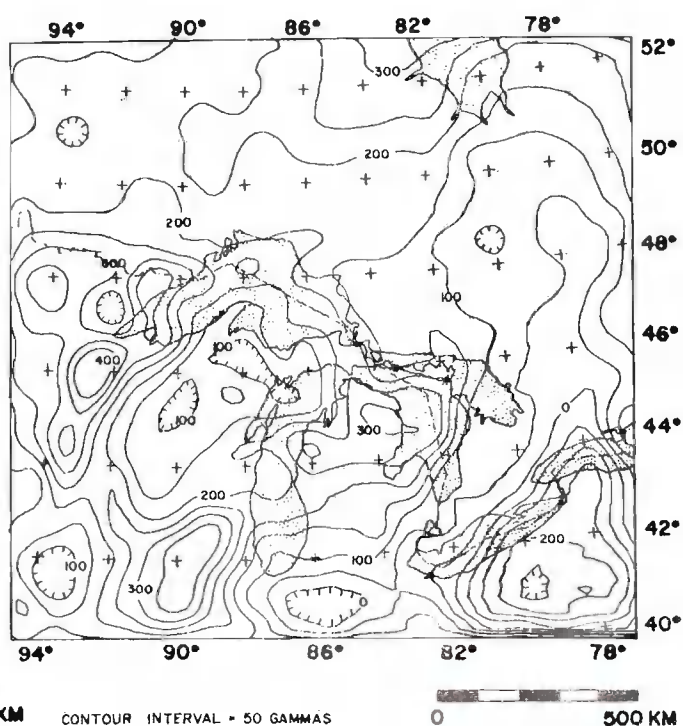


Figure 2. Central North America total magnetic intensity anomaly, reduced to the pole, upward continued to 50 km, data interval = 20 km (flat earth assumption).

SEISMIC REFRACTION STUDIES OF LAKE SUPERIOR CRUSTAL STRUCTURE

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A series of seismic refraction lines shot in Lake Superior (Figure 1) has been analyzed using simple travel-time inversion techniques extended by generalized ray tracing. The lines were shot by a single ship firing airguns and explosives, with radio-controlled buoys as receivers.

The upper 12 km of crust have been modeled, showing the velocity distribution down to and including the Upper Refractor, an anomalously-shallow, high velocity (6.4-6.9 km/sec) suite of refractors underlying the Lake Superior Basin.

Profiles in the western end of the lake confirm the essentially synclinal structure of the crust suggested by the geology of the lake margins and by previous seismic measurements.

Travel-time offsets observed on many of the profiles provide more precise definition of crustal faulting inferred from extrapolation of known faults on land and from gravity and aeromagnetic surveys. Evidence is shown for extension of the Isle Royale fault to the west, for extension of the Keweenaw fault to the east, and for the existence of the postulated Thiel fault roughly between the tip of Keweenaw Peninsula and the Slate Islands.

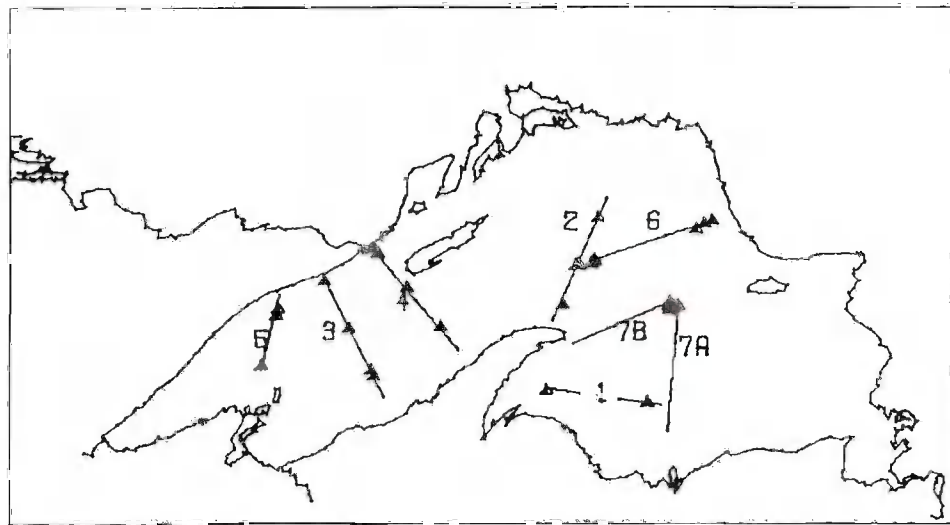


Figure 1

TOPOGRAPHY AND SURFICIAL STRUCTURE OF LAKE SUPERIOR BEDROCK
BASED ON SEISMIC REFLECTION PROFILES

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Thickness of the unconsolidated sediment and topography of the underlying bedrock surface of Lake Superior were interpreted from 8000 km (kilometers) of high-resolution seismic reflection profiles taken during 1966 and 1967. A depth-to-bedrock map was constructed by combining the isopach map of unconsolidated sediments (from our profiles) with the bathymetric map of the lake (Canadian Hydrographic Service Chart 885, 1973).

Lake Superior can be divided into three morphologic regions based on bathymetry and underlying bedrock: a western region composed of long linear valleys and gentle changes in relief, a central region composed of a single broad bathymetric depression, and an eastern region composed of a complex pattern of linear troughs and shoals.

The western region is dominated by a more or less continuous bathymetric and bedrock valley paralleling the north shore from Thunder Bay, Ontario, to Duluth, Minnesota, which reaches depths of more than 800 m (meters) below lake level near Silver Bay, Minnesota, and has more than 500 m of overlying unconsolidated sediments. This valley probably resulted from differential glacial erosion where the relatively erodible sandstone of the Oronto Group comes in contact with the relatively resistant underlying Keweenawan volcanic rocks and gabbro of the Duluth Complex. A second basement valley to the southeast parallels the north shore valley and probably represents the contact between the Oronto Group sediments and the overlying Bayfield Group sediments. The thickness of the Oronto Group is about 1.5 km in this area of the lake, using an assumed regional dip of 8° to the southeast. Another linear valley occurs south of and parallel to Isle Royale which is close to the possible location of the contact between the Freda Formation and Copper Harbor Conglomerate and the overlying Bayfield Group and Jacobsville Sandstone.

The central region is separated from the western region by a north-south basement ridge and consists of a broad valley with only 8-15 m of unconsolidated sediments overlying the bedrock surface.

The complex pattern of troughs and shoals of the eastern region form a north-south dendritic pattern with valleys as much as 100 km long, but only 5 to 10 km wide. The bedrock surface is more than 600 m below lake level in some places and is overlain by 300 m of unconsolidated sediments. These features are probably the result of initial stream erosion, followed by glacial scour. The stream erosion may well have followed a system of shear zones which have been observed in the shore exposures of the underlying sediments of the Bayfield Group and Jacobsville Sandstone to the south. All these bedrock valleys are truncated about 15 km north of the south shore where the lake floor rises abruptly to the coastline.

