

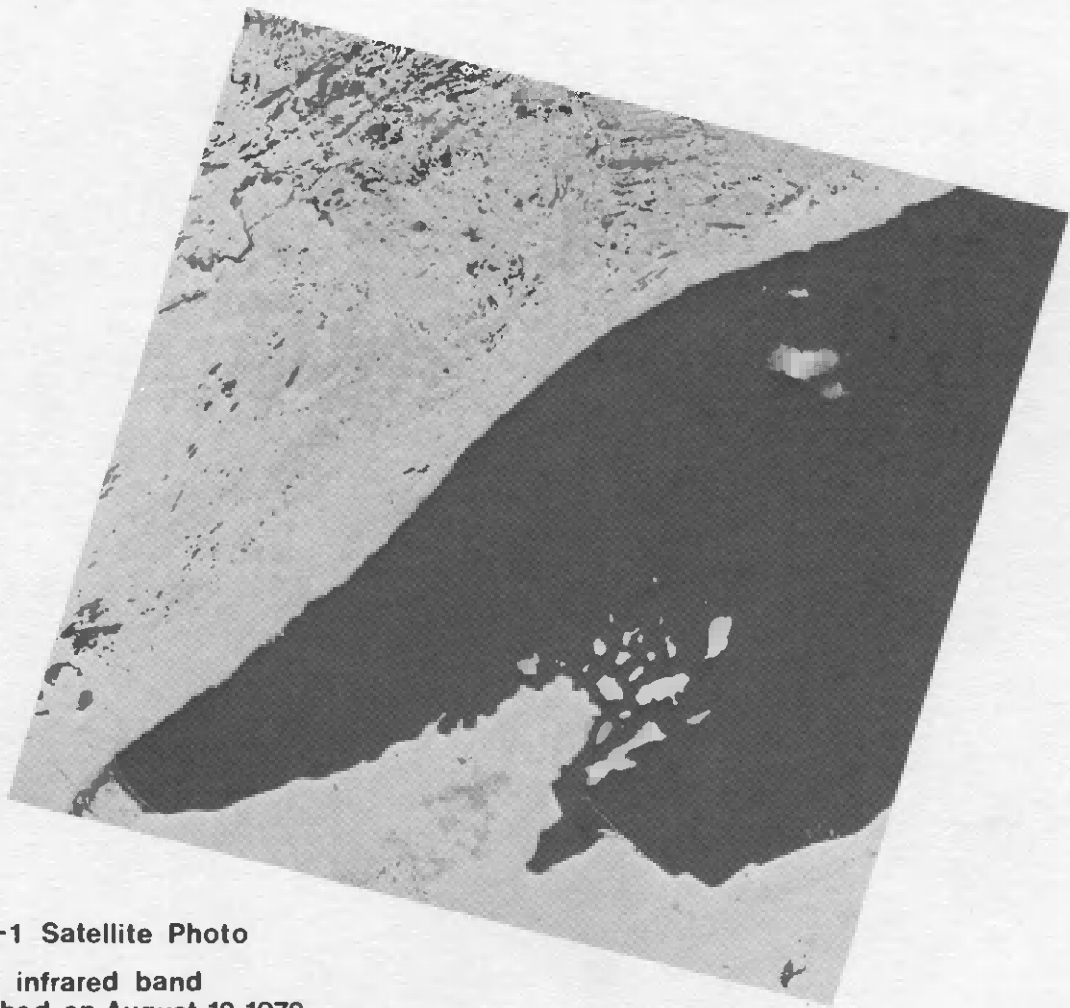
COOPERATIVE EXTENSION PROGRAMS



University of Wisconsin—Madison  
University of Wisconsin—Extension

# **Nineteenth Annual Institute on Lake Superior Geology**

**May 3-6, 1973  
Madison, Wisconsin**



**ERTS-1 Satellite Photo**

**Far infrared band  
photographed on August 12, 1972**

**Sponsored by the  
Wisconsin Geological and Natural History Survey  
University of Wisconsin - Extension  
and the  
Departments of Geology of the University of Wisconsin System**

Technical Program

and

Abstracts

for

the 19th Annual

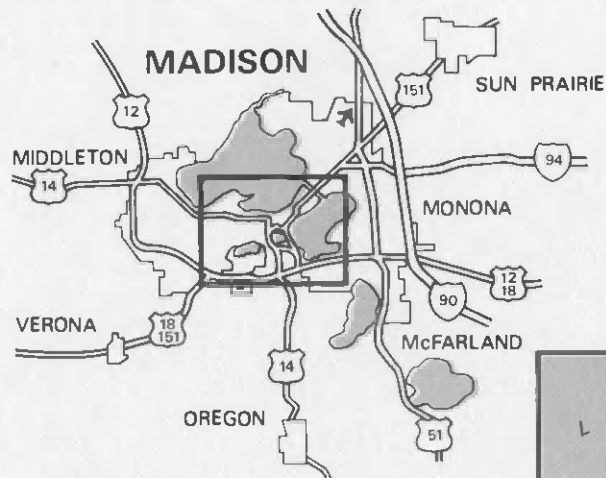
INSTITUTE ON LAKE SUPERIOR GEOLOGY.

held at

Sheraton Inn

Madison, Wisconsin

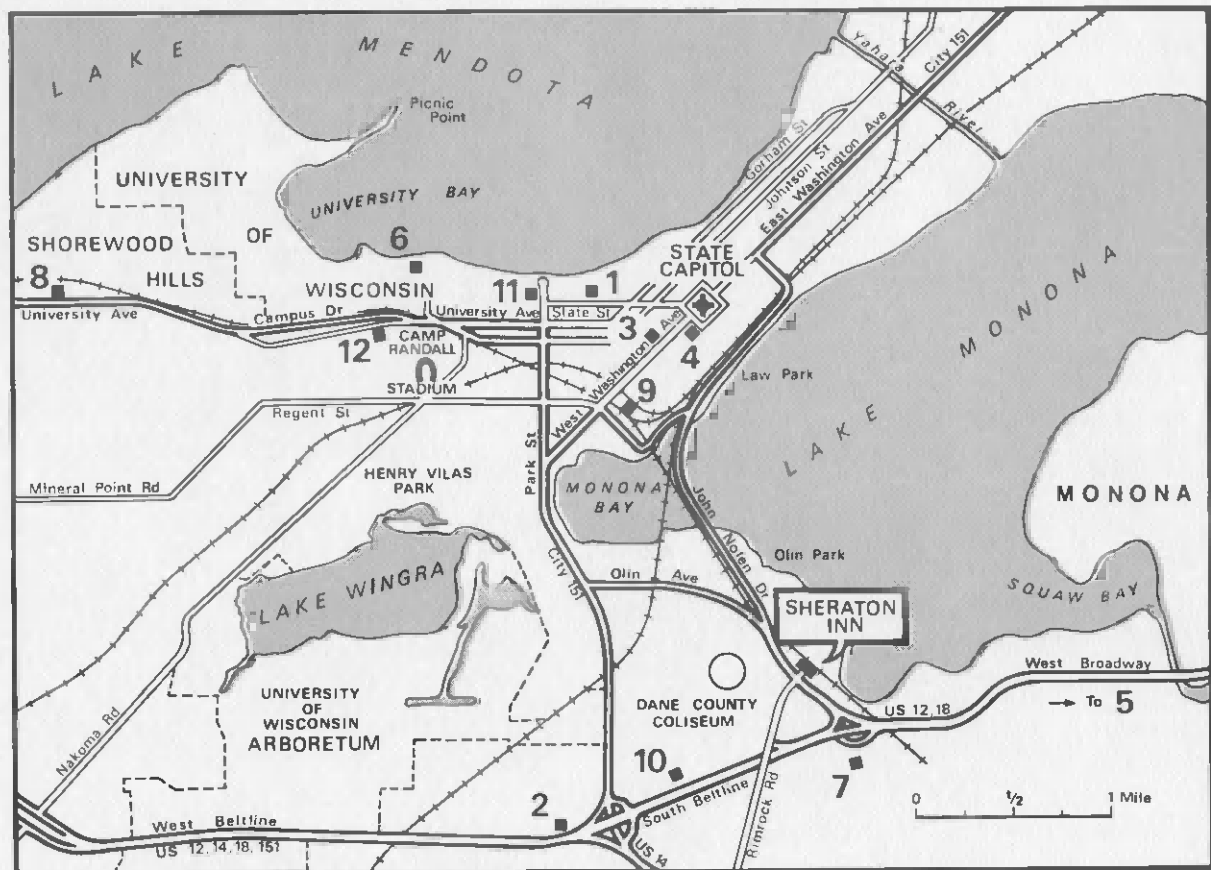
May 3-6, 1973



## South - Central MADISON, WISCONSIN

 SHERATON INN

- 1 MADISON INN
- 2 MAYFLOWER MOTEL
- 3 NATIONAL MOTOR INN
- 4 PARK MOTOR INN
- 5 QUALITY INN
- 6 Short Course Dorms:  
HUMPHRY HALL  
JORNS HALL
- 7 MURPHY'S RESTAURANT
- 8 POOLE'S CUBA CLUB
- 9 RHODE'S STEAK HOUSE
- 10 77 SIRLOIN STRIP
- 11 DEPARTMENT of GEOLOGY  
and GEOPHYSICS, SCIENCE HALL
- 12 WISCONSIN GEOLOGICAL  
and NATURAL HISTORY SURVEY



19th Annual

Institute of Lake Superior Geology

Sheraton Inn, Madison, Wis.  
May 3-6, 1973

Sponsored by the Wisconsin Geological & Natural History Survey and Departments of Geology, the University of Wisconsin System. Individuals from the U.S. Geological Survey, Department of Geology of the University of Kansas, and the Inland Steel Corporation also contributed greatly to arranging the program and field trips.

INSTITUTE BOARD OF DIRECTORS

- \* J.W. Avery (Treasurer), Jones & Laughlin Steel Corp.,  
Negaunee, Michigan.
- \* R.D. Reed (Secretary), Michigan Geological Survey,  
Lansing Michigan.
- M.E. Ostrom, Wisconsin Geological & Natural History Survey,  
Madison, Wisconsin.
- J. Kalliokoski, Michigan Technological University,  
Houghton, Michigan.
- D.M. Davidson, Jr., Dept. of Geology, University of  
Minnesota at Duluth, Duluth, Minnesota.
- M.W. Bartley, Thunder Bay, Ontario, CANADA

\* Permanent members

LOCAL COMMITTEE

M.E. Ostrom, Conference Chairman

Technical Program

C. Craddock, Chairman  
E. Cameron  
C. Dutton  
G. Medaris  
G. Mursky

Field Trips

M. Roshardt, Coordinator  
W. Broughton  
C. Dutton  
A. Heyl  
H. Klemic  
G. LaBerge  
G. Medaris  
P. Myers  
G. Mursky  
J. Ohlson  
L. Weis  
W. West  
R. Van Schmus

Physical Arrangements

P. Olcott, Chairman

Short Course Office  
College of Agricultural  
and Life Sciences  
University of Wisconsin-  
Extension



CARL E. DUTTON - AN APPRECIATION

Carl Dutton's career in geology extends through nearly half a century, and most of this time his headquarters have been in Science Hall on the Madison campus of the University of Wisconsin. He has worked extensively in Michigan, Wisconsin, and Minnesota, and he is well known to Precambrian geologists throughout the Lake Superior area. On the occasion of this meeting, his colleagues and friends in Madison extend this appreciation for his many contributions.

Carl was born in Dunkirk, Ohio, on January 24, 1904. He was educated at DePauw University (B.A., 1926), the University of Illinois (M.A., 1928), and the University of Minnesota (Ph.D., 1931). Carl and Val Dutton have two sons - John, a meteorology professor at Pennsylvania State University, and Robert, a physician in San Francisco - and five grandsons. They have lived in Shorewood Hills, just west of the Madison campus, since 1946.