(Wold, Hutchinson and Johnson, continued)

In general, the morphology of the bedrock surface in Lake Superior probably reflects the result of glacial scour along pre-existing stream valleys which, in turn, were controlled by formation contacts, pre-existing topography, and shear zones.

Over most of the lake, the acoustic impedance contrast across the unconsolidated sediment-bedrock interface is high enough so that the seismic energy is reflected back with little or no penetration into the bedrock. Despite this, there are some places where layering within the bedrock can be identified and apparent dips determined. Among the structural trends that have been determined from these dips are the following: a southwest-plunging synclinal feature bordering the Bayfield Peninsula; a syncline lying between the Apostle Islands and the Keewenaw Peninsula, which probably represents the center of the Lake Superior depositional syncline; a south-plunging syncline located between Michipicoten Island and Superior Shoals; and an apparent dip to the south of the bedrock in the southeastern region of the lake.

GEOPHYSICAL STUDIES OF THE SLATE ISLANDS, LAKE SUPERIOR

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Discussion of the origin of shock features found in the Canadian shield has existed in the literature for perhaps 20 years. Several well known crypto-explosion structures typify this debate between meteorite impact and endogenous process such as the Charlesvoix structure, the Brent crater, the Sudbury basin, the Clearwater complex and the Manicouagan caldera. In all, about 79 such structures have been identified. The Slate Islands of northern Lake Superior exhibit shock metamorphic features in common with many of these sites such as shatter-cones present locally in host rocks and intrusive brecciated clasts, and show deformation lamellae in quartz and plagioclase grains. In addition, the islands form the central uplift of a complex crater morphology which is ringed by a submerged trough and annular ridge with a diameter of about 30km.

On the other hand, the islands are located in a once tectonically active region associated with the Michipicoten triple junction and at the intersection of two major regional faults, one of which controls the location of late Precambrian alkalic magmatism. The shatter-cone structures and deformation lamellae may be associated with diatreme emplacement related to these regional features; and thus the Islands fall into the astrobleme-diatreme controversy.

However, the location of the Slate Islands in the Lake Superior Basin region with the recent water cover may have reduced erosion of the structure to a far greater extent than for many of the other cryptoexplosion sites. In addition the lake presents the opportunity for marine geophysical techniques that are not available for other sites. Currently, we are capitalizing on this situation by using a variety of marine techniques in association with airborne magnetics to help identify the geological process responsible for the formation of the Slate Islands.

During July, 1979, we conducted an aeromagnetic survey over a 30 X 60 km area over the Islands using active radar positioning at 1000 yard flight line spacing 1500 feet over the lake surface. This aeromagnetic data shows clear linear features which have been previously interpreted as regional faults and long wave-length arcuate trends apparently related to a deep-seated source centered at the location of the Islands. Shallow sources in the vicinity of the Islands produce short wavelength anomalies centered in the long wavelength magnetic depression.

LAKE SUPERIOR RED CLAY MINERALOGY:
CORRELATION WITH MECHANICAL BEHAVIOR

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In the red clay area of Douglas County three types of stratigraphic succession are observed from bore hole data: red clay ($\leq 25'$ thick) over older red clay, red clay over brown or gray clay, and red clay over brown sand.

The mean contents with standard deviation, of sand ($>44\mu$), silt ($44-2\mu$), coarse clay ($2-0.2\mu$), and fine clay ($<0.2\mu$) of red clay from 28 borehole samples is 3.5 ± 2.5 , 25.6 ± 12.4 , 39.8 ± 8.4 , and 28.8 ± 8.2 .

Smectite clay is dominant in the fine clay fraction; illite and chlorite are dominant in the coarse clays, and quartz; feldspars, and carbonates, are dominant in the silt and sand fractions. Particle size distribution and mineral contents correlate with the Atterberg limit values. The equations:

$$\text{Liquid limit} = 10.0 + 0.78 (\% \text{ coarse} + \% \text{ fine clay}) \text{ and}$$

$$\text{Plasticity index} = 0.1 + 0.51 (\% \text{ coarse} + \% \text{ fine clay})$$

have correlation coefficients of 0.76 and 0.84 respectively for this body of data.

The dominant failure mode in the Little Balsam Creek drainage south of Superior and in other similar locales involves drying and cracking of a surficial layer of clay which then slides as a décollement sheet over the underlying clay. This failure appears to have been promoted by deforestation of the area.

PALEOMAGNETISM OF KEWEENAWAN ROCKS

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Keweenawan paleomagnetic poles occur along a broad NW-SW trending line in the north central Pacific. Stratigraphic and radiometric evidence suggests that within this polar distribution there is a hairpin-shaped path, open to the SW (the so-called Logan Loop) along which there is a progressive anti-clockwise movement of poles with time. This path which is only about 10° of arc in width, emerges after filtering of the pole population using certain reliability criteria, and thus the scatter of data about this path is attributable to uncertainties in the data and not to variations in paleofield direction. Late Precambrian poles from elsewhere in North America, together with Keweenawan paleointensity and paleosecular variation (PSV) studies further support apparent polar wander (APW) as the underlying cause of Keweenawan paleopole distribution. There are problems however: more than 90% of Keweenawan poles lie along the western arm of the Logan Loop; its apex remains undefined and only two poles from a steeply-dipping volcanic sequence define the eastern arm. Furthermore, almost half the total length of the loop lacks data because Keweenawan igneous units contain asymmetric reversals with inclination differences averaging about 25° , across which there are no intermediate directions. There are three possible explanations of the reversal asymmetry: (1) APW, (2) a regional secondary magnetization component superimposed on originally symmetric (180°) reversals or (3) some intrinsic property of earth's internal field. Paleomagnetic, paleointensity and PSV data are generally in accord with (1), although one volcanic sequence is known where successive asymmetric reversals occur, a situation that poses problems for APW. Of the two remaining explanations (3) cannot be discounted while (2) is considered the least likely. Local overprinting events have recently been demonstrated but they appear to have different ages and causes. They may be due to Late Keweenawan igneous activity, burial of the Keweenawan sequence, emplacement of copper-bearing ores, and in one instance to meteorite impact. These magnetic overprints appear to be Early Paleozoic or very late Precambrian (500-900 Ma) in age and are thus important as they lie in an age interval poorly represented in North American paleomagnetic data.

STABLE ISOTOPE TRACER STUDIES IN THE CAMBRO-ORDOVICIAN AQUIFER
OF NORTHERN ILLINOIS

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Oxygen and hydrogen (deuterium) isotope ratios for water of the Cambro-Ordovician aquifer of northern Illinois closely approximate the ratios in meteoric water, implying that little isotope exchange has occurred between groundwater and rocks of the aquifer. $\delta^{18}\text{O}$ of groundwater in the system ranges from about -7‰ (vs. SMOW), characteristic of modern precipitation in Illinois, to about -12‰ , characteristic of modern precipitation in considerably colder climates than that of northern Illinois. The implication of this is that some of the water in the Cambro-Ordovician aquifer system of northern Illinois has been stored since the Pleistocene.

Sulfur and oxygen isotopes in sulfate of northern Illinois groundwater establish this sulfate to be a mixture of 2 end-member compositions. One end-member ($\delta^{34}\text{S} = +20$, $\delta^{18}\text{O} = +16$) presumably is derived from Paleozoic sulfate minerals in rocks associated with the aquifer. The other sulfate component ($\delta^{34}\text{S} = 2.6$, $\delta^{18}\text{O} = 1.5$) presumably results from oxidation of pyrite in the glacial drift overlying the aquifer.

The presence of natural isotope tracers in the groundwater of northern Illinois and adjacent areas should prove useful in establishing recharge and flow patterns in this important aquifer.

KAOLINITIC WEATHERING ZONE ON PRECAMBRIAN BASEMENT OF SOUTHEASTERN NORTH DAKOTA AND WESTERN MINNESOTA

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Detailed petrologic and geochemical studies have confirmed the existence of a deep weathering profile developed uniformly on a variety of Precambrian basement rocks in the southern Red River Valley. A suite of 26 drill cores from a drilling program in the Red River Valley (Moore, 1978), has provided new information on the basement of eastern North Dakota and western Minnesota. The Precambrian is penetrated at an average depth of approximately 300 m in the Red River Valley. The surface dips 5-10 m/km toward the north and west. Different rock types in the cores include intermediate to mafic metasedimentary and metavolcanic schists, and intermediate to felsic coarse-grained massive or gneissic rocks. The Precambrian rocks of the region are interpreted to be a buried extension of the Superior Province, and are divided into terranes of granitic rock and mafic schist, on the basis of patterns seen in Superior Province rocks which crop out to the east, and regional geophysical data (Lidiak, unpublished; Muehlberger and others, 1967; Ray and Karner, 1979).

In the southern part of the Red River Valley, a thick weathering residuum, up to 75 m thick, is developed on the upper surface of the Precambrian, wherever it is immediately overlain by Cretaceous rocks. Where the deepest, least-weathered rocks are foliated, ghost-like traces of the structures can often be followed up through all but the most extremely weathered material. Weathered mafic and intermediate rocks often contain numerous sand-size siderite nodules. The uppermost few meters of some cores is bauxitic in appearance, but aluminum oxides are generally absent. Scanning electron microscope/microprobe studies show that feldspars and micas are altered to kaolin-group minerals. Regardless of original rock type, the end product of weathering is generally a white to greenish kaolinitic clay containing suspended angular quartz grains. Trends in major element chemistry are similar to those reported by Goldich (1938) and Harriss and Adams (1966). Calcium is lost in the early stages of weathering, followed by sodium and potassium. Silicon is lost in the uppermost parts of some profiles. Iron values are high where aluminum values are low and vice-versa. This is apparently a function of original rock type.

The results of this study support evidence for a pre-Cretaceous kaolinitic weathering episode on the southwestern part of the Canadian Shield. This study, involving a variety of rock types subjected to identical weathering conditions, shows that different rock types alter to similar weathering products. The pathways taken by felsic and mafic rocks may differ.

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(Kelley and Karner, continued)

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HYDROGEOLOGIC INVESTIGATIONS AT A LANDFILL SITE IN THE
RED TILL (VALDERAN) REGION OF EASTERN WISCONSIN

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The practice of landfilling is the most widely used method of solid waste disposal in Wisconsin. The most acceptable landfill is the "sanitary landfill", in which refuse is placed in trenches or other specific locations, then compacted and covered daily with soil in order to isolate the solid wastes from the environment. Evaluation of the pollution potential of a land disposal site is an important aspect of solid waste management.

A hydrogeologic investigation was undertaken at an existing sanitary landfill, located in eastern Wisconsin, to determine the feasibility of increasing the depth of the present operation. The site is licensed to operate under the condition that trenches cannot be excavated deeper than 10 feet until an engineering study is completed and approved by the Wisconsin Department of Natural Resources.

In eastern Wisconsin, which is underlain by sedimentary bedrock, glacial erosion produced till that has considerable silt and clay and therefore has low permeability. The coefficient of permeability of the silty clay soil on the site has been measured in the laboratory as being $2 \text{ to } 6 \times 10^{-8} \text{ cm/sec}$. Analysis of geologic borings indicate that the site is underlain by more than 30 meters of glacial drift which is considered to function as an aquitard. Groundwater occurs either in the upper few feet, perched upon the underlying silty clay, or in occasional silty sand seams or pockets that are found in the till. An evaluation of the hydrogeologic conditions indicates that there is no hydraulic connection between the surface and underlying bedrock aquifer.

A thorough hydrogeologic investigation and a groundwater monitoring program are essential in location and operation of landfill sites. In addition to identifying potential pollution hazards associated with waste disposal, we should apply our knowledge of hydrogeologic conditions to promote sites and environments for waste disposal where there are natural safeguards that will assure protection of health and resources.

SEISMIC SURVEY OF A BURIED RIVER CHANNEL

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A seismic refraction survey of a portion of the Cannon River valley in Northfield, Minnesota revealed a sizable buried channel cut into Prairie du Chien bedrock.

The buried channel begins on the Carleton College campus. It is cut into dolomite which varies markedly in hardness from place to place. The channel is filled with layers of loam, sand and gravel. The modern river flood plain overlies the buried valley; the modern course of the river is offset from the buried channel.

In the portion of the channel mapped in detail, the slope of the channel is one to eight percent. The buried channel begins in a "waterfall" about one and a half meters high, then continues north 250 meters with a depth of up to six meters and a width of almost 100 meters. The channel changes character markedly in the center of the study area, from wide and gently-sloping to steep and narrow; in this section it has a channel slope of eight percent, is about 20 meters wide and has vertical sides. It then levels off at 18 meters deep and becomes wider (150 meters) at the end of the survey area. A tributary buried channel joins the main channel near the end of the study area.

A mile downstream the channel increases in depth to over 30 meters. A slope of 30 meters per mile is indicated for the buried channel; the modern slope of the river is only two meters per mile.

Buried channels are found in other parts of the Mississippi River system. Such channels have been described in the metropolitan Minneapolis-St. Paul area and in Dakota County as well as under the Mississippi River itself. The buried channel in Northfield may be related in age and mode of formation to other buried channels in the region.

Techniques used in the survey included computer processing of seismic refraction results permitting interpretation of data under conditions of extremely irregular bedrock topography.