Carl has divided his life between various academic positions and the U.S. Geological Survey, and he is widely respected as a teacher and a field geologist. He was a Teaching Assistant at Illinois, an Instructor at Minnesota, and an Assistant Professor at Wayne State University and at the University of Michigan. He joined the U.S. Geological Survey in 1943, becoming Regional Geologist in 1946 and Research Geologist in 1962. Since coming to Madison he has participated in the Mineral Resources cooperative program of the Wisconsin Geological & Natural History Survey and the U.S. Geological Survey, he has taught some classes & lectured in the Department of Geology and Geophysics, and he has been a valued counselor and friend to many professors and students.

During his stay at the University of Minnesota Carl was introduced to the geological problems of the southern Canadian Shield by Professors Frank Grout, John Gruner, and George Schwartz. His doctoral dissertation on the conglomerates and structure of the Ensign Lake area, Cook County, Minnesota, under Professor Gruner was the beginning of his life-long fascination with the Precambrian. He also became interested in iron formations and later began a research program in Michigan, eventually achieving international recognition as an authority on iron ores. He gave a paper on U.S. iron ore deposits at the International Geological Congress in Algiers in 1952, served on the U.N. Committee on Iron Ore Resources in Geneva in 1953-54, and spent six weeks studying iron deposits with the AID program in Yugoslavia in 1961. Carl is a Fellow of the Geological Society of America and serves as the Membership Secretary for the Society of Economic Geologists.

Through the years Carl has produced many papers and geologic maps, and only a few can be mentioned here. He has worked for many years in the Menominee iron district of Michigan and Wisconsin, and is co-author of USGS P.P. 513 and Map I-466. He is also co-author of USGS Maps MF-99 and MF-181 on the bedrock geology of the Cuyuna district, Minnesota. He is widely known for a series of papers on iron ore resources of the U.S., North America, and some foreign countries. He is co-author of USGS P.P. 570 and Map MF-225 on the geology and ore deposits of the Iron River-Crystal Falls district, Michigan. A very important contribution is a series of lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin, published as USGS Map I-631. These maps are a complete compilation of available information on the Wisconsin Precambrian, including many previously unpublished data carefully extracted from numerous field notebooks on hand in the files of the State Survey. In addition, Carl has written papers for several guidebooks and has served as a leader on many field trips, both formal and informal.

Carl Dutton is indeed a gentleman and a scholar in the highest tradition, and a wonderful man to have as a colleague. We thank him for his long service and numerous contributions to our profession, our state, and our university; for his enduring interest and careful work in the Precambrian; for his generous and patient assistance to his fellow geologists in the classroom, the office, the laboratory, and the field; and for his cheerful optimism, quiet modesty, and gently dignity. We enjoy and appreciate having Carl among us on this campus, and we hope he remains with us for many years.

## TABLE OF EVENTS

### Wednesday, May 2, 1973

|                |                                              |                             |
|----------------|----------------------------------------------|-----------------------------|
| 7:00-9:00 p.m. | Registration<br>Conference Smoker (Cash Bar) | Mezzanine<br>Ballroom North |
|----------------|----------------------------------------------|-----------------------------|

### Thursday, May 3, 1973

|                 |                       |                |
|-----------------|-----------------------|----------------|
| 8:00-10:00 a.m. | Registration          | Mezzanine      |
| 8:30-12:00 noon | Technical Session 1   | Ballroom North |
| 12:00-1:00 p.m. | Luncheon              | Ballroom South |
| 1:30-5:10 p.m.  | Technical Session 2   | Ballroom North |
| 6:00-7:00 p.m.  | Happy Hour (Cash Bar) | Ballroom South |
| 7:00-8:30 p.m.  | Banquet               | Ballroom South |

### Friday, May 4, 1973

|                 |                                                               |                |
|-----------------|---------------------------------------------------------------|----------------|
| 8:30-12:00 noon | Technical Session 3                                           | Ballroom North |
| 12:00-1:00 p.m. | Luncheon                                                      | Ballroom South |
| 1:30-4:45 p.m.  | Technical Session 4                                           | Ballroom North |
| 4:45-5:00 p.m.  | Business Meeting                                              | Ballroom North |
| 7:00 p.m.       | Buses for Field Trips 2 & 3<br>leave Sheraton Inn Parking Lot |                |

### Saturday, May 5, 1973

|            |                                                          |
|------------|----------------------------------------------------------|
| 7:30 a.m.  | Bus for Field Trip 1 leaves<br>Sheraton Inn Parking Lot  |
| 6:00 p.m.  | Bus for Field Trip 1 returns<br>Sheraton Inn Parking Lot |
| 10:00 p.m. | Bus for Field Trip 2 returns<br>Sheraton Inn Parking Lot |

### Sunday, May 6, 1973

|           |                                                          |
|-----------|----------------------------------------------------------|
| 7:00 p.m. | Bus for Field Trip 3 returns<br>Sheraton Inn Parking Lot |
|-----------|----------------------------------------------------------|

## TECHNICAL PROGRAM

### SESSION 1 - Morning, Thursday, May 3, 1973

Co-chairmen: Alan T. Broderick and L. Gordon Medaris, Jr.

|       |                                            |                                                                                                                      |
|-------|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| 8:30  | M.E. Ostrom                                | Welcoming Remarks                                                                                                    |
| 8:40  | P.K. Sims                                  | Tectonic history of Early Precambrian rocks in the Vermilion district, northeastern Minnesota. p. 34-35              |
| 9:05  | Edward M. Ripley & Donald M. Davidson, Jr. | Structural evolution of the Deer Lake ultramafic complex, Minnesota. p. 29                                           |
| 9:25  | M.S. Loughheed & J.J. Mancuso              | The biogenic origin of primary minerals in Lake Superior Precambrian iron-formation. p. 21-22                        |
| 9:50  | Discussion of papers                       |                                                                                                                      |
| 10:00 | Coffee break                               |                                                                                                                      |
| 10:30 | Klaus J. Schultz & Edward M. Ripley        | Petrology of some Early Precambrian differentiated ultramafic bodies in northeastern Minnesota. p. 32-33             |
| 10:50 | M.G. Mudrey, Jr. & A.L. Geldon             | A Lower Precambrian lamprophyre pluton near Ely, Minnesota. p. 25                                                    |
| 11:10 | John S. Klasner & Thomas R. Turner         | Precambrian north-south oriented faults in the western Marquette district, northern Michigan. p. 17-18               |
| 11:30 | Jens F. Touborg                            | Structural and stratigraphical analysis of the Geco sulphide deposit in Manitouwadge, northwestern Ontario. p. 38-39 |
| 11:50 | Discussion of papers                       |                                                                                                                      |
| 12:00 | Adjourn                                    |                                                                                                                      |
| 12:00 | Luncheon Ballroom South                    |                                                                                                                      |

**SESSION 2 - Afternoon, Thursday, May 3, 1973**

**Co-chairmen: Paul G. Schmidt and Greg Mursky**

|      |                                 |                                                                                                                       |
|------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 1:30 | M.D. Lewan                      | Geochemistry of the calcium-carbon dioxide metasomatism at Presque Isle, Marquette, Michigan. p. 19-20                |
| 1:50 | D.M. Mickelson                  | Summary of glacial geology of north-central Wisconsin. p. 24                                                          |
| 2:15 | E. Wm. Heinrich                 | An unusual manganese deposit in Keweenawan lava, Copper Harbor, Michigan. p. 12                                       |
| 2:35 | Thomas A. Vogel & Nancy Alyanak | "Framboidal" chalcocite from White Pine, Michigan. p. 42                                                              |
| 2:55 | Discussion of papers            |                                                                                                                       |
| 3:05 | Coffee break                    |                                                                                                                       |
| 3:35 | Roger W. Cooper                 | The Keweenawan volcanics north of the Gogebic range in Wisconsin. p. 9                                                |
| 3:55 | John C. Green                   | Progress report of the Committee on Keweenawan Stratigraphy. p. 11                                                    |
| 4:15 | R.J. Stevenson                  | A Keweenawan layered mafic intrusion near Finland, Lake County, Minnesota. p. 36                                      |
| 4:35 | W.F. Cannon                     | High grade magnetite deposits at Republic, Michigan: Their bearing on the genesis of Marquette Range hard ore. p. 6-8 |
| 5:00 | Discussion of papers            |                                                                                                                       |
| 5:10 | Adjourn                         |                                                                                                                       |
| 6:00 | Happy hour                      | Ballroom South (cash bar)                                                                                             |
| 7:00 | Banquet                         | Ballroom South Address by<br>Dr. Eugene Cameron<br>ANIMAL, VEGETABLE, OR MINERAL ?                                    |

SESSION 3 - Morning, Friday, May 4, 1973

Co-chairmen: Ralph W. Marsden and Carl E. Dutton

|       |                                 |                                                                                                                                     |
|-------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 8:30  | Richard Berger<br>and others    | Environmental geology and land use<br>planning, Chassel quadrangle, Houghton<br>County, Michigan. p. 3-4                            |
| 8:50  | Emmy Booy &<br>Ruth J. Sobanski | Engineering geology of the Military<br>Hill landslides, Ontonagon County,<br>Michigan. p. 5                                         |
| 9:10  | C.R. Bentley                    | Magnetotelluric evidence for lateral<br>variations of crustal structure in<br>northern Wisconsin. p. 2                              |
| 9:30  | Jens F. Touborg                 | The Atikokan Iron Range and its<br>iron-copper mineralization. p. 40                                                                |
| 9:50  | Discussion of papers            |                                                                                                                                     |
| 10:00 | Coffee break                    |                                                                                                                                     |
| 10:30 | G. Mursky<br>and others         | Mineralogical and chemical studies<br>of greenstones in Wisconsin. p. 26-27                                                         |
| 10:50 | W.R. Van Schmus                 | Geochronology of Precambrian Rocks<br>in eastern Wisconsin. p. 41                                                                   |
| 11:10 | L.G. Medaris, Jr.<br>and others | The Wolf River batholith - a late<br>Precambrian rapakivi massif in<br>northeastern Wisconsin. p. 23                                |
| 11:30 | J.L. Anderson                   | Graphical analysis of portions of<br>the granite system with application<br>to biotite-bearing granitic melts<br>and gneisses. p. 1 |
| 11:50 | Discussion of papers            |                                                                                                                                     |
| 12:00 | Adjourn                         |                                                                                                                                     |
| 12:00 | Luncheon Ballroom South         |                                                                                                                                     |

SESSION 4 - Afternoon, Friday, May 4, 1973

Co-chairmen: Paul C. Tychsen and Perry Olcott

|      |                                                       |                                                                                                              |
|------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| 1:30 | D.L. Roder &<br>E.N. Cameron                          | The petrology and geochemistry of<br>Round Lake intrusion, northwestern<br>Wisconsin. p. 30                  |
| 1:50 | J.E. Thresher                                         | The formation of the Pittsville<br>(Wisconsin) migmatite. p. 37                                              |
| 2:10 | Robert A. Jenkins                                     | The geology of Pembine and Beecher<br>townships, Marinette County,<br>Wisconsin. p. 15-16                    |
| 2:30 | John M. Ohlson                                        | The iron ore deposits at Black<br>River Falls, Wisconsin, geology<br>and operations. p. 28                   |
| 2:50 | Discussion of papers                                  |                                                                                                              |
| 3:00 | Coffee break                                          |                                                                                                              |
| 3:30 | G.H. Dury                                             | Southwest Wisconsin as a duricrusted<br>pediplain. p. 10                                                     |
| 3:50 | A.V. Heyl                                             | Upper Mississippi valley lead-zinc<br>district. p. 13-14                                                     |
| 4:10 | S.B. Romberger                                        | Upper Mississippi valley base metal<br>deposits: experimental solutions to<br>problems of ore genesis. p. 31 |
| 4:30 | Discussion of papers                                  |                                                                                                              |
| 4:45 | Business Meeting                                      |                                                                                                              |
| 5:00 | Adjourn                                               |                                                                                                              |
| 7:00 | Buses for field trips 2 and 3 leave from parking lot. |                                                                                                              |

# GRAPHICAL ANALYSIS OF PORTIONS OF THE GRANITE SYSTEM WITH APPLICATION TO BIOTITE-BEARING GRANITIC MELTS AND GNEISSES

J. L. Anderson, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706

## ABSTRACT

Graphical analysis of the system  $\text{SiO}_2$  -  $\text{KAlSi}_3\text{O}_8$  -  $\text{NaAlSi}_3\text{O}_8$  -  $\text{CaAl}_2\text{Si}_2\text{O}_8$  -  $\text{K}_2\text{Mg}_6\text{Si}_6\text{Al}_2\text{O}_{20}$  -  $\text{FeO}$  -  $\text{Fe}_2\text{O}_3$  -  $\text{H}_2\text{O}$  provides a tentative model to describe phase relations in biotite-bearing granitic melts and gneisses. Defining "FeO" as an arbitrary combination of  $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$  specifies the oxygen fugacity. Moreover, it has been necessary to split the system into three four component subsystems to evaluate separately the effect of the components  $\text{H}_2\text{O}$ ,  $\text{KMg}_6\text{Si}_6\text{Al}_2\text{O}_{20}$ , and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  on the rest of the system. Quartz, alkali feldspar, plagioclase, biotite, magnetite, granitic melt, and vapor are the considered phases. Application of Schreinemaker's rules combined with experimental data on alkali feldspar - biotite - magnetite and crystal-melt equilibria generates an array of topologies. The system is characterized by degenerate equilibria.