THE PEGMATITES OF THE QUETICO GNEISS BELT, NORTHWESTERN ONTARIO AND THEIR URANIUM POTENTIAL

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Reconnaissance studies along a roughly north-south traverse across the Quetico Gneiss Belt, utilizing road-cuts in Ontario Highway 527, have been made in order to characterize uranium-bearing pegmatites in and adjacent to the Gneiss Belt. Analyses of samples by the Geological Survey of Canada revealed uranium contents ranging from <10 ppm U to 36.3 ppm in the pegmatites.

The pegmatites are of two distinct types: a granitic pegmatite showing intrusive relationships to all other rocks in the area and an anatectic pegmatite intimately related to the gneisses of the Quetico Belt. The granitic pegmatites are located near the north and south margins of the Gneiss Belt and extend into the adjacent Wabigoon and Shebandowan-Wawa Greenstone Belts. The pegmatites occur as dikes or lensoidal bodies of plagioclase-perthite-quartz with varying amounts of biotite and muscovite. Accessory minerals include zircon, garnet, tourmaline, and rare hematite. Apatite occurs in the most uranium-rich sample.

The anatectic pegmatites occur as lenses and migmatite bands most strongly in the center of the Quetico Belt. The pegmatites are feldspar-rich (ca. 75%) consisting of oligoclase with microcline exsolutions, quartz, muscovite, and minor corroded biotite. Accessories include zircon, cordierite, sillimanite, garnet, and chlorite. The latter suggests that these pegmatites have been metamorphosed. Boudinage and ptigmatic folding of small dikes is also observed.

Uranium in the anatectic pegmatites was fairly uniformly distributed in the range of 2-7 ppm, but ranges to highs of 36.3 ppm in the granitic pegmatites. No uranium mineralization was identified, but zircon is the probable host in most rocks. The high value was found in an apatite-bearing rock, and this mineral is a likely host for uranium, as well. The pegmatites do not seem likely prospects for economic deposits of uranium, owing to a lack of identifiably mineralization and low concentrations. They may, however, be the ultimate source of disseminated uranium in the Sibley Group sandstones and unconformity-vein type uranium deposits in the Greenwich Lake area.

RELATIONSHIP OF CANADIAN URANIUM DEPOSITS TO THE GEOLOGIC SETTING OF WISCONSIN

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One logical and preliminary step in analyzing the uranium potential of a region is to access one area against another, based on geological data and the periods of mineralization. An important criterion, as it relates to Wisconsin, is the geochronological position of Precambrian rock units in Wisconsin and the periods of uranium mineralization in the Canadian Shield. The overwhelming number of Precambrian uranium deposits and occurrences in North America are distributed within the Canadian Shield which is often designated throughout the world as distinctive uranium metallogenetic province. Major uranium districts tend to be concentrated along the margins of the Canadian Shield (Figure 1) and include, among others, the Great Bear Lake area, the Great Slave Lake area, the Beaverlodge area, the Athabasca basin area, the Wollaston Lake area, the group of occurrences within the southern part of the Churchill Structural Province, the group of occurrences within the western part of the Superior Structural Province, the Port Arthur (now Thunder Bay) area, the Elliot Lake area, the group of uranium occurrences within the southeastern part of the Superior Structural Province distributed near the Grenville Front, the Makkovik-Seal Lake area and the deposits and occurrences within the Grenville Structural Province.

Uranium Mineralization and Orogenic Events within the Canadian Shield, the absolute age determinations of the host rocks, and the periods of uranium mineralization have revealed a definite pattern and a certain degree of correlation with orogenic events:

In the Elliot Lake area of the Superior Structure Province, the uranium mineralization belongs to 2,500 to 2,600 m.y. events and relates to the Huronian sedimentation, which closely followed the Kenoran Orogeny, that according to postassium-argon ages on micas spans the time between 2,230 to 2,730 m.y., with a maximum frequency at 2,480 m.y.

Within the Churchill Structural Province during the interval between the Kenoran and Hudsonian Orogenies (approximately 1,859 and 2,200 m.y.) two periods of uranium mineralization are evident, both of which correspond to the periods of granitization, metamorphism, and metasomatism. The first period, embraces the time interval around 2,200 m.y., and the second one around 1,920 m.y. with a highest peak at about 1,735 m.y. The uranium mineralization in the Beaverlodge Lake area, in northern Saskatchewan, took place around 1,780 m.y.

During the interval between the Hudsonian and Grenville Orogenies and coinciding with Stockwell's proposed Elsonian Orogeny (about 1,370 m.y.) uranium mineralization in the Great Bear Lake area show a range between 1,200 to 1,450 m.y.

(Mursky, continued, page b)

At the time of Grenville Orogeny which falls within the time interval of 800 to 1,100 m.y. and a mean age of 955 m.y., uranium mineralization occupies a time span between 880 and 1,100 m.y. and is exemplified by the deposits in the Beaverlodge Lake area, Saskatchewan; Great Bear Lake region, N.W.T.; and Bancroft region, Ontario. The uranium deposits in the Bancroft area are of similar age as the granitic intrusions and thus correspond to 950 and 1,070 m.y. interval.

Geochronologic results, and geological data show that Precambrian rocks in Wisconsin can be grouped into several distinct categories and age patterns:

- (1) The 2,500 m.y. and older orthogneisses, paragneisses, and granitic rocks which occur in the western and northern part of Wisconsin. The gneiss terraine is composed of several types of migmatic gneisses, including amphibolite and related mafic rocks, granitic gneisses and granite, pelitic gneisses and hybrid rocks. The assemblages seem to correspond to the Kenoran Orogeny in the Superior Structural Province of the Canadian Shield and coincide with the 2,500 to 2,600 m.y. old uranium mineralization in that region.
- (2) The 1,850 to 1,900 m.y. old volcanic and plutonic rocks which make up most of the basement complex of northern and northeastern Wisconsin. This suite consists of granitic to dioritic plutonic rocks which are intrusive into a complex of essentially contemporaneous volcanic rocks. The ages and distribution of these rocks suggest that they are directly related to Penokean Orogeny (1,850 to 1,900 m.y.) which, in time, coincides roughly with the Hudsonian Orogeny in Canada and its period of uranium mineralization (1,920 m.y.) as represented in the Churchill Structural Province.
- (3) The 1,780 to 1,800 m.y. old granitic and rhyolitic rocks which apparently constitute most of the Precambrian terraine in southern Wisconsin. These rocks consist primarily of rhyolites and granites. The rhyolitic units occur in southern Wisconsin, as inliers in the Paleozoic rocks, whereas the granitic rocks extend into central and northern Wisconsin. These rocks have been subjected to deformation and low-grade metamorphism which appears to be related to the Penokean Orogeny. In time, these rocks relate to the Hudsonian Orogeny in Canada and the 1,780 m.y. uranium mineralization which is represented by the Beaverlodge area of Saskatchewan.
- (4) The 1,500 m.y. old plutonic rocks in central and east-central Wisconsin. Some of these rocks are composed of quartz monzonite and show a striking similarity to the typical rapakivi massifs in Scandinavia and in the Great Bear Lake region of Canada, where the associated uranium mineralization, and particularly the isotopic data on pitchblende, are grouped around 1,400 m.y. mark.

It is therefore, quite clear that the considerations of the Precambrian age patterns in Wisconsin and the periods of uranium mineralization in the Canadian Shield would suggest abundant reason to investigate Precambrian

(Mursky, continued, page c)

terrain in Wisconsin for uranium as well as thorium. The most likely types of deposits in the Precambrian terraine in Wisconsin would be:

- (1) deposits associated with igneous rocks.
- (2) deposits in clastic sediments in Precambrian basins.
- (3) vein and/or replacement deposits near igneous complexes.
- (4) pegmatite deposits which would have a genetic relationship to igneous bodies.

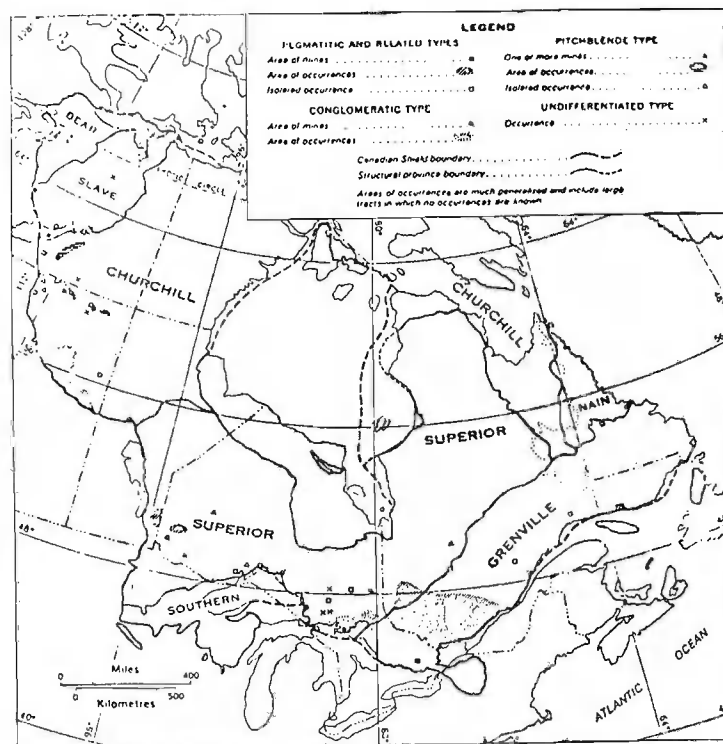


Figure 1 Distribution of present and former uranium mines and known occurrences in the Canadian Shield (After A. H. Lang, 1970).

URANIUM PROVINCES: ENRICHMENT IN GRANITIC ROCKS AND RELATIONS TO WISCONSIN

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Most uranium deposits, but particularly granitic igneous ones, are closely bound by time (geologic history) and space (tectonic setting) into "provinces". These provinces are proposed as the sites of original uranium concentration in early but evolved sialic crustal nuclei (shields). No major uranium deposits are known in rocks older than about 2.8 billion years. Since early Precambrian time, shield areas have undergone major modification, particularly along their margins. Throughout thermo-tectonic events (orogeny, etc.), uranium became mobilized and consequently reworked during each progressively younger event. The enrichment of uranium and its concentration into deposits is an important product of the tectonic reworking and chemical differentiation of the crust.

The Colorado Front Range and Egyptian Red Sea Hills are two plutonic uranium provinces. In each case, progressively younger and more alkaline plutons are enriched in uranium. The Pikes Peak Batholith in Colorado and the Younger Granites of Egypt as well as highly uraniferous bostonite dikes in both areas typify these intrusions. The two provinces also possess radio-genically enriched older "basement" rocks. It can be concluded that an original uranium concentration in these areas was enhanced through tectonic and magmatic reworking.

Many of the same rock types and geologic environments which are hosts for uranium deposits in the Front Range and Red Sea Hills exist in Wisconsin. However, even under apparently ideal chemical and tectonic conditions, no major uranium deposits are known in Wisconsin. This absence may be in part a function of thick glacial blanketing of the bedrock; however, it is most likely that the early parental crust for what is now Wisconsin did not provide an abundant source for eventual uranium enrichment. Much of that enrichment may be present to the north in Canada and west in Wyoming, but it decreases to the south and east away from the nuclear shield.

REGIONAL GEOCHEMISTRY AND METALLOGENY,
NORTH SHORE OF LAKE SUPERIOR, ONTARIO

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The Proterozoic and Archean terranes of the northern Lake Superior area include an exceptional variety of lithologies, with an accompanying array of mineral deposit types. Regional lake sediment and water surveys were undertaken to obtain information on the distribution and concentration of selected elements in lakes immediately north of Lake Superior.

The principal Archean lithologic domains, with attendant deposit types and examples are:

- 1) Supracrustal "greenstone" sequences, with massive sulphide (Manitou-wadge), gold vein (North Shore Gold) and iron formation (Wawa and Schreiber areas) types.
- 2) Felsic intrusions, with Cu-Mo porphyry type occurrences (Priske Twp. occurrence) and uraniferous pegmatites (Greenwich Lake).
- 3) Mafic intrusions, with Cu-Ni (Nicopor) and Zn-Cu (Zenmac) types.

Principal Proterozoic stratigraphic and intrusive units with major deposit types, and examples, are:

- 1) Aphebian Gunflint iron formation.
- 2) Aphebian Rove shale, with Ag veins (Creswell).
- 3) Helikian Sibley Group red-beds, with Pb-Zn-Ba veins (Dorion) and U+Cu veins (Greenwich Lake, Little Bear).
- 4) Helikian Osler Group volcanics, with native Cu-chalcocite veins and amygdule fillings.
- 5) Helikian gabbroic intrusions, including unmineralized Logan diabase sills, and the Crystal Lake gabbro with Ni-Cu mineralization (Great Lakes Nickel).
- 6) Helikian alkalic complex (Port Coldwell) with a magmatic Cu (Ni, Pd, Pt) zone, Pb-Zn-Ag veins in the metamorphic halo, and U zones near the northeast contact.
- 7) Helikian carbonatite (Prairie Lake) with U, Nb and rare earths.