In application, several conclusions can be made which are as follows: 1) Dependent on the number of degrees of freedom, the K/Na and Fe/Mg ratios in biotite can be a function of temperature, total pressure, chemical potential of water, oxygen fugacity, and the bulk composition of the rock. If oxygen fugacity is buffered and fluid pressure equals total pressure, divariant assemblages (with respect to T and P) have fixed biotite compositions. Such assemblages become trivariant if  $\text{H}_2\text{O}$  is not in excess such as in  $\text{H}_2\text{O}$  - undersaturated melts. One additional degree of freedom allows only one of the two ratios (i.e., Fe/Mg or K/Na) to be fixed. The other will vary with the bulk composition of the rock. As to which of the two ratios this is depends on the assemblage. Another degree of freedom will allow both ratios to vary with the bulk composition. 2) Biotite stability can strongly influence the composition of partial melts derived from gneisses of the assemblage quartz-plagioclase-biotite-magnetite. If the biotite remains stable beyond conditions of partial melting only tonalitic melts can result. 3) Alternatively, this assemblage cannot coexist in equilibrium with introduced granitic melt. A possible example is an injection gneiss south of Stevens Point, Wisconsin, where the alkali feldspar in the granitic veins is isolated from the host rock by plagioclase. 4) Application to rapakivi granite massifs, such as the Wolf River batholith of Wisconsin, is possible. Topological changes suggesting feldspar mantling and the replacement of alkali feldspar by biotite exist. The feasibility of such explanations is being studied.

## MAGNETOTELLURIC EVIDENCE FOR LATERAL VARIATIONS OF CRUSTAL STRUCTURE IN NORTHERN WISCONSIN

C. R. Bentley, Department of Geology and Geophysics, University of Wisconsin-Madison, Madison, Wisconsin, 53706.

### ABSTRACT

If two-dimensional inhomogeneity is the reason for apparent anisotropy in magnetotelluric studies, then one of the pair of curves at each site should be close to that which would be observed over a one-dimensional earth. On this basis, sites in Wisconsin can be divided into three geographically distinct groups with decidedly different average curves. The systematic grouping of sites implies that the differences reflect real differences within the crust, not just variations in the local near-surface conditions. That implication is strengthened by the fact that one boundary between groups corresponds to an abrupt change in structure deduced completely independently from seismic and gravity data alone (Ocola and Meyer, in press, J.G.R.). The two-dimensional assumption also implies that the "correct" curve of each pair corresponds to current flow parallel to the two-dimensional boundary. Plotting current direction corresponding to the accepted curve at each site reveals a parallelism with contours of Bouguer gravity anomalies, suggesting that the two-dimensionality controlling the tensor orientation is not near-surface at all, as has previously been assumed, but is associated instead with gross crustal structure.

ENVIRONMENTAL GEOLOGY AND LAND USE PLANNING,  
CHASSELL QUADRANGLE, HOUGHTON COUNTY, MICHIGAN

Richard Berger, Emmy Booy, and Brenton M. Hamil, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.

ABSTRACT

The Chassell Quadrangle is located in the southeastern quarter of the Keweenaw Peninsula. It includes land which was formerly utilized for copper mining as well as for agriculture. The area is sparsely populated and may be expected to undergo development in the future. An evaluation of geological factors affecting such development has been made.

About 85 percent of the land has a slope less than 15 percent, with more than half of that having a slope less than 5 percent. About one quarter of the land in the quadrangle has more than 50 feet of overburden, another quarter (mostly overlying the Jacobsville sandstone in the eastern area) 30 to 50 feet, and the rest (mostly in the westerly areas overlying the Portage Lake Lava flows) between 0 and 30 feet of overburden. Most of these soils are classified as silty to sandy loam (USDA classification) or SM or SC (Unified Soil Classification) having a low shrink-swell potential and good permeability (about 2.2 inches/hour). There is a prevalent hardpan layer at variable depth which is a sandy loam or SC. The pH of the soils is somewhat acid - 5 to 6. The corrosion hazard for metal and concrete is low. There is generally a thin topsoil. About 10 percent of the land area is underlain by alluvium and organic soils. These are mostly on the floodplains of rivers which would severely restrict the potential for utilization. These areas are generally classified as marshland.

Underground water supply is provided by the glacial drift and bedrock. Where the glacial drift is deep and in parts of the Portage Lake Lava series there is sufficient water for domestic supplies. The Jacobsville sandstone has sufficient water for domestic use. There are some problems with Fe content in water from the glacial and Jacobsville sources; septic tanks may contaminate some of the shallow aquifers.

About 80 percent of the land in the Chassell Quadrangle is well-drained. The Pilgrim, Pike, and Sturgeon Rivers drain the area to Portage Lake. There is substantial permanent marshland and during spring thaw temporary flooding occurs in many upland areas due to the impermeability of the underlying bedrock. In some areas directions of surface drainage differ from the drainage patterns at depth due to the presence of bedrock ridges masked by the glacial drift.

Old mine openings do not appear to be a major hazard in future planning, but shaft locations will have to be taken into account.

About 20 percent of the land is currently owned by large private organizations. Except for small state and municipal holdings, most of the land of the quadrangle is held by small individual landholders.

Current utilization is mostly in forestry and farming with potatoes, strawberries, and dairy products being the dominant crops. There is less than 10 percent of the land used for commercial and light industrial purposes. Recreational use of the land, e.g. hunting and snowmobiling is fairly widespread. Future use will probably include mining and recreation as well as agriculture. Development of industry will be partially controlled by access to water which is abundant along the shores of Portage Lake but less accessible in major quantities further inland.

## ENGINEERING GEOLOGY OF THE MILITARY HILL LANDSLIDES, ONTONAGON COUNTY, MICHIGAN

Emmy Booy and Ruth J. Sobanski, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.

### ABSTRACT

The valley of the East Branch of the Ontonagon River, Ontonagon County, Michigan is downcut through a thick series of glacial lake-deposited clays, the Ontonagon clays. These clays have proven a hazard to construction and maintenance of the U.S. Highway 45 because of the numerous slope failures of various sizes abutting on the highway. These failures are repetitive in nature, reflecting variation in moisture content with precipitation and snowmelt.

The layered nature of the Ontonagon clays causes substantial variability in the physical properties of the mass both laterally and vertically. In general the material can be classified as clays and clay-silts with fine sand contents ranging from less than 1 percent to 14 percent.

Atterberg Limits of these materials range from those for inorganic clays of low plasticity to those of high plasticity. Plastic limits range from 24 to 50, liquid limits from 27 to 100, and plasticity indices from 12 to 58. There appears to be no consistent pattern of variation of physical properties of the material with location within individual slides (e.g. at toes of slides or on the failure plane at the scarp) nor with elevation above a datum nor along the general north-south trend of the highway.

The natural moisture content of these failure-prone materials ranges from 18 to 41 percent in samples taken in the late Fall of 1972. This approaches the plastic limits of the soils. Free water has been observed at various times of year on these slides and the ground water table is frequently extremely close to the surface. Average precipitation in this area is 34 inches, much of it in the form of snowfall whose meltwater is a significant factor in the frequent occurrence of Spring slides.

It is extremely unlikely that chemical or electrical stabilization of these slopes will prove useful. Surface drainage appears to be the most economic form of slope control in this instance.

HIGH-GRADE MAGNETITE DEPOSITS AT REPUBLIC, MICHIGAN:  
THEIR BEARING ON THE GENESIS OF MARQUETTE RANGE HARD ORE\*

W.F. Cannon, U.S. Geological Survey, Washington, D.C. 20244

ABSTRACT

Hard ore (60-65 percent Fe) in the Marquette Iron Range consists of concentrations of specularite, magnetite, and martite. It characteristically occurs at the top of the Negaunee Iron-formation and over a few feet grades laterally and downward into jaspilite (30-35 percent Fe). Van Hise and Leith (1911) developed the now classic concept that the ore was formed by surface weathering and leaching of silica from the iron-formation prior to deposition of the unconformably overlying Goodrich Quartzite, and the ore was later deformed and metamorphosed to produce the present specularite-rich rock. This hypothesis has withstood critical examination by many geologists; evidence in its support is especially compelling in the eastern part of the Marquette Range. Boyum (1964) and Anderson (1968) have suggested that this concept, although probably valid, is not adequate to explain all features of the ore bodies. My own reexamination of these deposits leads me to support Boyum's and Anderson's conclusions. I believe that much of the ore, especially specularite-rich ore, has formed as suggested by Van Hise and Leith, but that magnetite-rich ore (commonly greater than 90 percent magnetite) has a different origin.

At the Republic open pit, the jaspilite unit at the top of the Negaunee Iron-formation is presently being mined. The jaspilite is the host rock for magnetite-rich hard ore, which was previously mined underground. The pit provides exceptional exposures of the high-grade magnetite ore bodies and their contacts with the surrounding jaspilite. Three critical features common to all magnetite-rich hard-ore deposits in the Marquette Range and difficult to explain by the weathering hypothesis are shown there better than at any other locality.

- 1) Although specularite is common to all hard-ore bodies, magnetite is the predominant mineral in many, particularly in higher grade metamorphic rocks toward the west end of the Marquette Range. The magnetite-rich ore contains textural evidence indicating that it has formed after regional deformation.
  - a) The ore is massive, deformational textures are absent, and magnetite grains are largely euhedral and undistorted.
  - b) Bodies of massive ore sharply truncate schistose and crenulated specularite-rich jaspilite.
  - c) The magnetite-rich ore is commonly somewhat vuggy and porous, containing specularite, dolomite, and quartz crystals in vugs.

- 2) Magnetite-rich ore is characteristically associated with quartz (+ dolomite, + sulfide) veins.
- 3) Although the magnetite-rich ore invariably occurs in hematitic iron-formation (jaspilite), the ore bodies are surrounded by narrow haloes in which jasper was converted to gray chert or milky quartz and some specularite was reduced to magnetite, indicating that the formation of magnetite-rich ore is associated with a reducing process rather than an oxidizing process such as weathering.

The magnetite-rich ore is probably of hydrothermal origin and because Penokean regional metamorphism is the only recognized post iron-formation thermal event, the fluids were probably derived by dehydration and decarbonatization of the iron-formation and underlying rocks during progressive regional metamorphism which reached sillimanite grade at Republic.

The localization of the ore at the top of the Negaunee Iron-formation might be explained through the buffering action of the iron-formation on the oxygen fugacity of the fluids. As fluids (considered here as  $H_2O$  for simplicity but probably also  $CO_2$  rich) are expelled during metamorphism and pass upward through the rock section, they will contact first the relatively reduced magnetite-silicate and magnetite-carbonate units in the lower part of the Negaunee and will tend toward an equilibrium oxygen fugacity ( $f_{O_2}$ ), such as point 1 on figure 1, determined by a buffer curve such as curve A, and will contain concentrations of ferrous and ferric iron species appropriate for that  $f_{O_2}$  and temperature. As fluids pass upward and contact the jaspilite, a redox reaction must occur in which the jaspilite is partly reduced by the conversion of specularite to magnetite and the fluids are oxidized to achieve an  $f_{O_2}$ , such as point 2, determined by the hematite-magnetite buffer (curve B). The increased  $f_{O_2}$  of the fluids and consequent lower solubility of ferrous iron species and the oxidation of some ferrous iron to less soluble ferric species results in the precipitation of magnetite. Textures clearly indicate that silica was removed during the hydrothermal activity and the magnetite presumably was precipitated in its place. Because the equilibrium  $f_{O_2}$  of the buffered assemblages is very small ( $10^{-40}$  to  $10^{-20}$  atm for the probable conditions of metamorphism), small volumes of rock can buffer very large volumes of fluid; and the system can remain buffered until all hematite in the jaspilite is converted to magnetite.

I propose that the magnetite-rich ore has formed by: 1) the reduction of hematite to magnetite during a hematite-magnetite buffer reaction; 2) the precipitation of magnetite from hydrothermal (metamorphic) fluids as the fluids were oxidized during that buffer reaction and the solubility of ferrous iron was decreased.

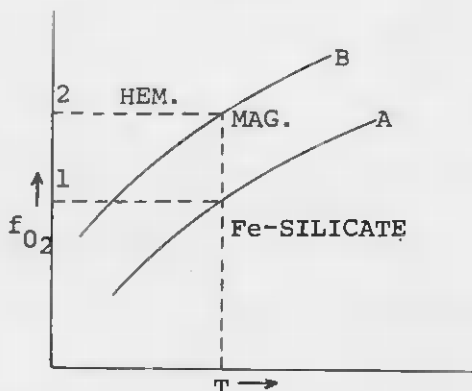


Figure 1.--  $T$ - $f_{O_2}$  diagram showing relative positions of hematite-magnetite buffer curve and a buffer curve determined by the equilibrium: quartz + magnetite = Fe-silicate. Points 1 and 2 illustrated difference in  $f_{O_2}$  controlled by the buffered assemblages at constant  $T$ .

The formation of magnetite-rich ore appears to require a restricted set of conditions:

- 1) Metamorphism must reach at least biotite grade, although most ore bodies and all large ones are in garnet or higher grade.
- 2) Iron-formation with mostly ferric iron, such as jaspilite, must be physically above iron-formation with abundant ferrous iron.
- 3) A stratigraphic or structural trap capable of concentrating the flow of fluids must be present. The Goodrich Quartzite and metadiabase sills and dikes were apparently relatively impermeable, and the Negaunee-Goodrich contact near anticlinal crests and dike-quartzite intersections were favorable loci for ore formation.

The absence of any of these three conditions inhibits the formation of magnetite-rich ore.

#### References

- Anderson, G.J., 1968, The Marquette district, Michigan, in Ridge, J.D., (ed.), Ore deposits of the United States, 1933-1967 (Graton-Sales Volume), V. 1: New York, Am. Inst. Mining, Metall., and Petroleum Engineers, p. 505-517.
- Boyum, B.H., 1964, The Marquette mineral district, Michigan: Inst. on Lake Superior Geology, 10th, Ishpeming, Mich., May 1964, Guidebook, 13 p.
- Van Hise, C.R., and Leith, C.K., 1911, The geology of the Lake Superior region: U.S. Geol. Survey Mon. 52, 641 p.

\* Work done in cooperation with Geological Survey Division, Michigan Dept. of Natural Resources

## THE KEWEENAWAN VOLCANICS NORTH OF THE GOGEBIC RANGE IN WISCONSIN

Roger W. Cooper, Department of Geology and Geophysics,  
University of Wisconsin-Madison, Madison, Wisconsin 53706

### ABSTRACT

The Keweenawan volcanic sequence north of the Gogebic Range has a total thickness of more than 35,000 feet and an attitude of about N65-75 E, 70-80 NW. This sequence of volcanic flows was investigated to determine if a stratigraphic division of the flows into mappable units could be achieved. Four units have been defined on the basis of texture, petrographic characteristics, and chemical analyses.

Unit 1, which is the basal unit, consists of about 5000 feet of pillow basalts and subalkaline basalts. The basalts are medium- to fine-grained and grayish-green. The textures most common in this unit are intergranular and subophitic, with ophitic texture less common.

Unit 2 is about 20,000 feet thick and consists of flows more alkaline than those found in Unit 1. The flows are aphanitic to fine-grained, bluish-gray to reddish-brown. The most common textures are intergranular and intersertal with microphenocrysts of plagioclase. Flows of rather basic composition near the bottom of the unit give way to intermediate and felsic flows upward.

Unit 3 is poorly exposed but estimated to be 2000 to 4000 feet thick. It is composed of porphyritic felsic flows that have a pink to slightly purple groundmass with abundant phenocrysts of feldspar and quartz.

Unit 4 is widely covered by glacial drift but estimated to be about 10,000 feet thick. The flows appear to be mainly mafic, gray, and usually not more than 20-25 feet thick. The flows are highly vesicular; pipe amygdules and vesicular tops are common. Interbedded with these flows are sedimentary rocks ranging from conglomerate to shale. The pebbles found in these beds are predominantly felsites. These interbedded flows and sedimentary beds pass upward into the Copper Harbor Conglomerate.

The Keweenawan volcanic sequence displays a general compositional trend from subalkaline tholeiitic basalts at the base upward through the porphyritic felsic flows of Unit 3. After the extrusion of these felsic flows there appears to have been intermittent volcanism of a more mafic nature along with erosion of the felsic flows.

## SOUTHWEST WISCONSIN AS A DURICRUSTED PEDIPLAIN

G. H. Dury, Departments of Geography and Geology, The University of Wisconsin-Madison, Science Hall, Madison, Wisconsin 53706.

### ABSTRACT

The Driftless Area of Southwest Wisconsin and adjacent parts of Minnesota, Iowa, and Illinois consists of dissected plateau country traversed by the Wisconsin and Mississippi Rivers. In the past, the area has been described in terms of one or more peneplains, and/or in terms of a series of cuestas.

In actuality, it is recognizable as a dissected pediplain: the few residuals that have escaped planation rise sharply from the summit surface and exhibit typical pediment profiles. Evidence of deep weathering is widespread, regardless of lithology. On carbonates, the deep weathering profiles consist of rotted rock and red residuum; but part of the latter may have been introduced subsequently to deep weathering. On arenites, the profiles are varyingly horizonated into pallid, mottled, and duricrusted zones, the pallid zones frequently showing the results of attack on quartz grains, and the crusts ranging from highly ferruginous to highly siliceous. Crust texture can be replicated in Australian samples. Ferruginous nodules in the Wisconsin profiles appear widely to have developed within bedrock.

On either side of the lower Wisconsin river, the deeply-weathered and duricrusted surface defines a wide shallow valley, into the floor of which the glacial sluiceway is incised. Investigation of possible comparable relationships for the Mississippi trench is in progress. As could be expected, there is evidence that the deep weathering was, to some extent at least, a ground-water phenomenon; and some thin crusts appear to have been deposited under carbonates in the subsurface.

Outstanding problems include the distribution of the deeply-weathered surface in glaciated, in addition to unglaciated, areas; the relationship of some ferruginous crusts to sulphide deposition or translocation; and the time-stratigraphic position of the latest local episode of deep weathering.

## PROGRESS REPORT OF THE COMMITTEE ON KEWEENAWAN STRATIGRAPHY

John C. Green, Geology Department, University of Minnesota, Duluth, Duluth, Minnesota 55812 and Minnesota Geological Survey

### ABSTRACT

An informal Committee on Keweenawan Stratigraphy was formed in February 1973 in response to the wishes of participants at the Symposium on Late Precambrian Geology of the Lake Superior Area at the Annual Meeting of the G.S.A. in Minneapolis. Its members are George V. Cohee, Campbell Craddock, Robert H. Dott, John C. Green (chairman), Harold A. Hubbard, Wm. H. McIlwaine, Glenn B. Morey, and Walter S. White. Some rather wide differences of opinion and usage are represented by the members and because of the short time elapsed since its organization, few areas of complete consensus have developed by the mid-March abstract deadline.

The name "Keweenawan" appears to be widely considered as applying to, if not formally defined as, a provincial lithostratigraphic supergroup, as well as to that part of geologic time when the Keweenawan Supergroup was being formed. It would then be composed of various groups and formations, but many of these stratigraphic units have yet to be formally defined. An attempt will be made to clarify their stratigraphic relationships.

The Committee is also wrestling with the problem of the most appropriate stratigraphic levels at which to define the base and the top of the Keweenawan, on the assumption that there should be some unifying geotectonic coherence implied by the name. In many respects the "Keweenawan Disturbance" could be compared with the Palisades Disturbance of Late Triassic time, and "Keweenawan" rocks could be defined as those formed as a result of this event or complex of events in the area of the Mid-Continent Gravity High or at least the Lake Superior District.

AN UNUSUAL MANGANESE DEPOSIT IN KEWEENAWAN LAVA  
COPPER HARBOR, MICHIGAN

E. Wm. Heinrich, Department of Geology and Mineralogy,  
University of Michigan, Ann Arbor, Michigan.

ABSTRACT

One of the rare non-cupriferous mineral deposits in Keweenaw lava is the manganese occurrence just east of Manganese Lake and about one mile south of Copper Harbor in sec. 4, T. 58N, R. 26W. Butler and Burbank (1929, p. 59) refer to that deposit as "... the Manganese mine" and state that "... some ore was shipped from the mine."

The deposit is a calcite-rich replacement lens in an amygdaloid that is stratigraphically a short distance below the base of the Copper Harbor ("Great") Conglomerate. Old workings indicate that the mineralization extends east-west along the strike of the amygdaloid for at least a few hundred feet. The replacement rock consists of material grading from nearly pure coarse-grained white calcite to high-grade black manganese oxide ore. The manganese minerals include hypogene braunite, orientite and manganite and some supergene pyrolusite. A trace of chalcocite and very minor goethite are the only other hypogene species, and limonite, chalcedony and opal in small amounts are supergene. The manganese minerals vein and replace the calcite.

This occurrence of orientite, a hydrous calcium-manganese silicate, is believed to be only the second recorded for the world. (The type locality is in Oriente Province, Cuba.) The mineral appears as glistening copper-red needles forming minute radial aggregates and exceedingly fine-grained matted lenses.

The host amygdaloid, other than being extensively replaced by calcite, which also fills the vesicles entirely alone, is relatively fresh. Neither native copper nor the characteristic suite of accompanying secondary silicates is present, although native copper mineralization of the cross-fissure type occurs at the Clark mine a short distance to the south.

The deposit is believed to be penesynthetic and volcanogenic in origin.

## UPPER MISSISSIPPI VALLEY LEAD-ZINC DISTRICT

A. V. Heyl, U.S. Geological Survey, Denver, Colorado 80225.

### ABSTRACT

The Upper Mississippi Valley district has been the source of about a billion dollars (present-day prices) worth of zinc and lead, and minor amounts of copper and barite. Ore deposits are chiefly in limestone and dolomite of the Galena, Decorah, and Platteville Formations, all of Middle Ordovician age. Locally, small deposits of lead, zinc, and iron sulfide have been mined from underlying Lower Ordovician dolomite and Upper Cambrian sandstone and overlying Upper Ordovician shale and Silurian dolomite. No post-Precambrian igneous rocks are known in the region, and granitic and metasedimentary Precambrian basement rocks unconformably underlie the district at depths of 1,500 to 2,000 feet. No algal reefs are known in the Middle Ordovician rocks, and a diastem, but not an unconformity, separates these rocks from Upper Ordovician shale. The strata are gently flexed and faulted, probably largely the result of gentle compressive and rotational adjustments in the underlying crystalline basement, especially along lineaments between basement blocks. Folds of three orders of magnitude are recognized, and many related joints and reverse, strike-slip, and normal faults of small to moderate displacements are present.