Trace element patterns in lake sediment and water closely reflect the chemical characteristics of the major lithologic domains, although glacial overburden and varying limnologic conditions clearly modify the elemental distributions. The trace element patterns in the lake sediments and waters may be divided into three groups:

(Coker and Franklin, continued, page b)

- 1) Patterns related to bedrock features, as indicated by our bedrock trace element data, which have only marginal ore deposit significance:
 - (i) Rove shale is characterized by elevated Zn, Ni, Ag, As and Hg in lake sediments and F in lake waters. The Ag deposits are not specifically outlined.
 - (ii) Port Coldwell Alkalic Complex is reflected by F in lake waters and by Zn and Ni in lake sediments; Pb in lake sediments form a halo around the Complex.
 - (iii) Logan diabase sills are clearly identified by high Cu levels in lake sediments; Fe and Ni levels in the lake sediments reflect the sills to a lesser degree.
 - (iv) In the Sibley Group the Kama Hill Formation, and to a lesser extent the Rossport Formation, are reflected by elevated As contents in the lake sediments.
 - (v) Wawa area volcanic and sedimentary strata are reflected by elevated Ni in lake sediments; elevated Mn, Fe, As, Co and Pb in lake sediments reflect the major iron formation within this Archean sequence.
- 2) In addition to the Wawa iron formation, certain deposit types are more specifically reflected by some of the lake sediment and water data. For example:
 - (i) Manitouwadge massive sulphides are reflected by Cu, Zn and Pb lake sediment data, as expected, although in addition there is significant F in the lake waters and U in the lake sediments, possibly reflecting the pegmatites present in the area.
 - (ii) Gabbro-hosted zinc deposits at Zenmac are reflected by the Zn and Co lake sediment data.
 - (iii) Mo-Cu-bearing felsic intrusions are identified by Mo and Cu lake sediment data.
 - (iv) Pb-Zn-Ba veins associated with the Sibley Group and the Port Coldwell Alkalic Complex are indicated by the Pb and Zn lake sediment data.
 - (v) The zones of uraniferous pegmatites north of Dorion, which are associated with unconformity - related uranium occurrences, are distinctly outlined by the lake sediment and water U data.
- 3) Finally, under specific physicochemical-limnological conditions an individual trace element, or group of trace elements, may be concentrated to unexpectedly high levels. The scavenging effect of both iron and manganese hydroxide precipitates on trace metals (mainly Zn, Co and Ni) in lakes is evident in this area.

GEOLOGY OF THE MCCASLIN RANGE, NORTHEASTERN WISCONSIN

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The McCaslin Range is located in portions of Forest, Oconto, Marinette, and Langlade Counties in northeastern Wisconsin. It forms a ridge two to five miles wide extending 25 miles in an east-west direction. The major geologic units in the area include the Lower Precambrian Waupee volcanics, McCauley Granite, and Hines Quartz Diorite, and the Middle Precambrian Baldwin Conglomerate, McCaslin Quartzite, Hager Rhyolite, Belongia Granite and High Falls Granite.

On the McCaslin Range, the Middle Precambrian McCaslin formation consists of massive red-grey quartzites and quartz-pebble conglomerates similar to those found in the Elliot Lake-Blind River uranium district in Ontario. It rests unconformably on Lower Precambrian greenstones, granites, and gneisses.

The dominant structure in the region is the McCaslin Syncline which trends approximately east-west. It plunges 5° to the west and appears to close to the east but is disrupted by the intrusive High Falls granite. The northern limb and nose of the syncline are represented by the McCaslin Range and Thunder Mountain, respectively, while the southern limb is represented by the Baldwin Conglomerate which is exposed near the town of Mountain, Wisconsin.

A well-developed metamorphic aureole related to the High Falls granite intrusion can be traced through progressive metamorphic changes in the Hager, McCaslin, and Waupee formations. The metamorphic mineral assemblage indicates a maximum temperature of approximately 700°C adjacent to the granite intrusion where sillimanite occurs, and grades westward through zones of andalusite and muscovite down to sericite at the extreme western end of the range.

The lithology and stratigraphic setting of the McCaslin formation on the McCaslin Range are similar to those of uranium producing basal Proterozoic sediments in Canada, South Africa, Brazil, and Australia.

Comparisons with known uraniferous conglomerates:

I. Similarities and indications of uranium mineralization:

- A. The McCaslin formation occurs immediately above the unconformity at the base of a Middle Proterozoic sequence.
- B. The basal member of the formation is a quartz-pebble conglomerate which is overlain by a sequence of cross-bedded and ripple-marked sandstones.
- C. A cobble of ore-grade conglomerate was reportedly found in the drift on McCaslin Mountain. (Wisconsin Geological Survey)

*Kennecott Exploration, Inc., Casper, Wyoming

(Mancuso and Motten, continued)

- D. Anomalous concentrations of uranium were reported by NURE in the McCaslin area. (NURE Hydrochemical & Stream Sediment Survey, Iron Mountain Quadrangle; 1978)

II. Apparent dissimilarities:

- A. Uraniferous conglomerates in Ontario, Brazil, Australia, and South Africa are dated at 2150 to 2800 m.y. (Robertson, 1974). The McCaslin formation is reportedly 1900 m.y. (Van Schmus, 1976).
- B. Accessory pyrite is apparently lacking in outcrops of the McCaslin formation, but is a major accessory in the known deposits.
- C. Hematite is a major accessory in the McCaslin formation but is lacking in the known deposits.

WISCONSIN INTEREST IN RADIOLOGICAL IMPACTS RESULTING FROM URANIUM EXPLORATION (DRILLING)

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Recent uranium exploration activity in northeastern and central Wisconsin has stimulated interest in assessing potential radiological impacts resulting from drilling into a uranium orebody. In the midst of far-ranging claims of significantly harmful impacts on one hand and the flat assertions of zero impact on the other hand, an informal technical working group was formed as a result of a legislative request in order to determine what facts are known about the exploration activity. The objectives of the working group have been to (1) identify existing information on uranium exploration impacts available in the reliable state, federal, and international literature; (2) consult state, federal, and international agencies having some experience with issues surrounding uranium drilling impacts; (3) if possible, prepare "worst case" estimates of radiological impacts on drillers and exploration geologists, and (4) investigate the feasibility of low-level radiation monitoring of uranium drill sites at areas having known uranium deposits, as well as at proposed uranium exploration sites in Wisconsin.

The report reviews the public policy aspects of investigating potential radiological impacts of uranium exploration and the general methodology of the working group's approach to evaluating these potential radiological impacts. Results to date indicate (1) the literature dealing with radiological impacts from drilling is limited, (2) interest of local, state, or federal government agencies in this topic ranges from total indifference to the prohibition of drilling activity (moratorium), (3) perceived radiation exposure to the exploration geologist and driller appears minor at this point, and (4) monitoring of actual drill sites may prove to be the most direct approach to resolving the issues surrounding uranium exploration activities. The status of the informal technical working group's investigations as of early May, 1980 will be presented.

GEOLOGIC MAPPING IN NORTHEASTERN WISCONSIN: AN UPDATE

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Continued reconnaissance mapping and a reinterpretation of geophysical data have significantly improved our understanding of the Precambrian geology of northeastern Wisconsin. The concept of four distinct tectonic regions separated by three major east to west trending boundary structures has not changed, however the nature of the boundaries and the rock types present within the southernmost three regions are now better known as a result of extended geologic mapping and a new gravity map.