The zinc-lead deposits range in plan from linear through arcuate to elliptical. They are epigenetic and postlithification deposits. Most ore filled open spaces in fractures, breccias, and vugs, but some impregnated and replaced wallrock. The open space is along shears, small reverse and bedding-plane faults, joints related to intermediate to small folds, and within solution-slump structures. Sphalerite and galena are the principal ore minerals, and the general sequence of deposition of main ore and gangue minerals was: quartz, illite, dolomite, pyrite, marcasite, cobaltite(?), sphalerite, galena, chalcopyrite, millerite, barite, and calcite. Wallrock alterations include solution of the carbonate rocks, silicification, dolomitization, changes in type of clay, addition of trace elements, and sanding of dolomite. Country rock between ore bodies is unaltered.

Oxygen-isotope, carbon-isotope, lead-isotope, sulfur-isotope, and sphalerite-stratigraphy studies are completed or in progress. Bubbles in sulfide and gangue minerals are filled with concentrated near-neutral chloride brines that have filling temperatures of 120° to 40°C. The lead in the galena is notably radiogenic.

The metals and sulfur are postulated to be derived from heated basin brines that were later diluted by meteoric waters. A magmatic fluid contribution is possible, but it is not supported by present fluid inclusion data. A magmatic hearth in the basin areas to the south and southwest is the most possible heat source. A large lateral component of flow through permeable Cambrian sandstone updip from the basins is probable, but available evidence

suggests some flow through basement fracture zones. Within the district the ore solutions flowed upward from the aquifers through available fracture systems into Middle Ordovician strata where they leached carbonate rocks. Changes in physical restraints and chemical properties of the ore solutions allowed ore minerals to be deposited in and near open spaces derived from leaching.

# THE GEOLOGY OF BEECHER AND PEMBINE TOWNSHIPS MARINETTE COUNTY, WISCONSIN

Robert A. Jenkins  
Department of Geology and Geophysics  
University of Wisconsin-Madison, Madison, Wisconsin

Four metavolcanic formations, separated by major faults, occur in Beecher and Pembine townships in northeastern Marinette County, Wisconsin. The formations are the Quinnesec Formation, the Mc Allister Formation, the Beecher Formation, and the Pemene Formation. The relative ages are uncertain but the order of naming is suggested as the order of decreasing age. All the formations have been folded and regionally metamorphosed to greenschist facies. In general the rocks have not been strongly sheared or altered, and primary structures are well preserved. The volcanics have been intruded by granite, granodiorites, quartz diorites, and ultramafics.

The Quinnesec Formation, over 10,000 ft. thick, consists predominantly of tholeiitic metabasalts and cala-alkaline meta-andesites. The formation is isoclinally folded; axial planes of the folds are vertical and strike east. The andesites are of two types, one nonporphyritic and pillowed, having its source to the west and the other, porphyritic and mainly agglomeratic, having its source to the east. A 100 to 1,000 ft. thick porphyritic rhyolite flow is interlayered with the andesites.

The Mc Allister Formation, 1,000 to possibly 10,000 ft thick, consists of metamorphosed tholeiitic basalt agglomerate. The formation strikes east, dips vertically, and faces south. Fragment size in the formation increases from west to east, suggesting a vent to the east.

The Beecher Formation, at least 10,000 ft. thick, strikes N50°W, dips vertically, and faces north. The lower 9,000 ft. consists mainly of rhyolite and rhyodacite flows. The upper 1,000 ft. of the formation is an alternation of bedded rhyolitic tuffs and acidic fragmentals. The lower part of the formation is more highly sheared and altered than other formations in the area. This may be due to intrusion of the Amberg granite into the lower part of the formation.

The Pemene Formation consists of 7,000 ft. of microspherulitic soda rich rhyolite and rhyodacite flows. The flows are interlayered with a few thin sedimentary units and were apparently extruded subaqueously. Individual flows are 500 to 1,200 ft. thick and traceable laterally for over four miles. The formation is folded into an east trending asymmetric doubly plunging syncline. The units on the north limb dip 55°S and those on the south limb are vertical.

Thin sections of the various rock types have been examined

for primary structures and to determine metamorphic grade. Whole rock major element analyses have been run using the electron microprobe. These analyses have been used to identify rock types and to determine the petrochemical characteristics of the volcanics.

The petrochemical trends indicate that the rocks of the area may be the products of several cycles of volcanism. Each formation is chemically distinctive. The Quinnesec Formation grades from tholeiitic basalts in the north to calc-alkaline andesites in the south, suggesting that it may have formed at the edge of an island arch environment. Preliminary analyses indicate that the Mc Allister Formation consists of tholeiitic basalts. It may therefore correlate with part of the Quinnesec Formation or it may represent a separate volcanic cycle. The Beecher Formation rhyolites and rhyodacites are typical calc-alkaline acidic volcanics. They may be the acidic end product of the Quinnesec volcanism. The Pemene Formation rhyolites are characterized by higher  $\text{Na}_2\text{O}$  and lower  $\text{K}_2\text{O}$  than normal rhyolites. These volcanics are distinctly different from the rocks of the Beecher Formation and therefore probably represent a separate period of volcanism.

The age of the volcanism in the area is not positively known but Banks and Rebello (1969) report a zircon U-Pb date for a rhyolite just to the west of the area of 1905 (+30 to -10) m.y. This rhyolite probably correlates with the Beecher Formation. If this correlation is correct then the acidic volcanism and possibly the mafic volcanism in the area is upper Middle Precambrian in age.

# PRECAMBRIAN NORTH-SOUTH ORIENTED FAULTS IN THE WESTERN MARQUETTE DISTRICT, NORTHERN MICHIGAN

John S. Klasner  
Western Illinois University  
Macomb, Illinois

Thomas R. Turner  
Michigan Technological University  
Houghton, Michigan

## ABSTRACT

Recent mapping in northern Michigan has indicated the presence of prominent N 10° W to N 20° E faults, many of which offset east-west trending Keweenaw diabase dikes. These faults are expressed as shear zones in lower Precambrian granites, offsets in the contact between middle and lower Precambrian rocks, topographic lineaments, and discontinuities in aeromagnetic trends.

Regionally these faults are on trend with major lineaments observed by other workers in the area. Hinze and others (1966) on the basis of aeromagnetic studies in eastern Lake Superior show a major north-northeast trending fault extending north across the lake just east of the tip of the Keweenaw Peninsula. La Berge (1972) in north central Wisconsin has mapped major northeast trending shear zones up to one mile in width. These features coupled with major lineations on pseudo radar photographs suggest that a major fault zone bisects the arcuate shaped area outlined by the mid-continent gravity high and proposed Keweenaw rift.

With regard to the timing of movement, studies in the western part of the northern complex near Herman, Michigan suggest that at least some of the faults may have been active prior to Penokean metamorphism. For example, a body of gabbro occupies a north-south fault that cuts granite gneiss, and the gabbro is interpreted to have been metamorphosed by Penokean or some earlier thermal event.

In many places east-west Keweenaw dikes are offset at the north-south faults. No evidence has been found for shearing of the dikes at these faults and in some instances the Keweenaw dikes have been found to intrude along the fault zone. Nevertheless, the conclusion seems inescapable that the numerous occurrence of offset dikes at the north-south faults must denote post-Keweenaw fault movement.

## References

Hinze, Wm. J., O'Hara, N.W., Trow, J.W. and Secor, G.B., 1966, Aeromagnetic Studies of Eastern Lake Superior, in the Earth Beneath the Continents, Steinhart & Smith, ed., A.G.U. Geophysical Monograph 10, pp. 95-110.

La Berge, G.L., 1972, Lineaments and Mylonite Zones in the Precambrian of northern Wisconsin [abs.]: 18th Ann. Inst. on Lake Superior Geology, Houghton, Michigan, paper 27.

GEOCHEMISTRY OF THE CALCIUM - CARBON DIOXIDE METASOMATISM  
AT PRESQUE ISLE, MARQUETTE, MICHIGAN

M. D. Lewan, Department of Geology and Geological Engineering,  
Michigan Technological University  
Presently With Shell Oil Company, New Orleans, Louisiana 70160

ABSTRACT

A highly veined rock composed of dolomite and quartz with minor hematite, overlies the Presque Isle serpentinitized peridotite at Marquette, Michigan. Petrographic and field observations clearly indicate that this rock was originally highly serpentinitized peridotite which has since been subjected to metasomatic solutions.

The author (Lewan, 1972) has interpreted this dolomite-quartz rock as originally being a peripheral shear zone which developed during the tectonic intrusion of the peridotite. Either during or after its emplacement water from the surrounding country rocks circulated through this highly fractured peripheral zone causing extensive serpentinitization to the still warm but cooling peridotite. Following the period of serpentinitization a potash rich granite was emplaced and was apparently illitized by late stage magmatic water along its outer boundary where it comes in contact with the peridotite. Both the highly serpentinitized peridotite and illitized granite were susceptible to metasomatic solutions which resulted in the formation of the now existing dolomite-quartz rock. The objective of this study was to investigate the chemical parameters and prevailing conditions which may have induced this period of metasomatism.

Comparative analysis of the chemical composition of the dolomite-quartz rock with the serpentinitized peridotite and illitized granite indicates that calcium and carbon dioxide were introduced into the system with partial removal of silica and magnesium. Experimental work by Gordon and Greenwood (1970) and Ellis (1959), along with free energy calculations suggest that the metasomatism probably never exceeded 300°C. Luce (1972) has shown that serpentine is most soluble in acidic waters which gradually become more basic as the serpentine dissolution continues. This increase in pH probably also accompanied the metasomatic solutions during the dissolution of the highly serpentinitized and illitized peripheral zones which eventually resulted in the mobilization of silica released from the serpentine lattice and the precipitation of dolomite.

This period of metasomatism has been dated as pre-Jacobsville sandstone and post-granite illitization. The occurrence of the peridotite in greenstone terrain offers an attractive hypothesis that this metasomatism may have been a result of the expulsion of fluids from neighboring rocks during the regional metamorphism of the area.

#### REFERENCES CITED

- Ellis, A. J. (1959), The Solubility of Calcite in Carbon Dioxide Solutions, *Am. J. Sci.*, 257, pp 354-365.
- Gordon, T. M., and Greenwood, H. J. (1970), The Reaction: Dolomite + Quartz + Water = Talc + Calcite + Carbon Dioxide, *Am. J. Sci.*, 268, pp 225-242.
- Lewan, M. D. (1972), Metasomatism and Weathering of the Presque Isle Serpentinized Peridotite, Marquette, Michigan, Michigan Technological University, unpublished M.S. Thesis, 55 pp.
- Luce, R. W., Bartlett, R. W., and Parks, G. A. (1972), Dissolution Kinetics of Magnesium Silicates, *Geochim. Cosmochim. Acta*, 36, pp 35-50.

## THE BIOGENIC ORIGIN OF PRIMARY MINERALS IN LAKE SUPERIOR PRECAMBRIAN IRON-FORMATION

M. S. Loughheed and J. J. Mancuso, Department of Geology,  
Bowling Green University, Bowling Green, Ohio 43403

### ABSTRACT

Primary minerals in the Lake Superior Precambrian iron-formations are the direct products of the life processes of a melange of filamentous and unicellular organisms together with associated bacteria. Primary minerals so formed are aragonite and/or calcite, magnetite, and opal. Pyrite is formed during decay of organic material with attendant sulfate reducing bacteria and is therefore later in origin than the above three minerals although it too is of biogenic origin and may be considered primary. Hematite occurs as an alteration product of earlier formed minerals and is not considered a primary mineral.

Aragonite or calcite crystals are biogenically deposited structural elements occurring as submicron width prisms oriented normal to an algal mat, and producing in turn a carbonate mat. A succession of algal and carbonate mats (laminae) occurs in horizontally banded iron-formation; in domical or columnar stromatolites; as coatings on granules (pellets); or forming micro-oncoliths. Micro-oncoliths are typically 20-50 microns in diameter. Calcium carbonate can be dolomitized, sideratized, or silicified.

Magnetite initially occurs as a diffuse cloud of sub-micron sized crystals within the protoplasm of unicellular plants. Too high a concentration of oxygen produced by photosynthesis in these unicellular plants can be lethal to them; they therefore oxidize iron that is dissolved in the water to produce magnetite, thereby attenuating a lethal buildup of oxygen. During deposition and early diagenesis the submicron crystals of magnetite may be recrystallized to form coarser octahedra of magnetite. Diagenesis may subsequently produce megascopic subhedral masses of magnetite. Some magnetite is produced by oxidation of siderite during the depositional stage, which subsequently may be recrystallized during diagenesis in a similar manner to that of primary biogenic magnetite.

Siliceous tests of microorganisms yield the hydrous silica, which during deposition is almost invariably comminuted to an opaline slurry. This slurry readily dehydrates during diagenesis to chalcedony or more often to chert. From five to seven types of siliceous tests of unicellular organisms

occur. Usually the cavities are filled with organically stained chalcedony, and often submicron sized anhedral carbonate are present. The test walls are not organically stained; they are water clear. Occasionally the core and test are recrystallized to an optically oriented sphere or ellipsoid of quartz. The tests range in width from 5 to 25 microns although a few may exceed 50 microns. Preservation of siliceous tests occurs only when they were deposited in quiet water, never when water current activity prevailed. They therefore are not found in association with granules or stromatolites.

Pyrite may be thought of as primary in the sense that it results from iron in the water reacting with sulphur produced by sulfate reducing bacteria during decay of organic debris. Pyrite occurs as discrete octahedrons or octahedrons modified by a cube, as framboidal octahedra, or as framboidal mats or spheres. Secondary replacement pyrite formed during diagenesis is ubiquitous.

THE WOLF RIVER BATHOLITH -- A LATE PRECAMBRIAN RAPAKIVI  
MASSIF IN NORTHEASTERN WISCONSIN

L. G. Medaris, Jr., J. L. Anderson, and J. R. Myles, Department of  
Geology and Geophysics, University of Wisconsin, Madison 53706

ABSTRACT

Anorogenic, epizonal granitic rocks of the Wolf River batholith, covering an area of approximately 3600 square miles, represent a major element of the Precambrian terrain in northeastern Wisconsin. This batholith, 1450 to 1500 m. y. in age, has lithologic, mineralogic, chemical, and structural features that are similar in every respect to those of the classic rapakivi massifs in Finland.

A variety of rock types have been distinguished, including granite, quartz monzonite, syenite, monzonite, rhyolite, and trachyandesite, but quartz monzonite is predominant, accounting for 87% of the exposed area. A porphyritic texture is characteristic, in which phenocrysts of alkali feldspar and, to a lesser extent, plagioclase and quartz are set in a medium- to fine-grained matrix of quartz, two feldspars, and mafic minerals. Rapakivi texture is extensively developed in the Waupaca quartz monzonite and occurs in minor amounts throughout the batholith. Quartz is euhedral in many lithologic units; biotite and hornblende are generally anhedral and interstitial to feldspars and quartz.

The granitic rocks of the batholith tend to be rich in  $\text{SiO}_2$  and alkalis, particularly  $\text{K}_2\text{O}$ , and poor in  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ , and  $\text{MgO}$ . The batholith has alkaline affinities, although only peraluminous and metaluminous types have been recognized so far. Values of normative Q-Ab-Or for representative specimens plot close to a low pressure thermal trough and minimum for the experimental "granite" system, with a slight displacement towards normative Or.

Perthitic alkali feldspar is the predominant mineral in the batholith, accompanied by quartz and plagioclase, ranging in composition from An 3 to 40, with most values falling between An 10 to 25. Iron-rich biotite and hornblende are the predominant mafic minerals, although olivine, clinopyroxene, and orthopyroxene occur in monzonite and trachyandesite. Fluorite is the most widespread accessory mineral in the batholith, and a halogen-rich environment is reflected in high Cl and F contents of biotite and hornblende.

The Wolf River batholith may have crystallized from relatively dry granitic magmas that were derived by partial melting of pre-existing crustal materials, consisting of basaltic volcanics, volcanoclastic sediments, and quartz dioritic to granodioritic plutonic rocks.

## SUMMARY OF GLACIAL GEOLOGY OF NORTH-CENTRAL WISCONSIN

D. M. Mickelson, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706

### ABSTRACT

The Pleistocene glacial chronology of central and northern Wisconsin is not well established. Early workers (Owen, 1847; Chamberlain, 1882, Weidman, 1907) outlined the distribution of glacial deposits and recognized a presumed older drift outside the terminal moraines of Wisconsin age. Hole (1943) and Thwaites (1943) concluded that the older drift (Border Drift) was of one age and was deposited in the pre-Cary (pre-late Woodfordian) time. Radiocarbon dates (Black and Rubin, 1968) beneath the Border Drift in Wood County are  $> 45,000$  years B.P. In southern and western Wisconsin wood from an old till possible correlative with the Border Drift is dated at about 30,000 years B. P. and is considered Rockian (late Altonian) age. The Border Drift may actually consist of 2 tills of differing age. The lower till was deposited by ice moving from the west in Marathon County (LaBerge, 1972) and the upper till by ice moving from the northwest in southern Lincoln and Langlade Counties.

Three ice lobes built terminal moraines in Lincoln and Langlade Counties during late-Woodfordian time. The Wisconsin Valley Lobe advanced from the northwest depositing a reddish-brown, sandy basal till. To the east, the Langlade Lobe deposited a dark reddish-brown basal till as ice flowed from the northeast. Further east, the Green Bay Lobe, advancing from the east and southeast, deposited a brown, sandy, dolomitic till.

No absolute dates are available, but stratigraphic and geomorphic evidence suggests that the advance of these lobes to their terminal moraines was not contemporaneous as reported by Thwaites (1943). At the junction of the Wisconsin Valley Lobe and Langlade Lobe no stratigraphic sections showing 2 tills are available. Relationships of till fabric azimuths, moraine alignments and drainage features indicate an early advance of the Langlade Lobe and the formation of the Parrish Moraine. This was followed by an advance of the Wisconsin Valley Lobe and the formation of the Harrison Moraine which was followed shortly thereafter by a readvance of the Langlade Lobe to a position 6 miles short of its maximum advance and the formation of the Summit Lake Moraine. Stagnant ice of the Wisconsin Valley Lobe may have been present during this readvance.

To the east, the Green Bay Lobe advanced to its maximum position and retreated at least 20 miles before the maximum advance of the Langlade Lobe. Green Bay Lobe till is stratigraphically beneath that of the Langlade Lobe at least 5 miles in from the margin of the Langlade Lobe. Outwash streams from the Langlade Lobe ice cut outwash and till of the Green Bay Lobe.

## A LOWER PRECAMBRIAN LAMPROPHYRE PLUTON NEAR ELY, MINNESOTA

M. G. Mudrey, Jr.<sup>1</sup> and A. L. Geldon, University of Minnesota and Minnesota Geological Survey.

### ABSTRACT

One of the better exposed bodies of lamprophyre within the Early Precambrian Vermilion district of Minnesota is located 8 km northwest of Ely, on the north side of Burntside Lake. The crudely elliptical pluton, about 1 km by 0.5 km, is situated in the core of a fold outlined by Lower Precambrian migmatized biotite schist and amphibolite; however the pluton is virtually unmetamorphosed and is discordant to the structure.

The pluton has a narrow, discontinuous border zone of uralitized phlogopite-bearing pyroxenite and an inner zone of lamprophyre. These two rock types are considered comagmatic based on field relations, petrography, and chemistry. Both the pyroxenite and the lamprophyre are cut by numerous, thin dikes of monzonitic to adamellitic composition, which contain xenocrysts of the same mafic minerals that occur in the pyroxenite and lamprophyre. The dikes are probably comagmatic, but could represent a late pink leucocratic phase of the adjacent Vermilion granite.

The lamprophyre is a melanocratic porphyry. Approximately 2/3 of the exposed lamprophyre is a biotite-bearing hornblende spessartite; the remaining 1/3 is augite inokersantite. The spessartite is dominated by uralitized diopsidic augite with subordinate chloritized biotite, sericitized andesine, and interstitial potassium feldspar; the relatively unaltered inokersantite is dominated by diopsidic augite and biotite with subordinate andesine and interstitial potassium feldspar. A crude subhorizontal layering within both types of lamprophyre is marked by an upward increase in grain size of the groundmass and decrease in size of the phenocrysts; an increase in amount of potassium feldspar at the expense of total ferromagnesian minerals; and a change in the compositions of the ferromagnesian minerals--mainly an increase in the iron/magnesium ratios.

Calculated compositions for the rocks based on modal data and microprobe analyses of constituent phases indicate that this pluton may be related to an alkali basalt parent, an uncommon petrochemical type in Lower Precambrian terranes.

The pluton was emplaced in a semicrystalline state and cooled rapidly. Initially higher oxygen fugacity, as indicated by early crystallization of magnetite and apparently high ferric/ferrous ratios in biotite, decreased somewhat during crystallization. Disequilibrium textures indicate that crystallization began at depth and concluded at shallower, synvolcanic depths.

<sup>1</sup>Now at Dry Valley Drilling Project, Department of Geology, Northern Illinois University, DeKalb, Illinois 60115.

Mineralogical and Chemical Studies  
of Greenstones in Wisconsin

by

G. Mursky, G. Schriver and A. R. Venditti  
Department of Geological Sciences  
University of Wisconsin-Milwaukee  
Milwaukee, Wisconsin

ABSTRACT

Central, northern and northeastern parts of Wisconsin contain numerous belts of Precambrian volcanic-sedimentary sequences which are commonly referred to as greenstones. The units appear to be chiefly of middle Precambrian age and they have been included by Stockwell (1970) in the Southern Province or Penokean Fold Belt which forms the southern extension of the 2.5 to 2.7 b.y. old Superior Structural Province of the Canadian Shield. The volcanic rocks in Wisconsin have chemical characteristics similar to Archean volcanic assemblages of the Superior Province and these similarities are reflected by the following trends:

- (1) The alkali-lime index, as proposed by Peacock (1931), for Wisconsin's volcanic rocks has a range from 59 to 64 and thus parallels, very closely, the alkali-lime index of volcanic rocks from the Superior Province which show a range from 56 to 64 (Wilson and others, 1965).
- (2) Volcanic rocks from Wisconsin are potassium-poor and compare to Goodwin's (1968) trend of potassium-poor volcanic rocks in the Superior Province.
- (3) The Niggli silica and total alkali values for volcanic rocks from Wisconsin, when plotted in relation to Wilson's (1965) standard curve drawn for oceanic alkaline and orogenic calc-alkaline suites, plot on the orogenic calc-alkaline side of the standard curve nearly in the same region as the plots for the volcanic suites from the Superior Province.

The greenstones have been metamorphosed to greenschist facies or lower amphibolite facies. Reconnaissance and detailed work has not revealed any sulphide mineralization except for some disseminated pyrite.

### References

- Goodwin, A. M., 1968, Evolution of the Canadian Shield:  
Geol. Assoc. Can. Proc., v. 19, p. 1-14.
- Peacock, M. A., 1931, Classification of Igneous Rocks: Jour.  
Geology, v. 39, p. 54-67.
- Stockwell, C. H., 1970, Geology of the Canadian Shield  
(Introduction), Chapter IV in Geology and Economic  
Minerals of Canada, 5th Ed., Department of Energy,  
Mines, and Resources, Ottawa, Canada, p. 44-54.
- Wilson, H. D. B., Andrews, Peter; Moxham, R. L., and Ramlal,  
K., 1965, Archean Volcanism in the Canadian Shield:  
Can. Jour. Earth Sci., v. 2, no. 3, p. 161-175.

THE IRON ORE DEPOSITS AT BLACK RIVER  
FALLS, WISCONSIN, GEOLOGY AND OPERATIONS

John M. Ohlson, Inland Steel Company, Ishpeming, Michigan 49849

ABSTRACT

The presence of iron bearing rocks in the Black River Falls area of west-central Wisconsin has been known since 1839. Attempts to utilize this resource before the turn of the century were unsuccessful. Inland's facility, which opened in 1969, utilizes standard grinding and magnetic separation techniques.