The new gravity data have enabled estimation of the extent of several known plutons in the central part of the area and suggest the presence of several granitic and mafic plutons in the southern and western parts of the sheet. The northern and eastern boundaries of the Wolf River Batholith is delineated by its gravity signature and recent mapping. The resulting interpretation indicates a sharp contrast between rocks of the Batholith and the granitic terrane of the Amberg-Athelstane-High Falls area.

The southernmost boundary zone, which follows the Wolf River contact in the east appears to be a major fault zone in the southwest. This zone truncates northeast trending cataclastic zones known from previous mapping in Marathon County. The central boundary zone is marked by east-west trending faults and cataclastic zones in the east, but to the west of the Cavour area becomes less defined and is characterized by a distinct class of hornblende-bearing dioritic intrusions, ranging from gabbro to granodiorite. These rocks crop out in a band for over 100 km from east to west in near proximity to the central boundary.

Field work in 1980 will concentrate in the unmapped and poorly exposed northwestern portion of the sheet. A program of test drilling is planned for problem areas throughout the area, and a geochronological study of important rock types is now in progress.

ANALYSIS OF A NEW GRAVITY MAP FOR
THE MERRILL-RHINELANDER AREA, WISCONSIN

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The Wisconsin Geological and Natural History Survey and Northern Illinois University have completed a new gravity map of northeastern Wisconsin. Data east of 89 degrees longitude and in Vilas County were recompiled from earlier surveys, using the new Geodetic Reference System - 67 formula and the International Gravity Standardization Net - 71 datum. The remainder of the map, including Oneida, Lincoln, western Langlade, and northern Marathon counties, consists of new data on approximately a one-mile grid.

Preliminary interpretation of the new data suggests that a rather simple, qualitative analysis is sufficient to delineate the regional variations in rock type. The gravity data, used in conjunction with the aeromagnetic data, are a valuable guide for and constraint on the geologic mapping of the hidden Precambrian rocks.

PETROLOGY OF THE BEAR LAKE INTRUSIVE, KEWEENAW PENINSULA, MICHIGAN

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The Bear Lake intrusive is a nearly circular felsic plug which intrudes the Upper Keweenaw Freda formation. It is located in the Keweenaw Peninsula eight miles (13 km) north of Houghton, Michigan.

Earlier work on the Bear Lake intrusive by the Michigan Geological Survey was part of a larger investigation designed to test a model of copper mineralization. Basically, the model suggested that the several, isolated intrusive/extrusive bodies of Keweenaw age in the Keweenaw Peninsula may be the source for copper sulfide mineralization (Snider and Parker, 1979). The Bear Lake intrusive appeared to offer an opportunity to test this model.

Field work by the Michigan Geological Survey in 1978 indicated the possibility of copper mineralization associated with the Bear Lake intrusive. Anomalous copper values of 190 ppm in the intrusive, the presence of two VLF-EM conductors and anomalous copper values in the soil over these conductors supported this hypothesis.

In 1979 the Institute of Mineral Research joined the project. A vertical diamond drill hole was put into the largest conductor. The 208 feet (63 m) deep hole penetrated 86 feet (26 m) of glacial overburden, 30 feet (9 m) of highly altered fragmental rocks (volcanoclastic?) and 25 feet (7.6 m) of clastic sediments ranging from siltstones to coarse arkoses. The bottom 67 feet (20 m) cored the intrusive which became more coarsely crystalline with depth. The intrusive has apparently metasomatized and otherwise altered the overlying sediments. These overlying sediments have not been found in outcrop.

Minor amounts of native copper were present as finely disseminated grains in quartz veinlets between 162 and 180 feet (49 and 55 m) of depth.

Reference

Snider, D.W., and Parker, B.K. (1979) Geochemical and Geophysical Anomalies Associated with the Bear Lake Intrusive, Sections 24 and 25, T56N, R34W, Houghton County, Michigan, 25th Annual Institute on Lake Superior Geology, Duluth, MN, May 8-13, Abstract, p. 38.

THE COSUNA PROJECT - A NEW CORRELATION CHART
FOR THE NORTHERN MID-CONTINENT REGION

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Late in 1976, the American Association of Petroleum Geologists initiated a national project called "Correlation of Stratigraphic Units of North America" (COSUNA), and soon afterward gained official support in this country from the United States Geological Survey and numerous other professional societies. It is designed to be a project of voluntary effort, and the objectives are (1) to develop a series of stratigraphic charts correlating rock units of both the surface and subsurface across geologic provinces of the United States, and (2) to summarize the thickness and lithology of each lithostratigraphic unit throughout the geologic column, as well as to identify pertinent paleontological and radiometric data. Although the data base will conform insofar as possible to the standards set forth in the International Code of Stratigraphic Nomenclature it will be necessary to include information not formally specified within the Code to insure as complete a data base as possible for the entire country.

For the purposes of this project, the United States has been divided into 20 regions. The Minnesota Geological Survey has volunteered to coordinate the program in the states of Minnesota, Wisconsin, northern Michigan and eastern South Dakota, which comprise the COSUNA Northern Mid-continent Region. The stratigraphic succession in this region is summarized in approximately 40 columns erected to represent major lateral changes in lithology, structure, and age. This correlation chart, as well as all the other COSUNA charts, has been constructed following the general format used for the charts of western Canada (Douglas and others, 1970). The COSUNA charts have a vertical time scale, with the Archean and Proterozoic units chronostratigraphically. Thus they differ from the correlation charts previously published by the Geological Society of America in that each column depicts stratigraphic relationships among rocks of all ages rather than rocks of only one geologic system.

Because rocks ranging in age from early Archean ($>3,600$ m.y.) to Holocene ($<10,000$ years) occur in the Northern Mid-continent Region, a mixture of chronometric and chronostratigraphic criteria of varying degrees of accuracy and precision were used to portray what is a very complex stratigraphic succession. This has resulted in many stratigraphic and cartographic problems that have not yet been resolved. Nonetheless, the COSUNA Project Director, Dr. Orlo Childs (University of Arizona), has invited any interested groups or individuals to participate in the review of the geologic columns in areas in which they have expertise. Therefore, as part of this review process, we actively solicit assistance in preparation and evaluation of this chart.

(Morey and Bergstrom, continued)

Reference Cited

Douglas, R.J.W., and others, 1970, Geotectonic Correlation Chart for Western Canada, in Douglas, R.J.W., ed., Geology and Economic Minerals of Canada: Geological Survey of Canada, Economic Geology Report No. 1, Chart III.

MINERALOGY AND CHEMISTRY OF MIDDLE PRECAMBRIAN (Xg) GRANITIC PLUTONIC ROCKS FROM NORTHERN WISCONSIN

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A study of Middle Precambrian igneous intrusive rocks from northern Wisconsin is in progress to gain further understanding of the Penokean orogeny. The rocks are separated into two suites by radiometric dating. Van Schmus (in press) and Sims and Peterman (in press) estimate that the older (Penokean) suite is 1800-1900 m.y. old. The range of rock types is granite-granodiorite-tonalite (IUGS classification). The older suite has been studied in Price, Rusk, and Sawyer counties. The common primary igneous mineral assemblage is quartz + plagioclase + biotite + alkali feldspar + hornblende. These rocks appear to be syntectonic. Van Schmus (in press) estimates that the younger suite is 1765 m.y. old. This suite ranges from granite to quartz monzonite, and has been studied in Sawyer, Oneida, and Marinette counties. The common primary igneous mineral assemblage is quartz + plagioclase + alkali feldspar + biotite + hornblende. The younger suite appears to be post-tectonic. From estimates by powder diffraction methods, K-feldspars from both suites appear to be ordered (between intermediate and maximum microcline). Preliminary results of mineral chemistry have been obtained by electron microprobe. In the older suite, biotites have 0.65-0.73 wt.% FeO/FeO+MgO (total iron determined as FeO), hornblendes have 0.61-0.76 wt.% FeO/FeO+MgO, plagioclases are normally zoned and have 31-49 mole% An, and alkali feldspars have 87-92 mole% Or. In the younger suite, plagioclases have 30-36 mole% An, and alkali feldspars have 84-89 mole% Or. Two feldspar geothermometry yields temperatures of 600-800°C (range for both suites). Major element rock chemistry has been determined by microprobe analysis of glass beads (sample fused with flux). Some trace elements have been determined by INAA. Both suites may have been metamorphosed during a 1600-1650 m.y. old regional metamorphic event which reset Rb-Sr systematics in east-central Wisconsin and the Fox River Valley (Van Schmus et al., 1975). Comparison with Mesozoic-Cenozoic intrusives of known tectonic setting allows inferences to be made about the tectonic setting in which the Middle Precambrian intrusives were generated. Chemical data are consistent with (but not criteria for) generation of the older suite during plate subduction, and generation of the younger suite related to a subsequent collision event. This seems to be in general agreement with the geologic model presented by Cambray (1978).

* Student paper

METALLIC MINERALS OF SILVER ISLET, LAKE SUPERIOR

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Silver Islet is located in Thunder Bay near the tip of the Sibley peninsula. Between 1869 and 1922 the Silver Islet vein produced \$3,260,000. The general geology of the island was described by Franklin (1970). The main Silver Islet vein strikes N35°E, dips 70 to 80 degrees to the east, occupies a fault cutting the Rove formation and a gabbro dike. It has a maximum width of 20 feet (7 meters) which narrows to 8 to 10 feet (3 meters) in the dike and 2 to 4 feet (1 meter) in nearby shale, and has been traced to a depth of 1200 feet (400 meters).

In the present study, the metallic minerals in polished sections from 5 samples (#1-5) from the Silver Islet vein were analyzed by electron microprobe. The presence of the following previously-reported minerals was confirmed; galena (gn), sphalerite (sl), chalcopyrite (cp), niccolite (nc), gersdorffite (gf), and native silver (Ag). In one sample (#3) pink dolomite is cut by a thin (1 mm) vein of pyrrhotite (po) and pentlandite (pn) which appear to show mutual exsolution relationships. Another sample (#5) has safflorite (sf) closely associated with Fe-gersdorffite (Fe-gf). Gersdorffite in another sample (#1) is near the Ni end member (Ni-gf). Compositional ranges of major and minor elements are shown in Table 1.

TABLE 1

Ranges of Analyses
(Atomic percent)

	po Fe ₉ S	pn (Fe,Ni) ₈ S	sf (Fe, Co)As ₂	Fe-gf (Ni,Co,Fe)AsS	Ni-gf (Ni,Co,Fe)AsS	cp CuFeS ₂	nc NiAs	Ag Ag	sl ZnS	gn PbS
Fe	47	30-33	23-26	24	0.5-2	25	-	-	0-5	-
S	53	50-52	2	32	31-35	51	5-9	-	50-54	13
Ni	-	14-18	-	-	25-30	-	43-47	-	0-0.1	-
Co	-	-	6-7	8	1-3	-	0.3-4.4	-	-	-
As	-	-	66-68	36	33-35	-	40-46	-	-	-
Ag	-	1-2	-	-	0-2	1-2	-	96-98	-	-
Cu	-	-	-	-	-	23	-	-	-	-
Zn	-	-	-	-	-	-	-	-	44-48	-
Pb	-	-	-	-	-	-	-	-	-	87
Sb	-	-	-	-	-	-	0.7-2.9	-	-	-
Hg	-	-	-	-	-	-	-	2-4	-	-
Cd	-	-	-	-	-	-	-	-	<0.5	-

The paragenesis of these minerals is not simple, but the possibilities are constrained by the analyzed compositions of the minerals involved.

REFERENCE

Franklin, J.M., 1970, Metallogeny of the Proterozoic Rocks of the Thunder Bay District, Ontario; Ph.D. Thesis, Western University, London, Ontario, pp. 173-175.

GROUND WATER GEOCHEMISTRY AS AN AID TO GEOLOGIC
MAPPING OF DRIFT-COVERED AREAS: TEST CASES IN WESTERN MINNESOTA

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Ground water anomaly maps have been used for decades as tools for mineral exploration. In conjunction with regional geophysical maps and whatever direct subsurface data are available, maps of geochemical variations in ground water also appear to be useful for determining structural and lithologic trends in bed rock beneath glacial drift. Contoured maps of alkalinity, specific conductivity, dissolved oxygen, and dissolved radon in ground water can be made at relatively modest cost from data acquired with portable field equipment. Other geochemical species such as helium, the metals, and sulfate are useful also, but have the disadvantage of requiring laboratory analysis.

Because the complex relationship between ground-water geochemistry and bed rock involves geologic and hydrologic variables that are difficult to assess, interpretation of ground-water geochemical maps is rarely straightforward. Significant poorly known factors in interpretation are drift thickness, drift composition, and the degree of hydrologic interconnection between drift and bed rock. However, the coincidence in trend observed in parts of western Minnesota between geochemical anomalies and geophysical anomalies, and, less commonly, between geochemical anomalies and mapped geologic contacts strongly suggest bedrock influence on the hydrogeochemical system. The details of this influence warrant further investigation and we intend to study the hydrogeochemical interactions among ground water, bed rock, and drift, especially as they apply to the distribution of radium and radon. Though many important questions remain, maps of geochemical variations in ground water have the potential to help with the vexing problem of mapping bed rock beneath the vast drift-covered tracts of the southern Lake Superior region.

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