The rocks of the area are a sequence of steeply dipping highly metamorphosed sediments including a thin-banded magnetite-quartz iron formation. The sediments lie on a granite gneiss basement and are intruded by both acid and basic dikes. The entire Precambrian sequence is overlain by flat lying Cambrian sandstones. Water is obtained from wells in a concealed Pleistocene valley which was discovered by geophysical methods.

Plant water circulates in a closed system. Experimental tree and grass planting with the help of the Wisconsin Department of Natural Resources, the University of Wisconsin Extension Service, and the Soil Conservation Service was started on the waste disposal piles within a year and a half of plant startup. The plant and waste disposal areas were designed from the outset to have a minimum environmental effect.

## STRUCTURAL EVOLUTION OF THE DEER LAKE ULTRAMAFIC COMPLEX, MINNESOTA

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

### ABSTRACT

The Deer Lake Ultramafic Complex is located 6.5 kilometers southeast of Effie, Minnesota. The magnetic anomaly associated with this Archean Complex is 13 kilometers long and 3 kilometers wide and trends S. 45W. from the south tip of Deer Lake to just northeast of the town of Big Fork.

The stratigraphic succession within this Complex consists of two stratiform differentiated gabbroic sills, one nonstratiform gabbroic sill and two locally discordant ultramafic lenses. The stratiform sills (700-1,100 m. thick) are composed of: basal peridotite (160-330 m.), orthopyroxene clinopyroxenite (less than 160 m.), gabbro 450-650 m.) plus or minus medium- to fine-grained differentiated felsic cap rock. Zones of plumose texture have been observed along contacts between all mafic units. These zones are interpreted as spinifex-like chill contacts rather than sequential contact metamorphic effects.

Deformation of the Complex commenced with a period of folding which produced two anticlines with an intervening syncline. The axial plane trends of these upright, nonplunging, isoclinal folds is N. 45 E. with a wavelength of 1200 meters and an amplitude of 400 meters. Folding was produced in response to the emplacement of the Zeisser's Island Pluton located just southeast of the central portion of the Complex. Local bending of the Complex to an east-west trend around the north end of the Pluton also occurred at this time. Conjugate shear fractures trending N. 20 W. and N. 80 W. developed in response to the same NW-SE stress system which produced folding.

The second stage of deformation resulted from extensional release with the development of normal faults and joints. The faults trend N. 45 W. and have minimum dip separations on the order of 400 meters. Faulting produced 800 meter-wide graben and horst structures. Longitudinal (N. 45 E.) and traverse (N. 45 W.) release joints are believed to have developed under the same stress orientation as the normal faults.

Strike slip faulting along a N. 45 E. trend characterizes the final stage of deformation. Right-lateral strike separation displacement offset normal faults about 300 meters. Renewed movement along this fault presumably produced an additional 100 meters strike separation displacement of middle Precambrian diabase dikes.

THE PETROLOGY AND CHEMISTRY OF THE ROUND LAKE INTRUSION,  
NORTHWESTERN WISCONSIN

D. L. Roder and E. N. Cameron  
Department of Geology and Geophysics  
University of Wisconsin, Madison, Wisconsin 53706

ABSTRACT

The Round Lake intrusion is a northeast-trending Precambrian mafic layered intrusion found by subsurface drilling of an area ten miles east of Hayward, Wisconsin. The body may be as much as eight miles long and two miles wide. Portions drilled consist of magnetite-troctolite with anorthositic gabbro layers that range from three-fourths inch to more than eighty feet in thickness. Diabase intersected by the drill holes appears to form later intrusions.

Mineral assemblages in the magnetite-troctolite and anorthositic-gabbro are the same, the two rock types differing only in mineral proportions. Plagioclase, olivine, titanomagnetite, ilmenite, and apatite are cumulus minerals. Clinopyroxene, biotite, and plagioclase are intercumulus minerals. The magnetite-troctolite averages 28 volume per cent plagioclase, 36 per cent olivine, 33 per cent iron-titanium oxides, 3 per cent augite and biotite, and a trace of apatite. The anorthositic-gabbro averages 66 per cent plagioclase, 22 per cent olivine, 8 per cent iron-titanium oxides, 4 per cent augite, and less than one-half per cent apatite.

Titanomagnetite in these rocks is an irregular microintergrowth of magnetite and ulvöspinel. Ilmenite occurs as primary granular aggregates, as (111) lamellae in titanomagnetite, and as granular aggregates around titanomagnetite grains. Hercynite is found as tiny "dots" in titanomagnetite. Magnetite appears to have settled as euhedral crystals. Anhedral aggregates are thought to be due to enlargement or partial recrystallization of touching crystals after settling.

Only small-scale cryptic layering is displayed by the intrusion. Plagioclase ranges from  $An_{51}$  to  $An_{45}$ , but no consistent chemical trend is evident. In core from drill hole X-3, anorthositic-gabbro and magnetite-troctolite are interlayered; olivine in anorthositic-gabbro ranges from  $Fo_{53}$  to  $Fo_{56}$ , whereas olivine in magnetite-troctolite ranges from  $Fo_{57}$  to  $Fo_{62}$ . In core from drill hole X-2, anorthositic-gabbro layers are poorly developed. In this core, olivine ranges from  $Fo_{57}$  to  $Fo_{51}$ . Augite has an average composition of  $Ca_{45}Mg_{37}Fe_{18}$ . Microprobe analysis of titanomagnetite gives the following range of composition: total iron as FeO 65 to 74 weight per cent,  $TiO_2$  20 to 24 per cent, MgO 0.5 to 3.8 per cent,  $Al_2O_3$  2.3 to 3.9 per cent,  $V_2O_3$  1.0 to 1.3 per cent, and  $Cr_2O_3$  0.1 to 1.2 per cent. Primary ilmenite has an average composition of  $Ilm_{98}Hem_2$  and contains up to 5 weight per cent MgO.

Information at hand indicates the presence of sizeable concentrations of iron-titanium oxides, but further exploration will be necessary to determine their form, extent, and relations to the Round Lake intrusion as a whole.

UPPER MISSISSIPPI VALLEY BASE METAL DEPOSITS: EXPERIMENTAL  
SOLUTIONS TO PROBLEMS OF ORE GENESIS

S. B. Romberger, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706

ABSTRACT

Chemical models for the transport and deposition of base metals in Mississippi Valley Type Deposits are studied experimentally using a mineral synthesis approach. The object is to supply evidence to support the hypothesis that these ores have been deposited from metal-containing, sulfur-deficient, chloride-rich solutions entering a sulfur-containing reducing environment. Copper, iron, lead, and zinc sulfides were synthesized together in 3 molal sodium chloride solutions between 20° and 200°C under the vapor pressure of water. Copper, iron, lead, zinc, barium, and calcium were introduced as solid carbonates or soluble chlorides along with elemental sulfur. The amount of sulfur added was in excess of that necessary to react with all metal. The products depended on the starting composition of the experiments, but were generally covellite, pyrite, sphalerite, galena, digenite, barite, anhydrite, and a second generation calcite. Morphology of some of the composite metallic sulfide grains suggest initial reaction occurred above the melting temperature of sulfur. Nonequilibrium is indicated by the presence of unreacted sulfur in the cores of grains together with high metal concentrations in the co-existing solutions. No metal carbonates remained in the run products.

The sulfides showed a regular zonation in relation to the unreacted sulfur and calcite. Summarizing the zoning in terms of paragenesis, covellite is early, followed by galena and sphalerite. Pyrite forms before galena and sphalerite but its relationship to covellite is unclear. Barite and anhydrite form independently of the sulfide zoning, however the second generation calcite is the last phase to form. The factors which appear to cause precipitation, in order of importance, are: increasing sulfur activity, increasing pH of solution, and decreasing temperature.

To aid in determining the chemical conditions underwhich sulfide precipitation took place, the aqueous solutions were analyzed for copper, zinc, lead, iron, barium, and calcium. The concentration of the metals and barium decreased with decreasing temperature and increasing time; that of calcium either increased or decreased, depending on the starting conditions. The following is a typical variation of the molar ratio Cu:Fe:Pb:Zn in solution after a starting ratio of 1.0:1.0:1.0:1.0: at 200°C, 1.0:0.14:140:360; at 120°C, 1.0:1.0:830:2280; and at 25°C, 1.0:0.15:3.3:150. The copper concentration typically dropped from a few 1000 ppm in the starting solution to less than 5 ppm at 200°C, to less than 1 ppm at 25°C. These variations are consistent with the paragenesis observed in the minerals. Because equilibrium was not established the major significance of these data is to demonstrate relative tendencies for metal sulfides to precipitate under the conditions of the experiment.

PETROLOGY OF SOME EARLY PRECAMBRIAN  
DIFFERENTIATED ULTRAMAFIC BODIES  
IN NORTHEASTERN MINNESOTA

Klaus J. Schulz and Edward M. Ripley, University of Minnesota, Duluth,  
Duluth, Minnesota 55812.

ABSTRACT

Mapping in the Newton Lake Formation north of Ely, Minnesota and the Deer Lake Area in northern Itasca County, Minnesota has located a number of mafic-ultramafic bodies of Early Precambrian age, many of which are differentiated. Detailed mapping of these bodies has shown that they are conformable to the surrounding country rocks, indicating that they are either sills or flows. Country rocks in both areas consist of metasedimentary and largely pillowed metavolcanic rocks. No evidence for contact metamorphism has been observed between the bodies and the country rocks.

The bodies range from 400 to 1,000 feet in thickness and have lateral extents from a mile to several miles. The rocks of the Deer Lake Area have been faulted and tightly folded while those north of Ely are faulted and only broadly folded. Serpentinization and other alteration is extensive in all the bodies with metamorphism generally of the green-schist facies.

In both areas, bodies composed solely of gabbro or peridotite exist, however most appear to be differentiated. The typical sequence in the differentiated ones, from bottom to top, is peridotite, pyroxenite, porphyritic gabbro, gabbro. The peridotite is composed of rounded to euhedral olivine and rare chromite surrounded by poikilitic pyroxene and amphibole. At least some of the peridotites contain both orthopyroxene and clinopyroxene and would be classified as Iherzolite. The pyroxenite is in sharp contact with the peridotite and contains subhedral diopsidic augite and in some cases also contains bronzite. Plagioclase, in varying amounts, forms the intercumulate phase. With increasing plagioclase content the pyroxenite grades into porphyritic gabbro composed of augite, plagioclase and pyroxene phenocrysts, which are now completely altered. The gabbro contains plagioclase, augite, and secondary actinolite with varying amounts of interstitial quartz and micrographic intergrowths. Cumulate textures in the peridotite, pyroxenite, and porphyritic gabbro along with minor layering and size grading indicate that selective crystallization and gravity settling of phases were the main mechanisms of differentiation. Many of the bodies examined were also found to have complex chilled margins.

A detailed study of sulfide mineralization in the bodies of the Deer Lake Area shows that nickel, copper, and iron sulfides are concentrated in the chilled margins, making up 2 to 3% of the rock. The

basic sulfides appear to have formed from an immiscible sulfide-oxide liquid, which at the time of intrusion, coexisted with the silicate magma. A general layering of sulfide phases was also found to exist through the bodies with nickel sulfides concentrated in the peridotite, copper sulfides in the pyroxenite and porphritic gabbro and iron sulfides in the upper gabbros. These sulfides appear to have been in solution in the silicate magma, precipitating as late phases with the intercumulus minerals.

Chemical analyses of samples from the bodies north of Ely show a general iron enrichment with differentiation. The bodies appear to be tholeiitic in nature and very similar to differentiated ultramafic bodies of Early Precambrian age in Canada, Africa, and Australia.

# TECTONIC HISTORY OF EARLY PRECAMBRIAN ROCKS IN THE VERMILION DISTRICT, NORTHEASTERN MINNESOTA

P. K. Sims, Minnesota Geological Survey, St. Paul, Minnesota 55108

## ABSTRACT

The Vermilion district, in northeastern Minnesota, contains a sequence of complexly intertonguing volcanic and volcanoclastic rocks that is bordered on the north by the Vermilion granite-migmatite massif and on the south by the Giants Range batholith. The supracrustal rocks dominantly have greenschist-facies assemblages; adjacent to the intrusive granitic rocks (ca. 2700 m.y. old) they have amphibolite-facies assemblages.

The supracrustal rocks trend generally eastward, are steeply inclined, and have been complexly folded and faulted. Two generations of folds have been distinguished in the western part of the district. The older generation is represented by tight to close folds that trend northwestward and have planar, steeply inclined axial surfaces and gently-plunging axes. The younger generation folds are superposed on the older folds in the extreme western part of the district. These folds trend eastward and have planar upright axial surfaces and steep plunges; they are accompanied by a pervasive steep cleavage and associated lineations that obscure most structures related to the older deformation. Judged from the divergent trends of structures and the generally steep plunges of lineations, the rocks in the eastern part of the district also were folded during two or more periods of deformation.

Three steep fault systems, each of which has associated mylonite, post-date the folding. The oldest (?) faults have a dominant vertical component of movement. The major fault in this system occurs at the approximate boundary between the low-grade supracrustal rocks and the Vermilion granite-migmatite massif; another fault separates the eastern part of the Giants Range batholith and associated amphibolite-facies rocks from the supracrustal rocks. These faults probably have vertical movements of 3,000 to 5,000 feet, and appear to have developed largely in response to isostatic adjustments between crustal blocks having different rock densities.

The next younger (?) system is represented mainly by straight, steep, north-north-east trending faults that cut both the granitic rocks and the volcanic rocks and have left-lateral displacements of as much as 4 miles. These faults locally are abundant and closely spaced. Some of them appear to displace supracrustal rocks more than the intrusive rocks, suggesting that they pre-date emplacement of at least some of the granitic rocks.

The youngest faults are transcurrent faults having horizontal right lateral displacements. The major fault in this system is at least 250 miles long and transects several greenstone-granite complexes. In northwestern Minnesota it appears to have displaced distinctive gravity anomalies a distance of about 35 miles; in the Vermilion district, where it consists of several strands, it has displaced the upper part of the volcanic pile a distance of about 12 miles, distorting it from a thick almond-shaped lens to a tenuous east-trending mass.

Metamorphism, folding, and emplacement of the granitic rocks were broadly

synchronous, and occurred during the Algoman orogeny. The folding of the supracrustal rocks is attributed to compression resulting from the relative upwelling and convergence of the flanking batholiths, a mechanism demonstrated experimentally by Ramberg (1967). The Vermilion massif and at least a part of the Giants Range batholith continued to rise because of their buoyancy after crystallization of the granitic rocks. The transcurrent faulting took place during a late stage of the orogeny, after the crust had attained sufficient strength to transmit regional compressive stresses. Cataclasis related to the fracturing can account for the disparity between whole-rock and mineral ages in the Giants Range batholith (Prince and Hansen, 1972).

A KEWEENAWAN LAYERED MAFIC INTRUSION  
NEAR FINLAND, LAKE COUNTY, MINNESOTA

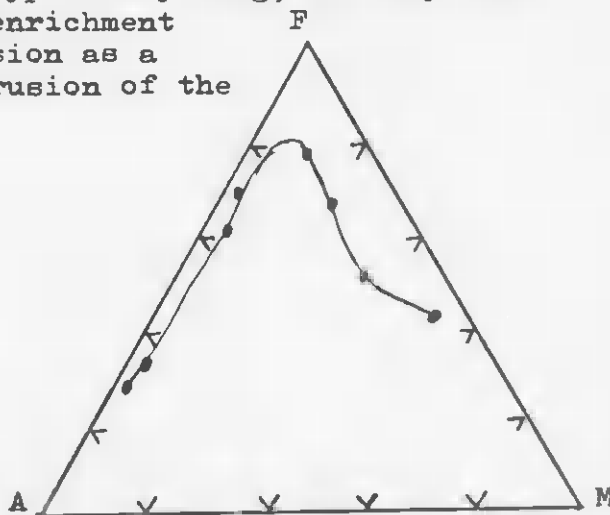
R.J. Stevenson, Department of Geology, University of  
Minnesota-Duluth, Duluth, Minnesota 55812

ABSTRACT

The Sonju Lake Intrusion, four and one half miles NNE of Finland, Minnesota, has an exposed area of one and one half by two and one half miles. The intrusion is surrounded on three sides by diabase and granophyric granite of the Beaver Bay Complex, and the western side is obscured by glacial drift. It shows igneous lamination, cryptic layering, and rhythmic layering, and has a stratigraphic thickness of approximately 3500 feet based on the strike and dip of the igneous lamination. The rock units comprising the intrusion are, from the base to the top respectively: basal picrite; a troctolite; a gabbro; an apatite-rich ferrogabbro; an olivine-hedenbergite quartz-bearing diorite; a hedenbergite granodiorite; and a hedenbergite adamellite. The ferrogabbro contains 19.26% FeO and 43.50% SiO<sub>2</sub>.

The compositions of the major minerals vary with stratigraphic height; they have been studied by electron microprobe and optical methods. The plagioclase varies from An<sub>83</sub> in the basal picrite to An<sub>16</sub> in the hedenbergite adamellite. The olivine varies from Fo<sub>71</sub> in the basal picrite to Fo<sub>12</sub> in the uppermost apatite-rich ferrogabbro. The cumulus clinopyroxene ranges from Ca<sub>43</sub>Mg<sub>46</sub>Fe<sub>11</sub> in the lowest gabbro to Ca<sub>40</sub>Mg<sub>25</sub>Fe<sub>35</sub> in the uppermost apatite-rich ferrogabbro. The intermediate and felsic rocks have hedenbergites clustered around Ca<sub>49</sub>Mg<sub>03</sub>Fe<sub>48</sub>.

The igneous lamination, cryptic layering, and rhythmic layering and the extreme iron-enrichment trend all establish this intrusion as a differentiated, tholeiitic intrusion of the Skaergaard type.



## THE FORMATION OF THE PITTSVILLE (WISCONSIN) MIGMATITE

J. E. Thresher, Department of Geography and Geology, University of Wisconsin-Extension, Madison, Wisconsin 53706.

### ABSTRACT

The Pittsville migmatite was formed during the Precambrian by the intrusion of a hydrous granitic magma into a series of diabases and basalts. Due to the hydrous nature of the granite, spacially extensive transport of magma into the country rock took place which has been recorded by poikiloblasts of quartz and potash feldspar within the older rocks, and the presence of original hydrous minerals within the granite.

The observed lithologic layering in the migmatite has formed axial planar to a series of subisoclinal northwest plunging folds. Contemporaneous (or nearly so) with this folding was the development of almandine-amphibolite facies minerals within the migmatite. Later more open east-west trending subhorizontal folds were imprinted on this fabric, and this was followed by a greenschist facies metamorphic event, apparently unrelated to the folding.

Two episodes of jointing were recorded within the rocks, the first of which effected only those of Precambrian age. The later episode also fractured the overlying upper Cambrian sandstones and is thus at least lower Paleozoic in age. Many of these joints are filled with quartz, granite and/or chlorite.

The migmatites were later intruded by a granitic pluton which is considered to be related to the greenschist facies met and possibly the filling of the joints. Several younger granitic and basaltic dikes crosscut the crystalline rocks locally.

The entire sequence is unconformably overlain by upper Cambrian sandstones and conglomerates which are especially prevalent in the southern part of the Pittsville area.

## STRUCTURAL AND STRATIGRAPHICAL ANALYSIS OF THE GECO SULPHIDE DEPOSIT IN MANITOUWADGE, NORTHWESTERN ONTARIO

Jens F. Touborg, Department of Geology, University of Ottawa and  
Department of Geology, University of Toronto, Ontario, Canada.

### ABSTRACT

In the Manitouwadge area high grade metamorphosed rocks consisting of metavolcanic-and metasedimentary series lie downfolded in a northeast plunging syncline, the core of which is occupied by a granodiorite body. Regional sulphide mineralization of stratabound nature occurs within a quartz-muscovite schist horizon along the contact of metasedimentary-and overlying metavolcanic series in the upper part of the sequence.

The Geco Copper-Zinc-Silver sulphide deposit being located within a synclinal dragfold on the northeast limb of the syncline consists of a tabular body of massive sulphides enveloped by a haloe of disseminated pyrite-pyrrhotite-chalcopryrite mineralization. A discontinuous zone of disseminated chalcopryrite-pyrrhotite-sphalerite-gahnite mineralization occurs along the north contact of the quartz-muscovite schist horizon. The south contact of this contains disseminated sphalerite mineralization in a discontinuous zone followed by magnetite-chert iron formation.

The massive sulphide body which strikes east-west and dips steeply to the north is composed of a string of 5-6 elongated lenses becoming successively smaller towards the east. The plunge of these parallels the axis of the dragfold. In detail the massive sulphide body consists of 3 principal rock types: 1) compact ore: coarse grained pyrite rich sphalerite ore. 2) layered ore: coarse grained pyrrhotite-chalcopryrite-sphalerite-pyrite-Mg silicate rich ore. 3) schistose ore: fine grained kneaded ("durchbewegte") ore of similar composition to the layered type. These 3 types define a mineralogical-textural-compositional zoning pattern within the lenses; the compact type is confined to the central and thickest part of the lenses, the layered ore is arranged along the north contact and increases in amount with decreasing width of the lens; the schistose ore dominates in the pinch-out areas. Within the compact ore sphalerite rich zones are developed towards the south contact.

Textures indicate a metamorphic recrystallization of sulphides and silicates. Annealing fabrics exist in monomineralic aggregates; pyrite porphyroblasts reveal a composite aggregate structure and are composed of 2 varieties of pyrite; microfold structures are characteristic of the layered-and schistose massive types as well as the disseminated types.

Dyke chronology: 3 sets of synkinematic dyke intrusions emplaced as follows, 1) quartz diorites, 2) amphibolites and, 3) granodiorite and granite pegmatites show discordant relationships to the layered rocks including all the disseminated mineralized zones. None of these dyke generations transect the massive ore-quartz-muscovite schist contact. Dykes of

1) and 2) generations occur as highly folded boudinaged fragments within the massive sulphide ore types. Significant metamorphic reaction zones are present in-and around the fragments and appear as follows: magnetite-sulphide impregnated zones in the silicate rock and sphalerite rich rims up to 5" wide around the boudinaged fragments. Within the sulphide rims, Zinc rich sphalerite zones are concentrated near the silicate contact, Iron rich sphalerite zones away from this.

In conclusion the sulphide mineralization is regarded as a metamorphosed bedded sulphide deposit. The lithological zoning in the boudin-shaped massive sulphide ore represents a primary stratigraphical configuration, although accentuated during the deformation. Stratigraphical tops have not been determined in the Manitouwadge area. However the distribution of relatively copper rich zones to the north, zinc rich zones to the south followed by magnetite-chert iron formation defines a broad pattern comparable to the vertical zoning in other synvolcanic sulphide deposits. It is proposed that the Manitouwadge syncline represents the refolded limbs of an overturned nappe structure with an east-west axis.

## THE ATIKOKAN IRON RANGE AND ITS IRON-COPPER MINERALIZATION

Jens. F. Touborg, Suite 1006, 77 Howard St., Toronto M4X 1J9, Ontario Canada.

### ABSTRACT

The Atikokan Iron Range in northwestern Ontario contains widespread magnetite-basemetal sulphide mineralization which is spatially associated with lensoid bodies of ultrabasic-basic igneous rocks composed of pyroxenites, gabbros, amphibolites and peridotites.

The lenses, having a strong geophysical response, are concordantly enclosed in metavolcanic rocks of basaltic-andesitic composition and define a 16 mile long zone of stratigraphical continuity. It strikes uniformly east-northeast and dips steeply to the north. The zone lies a few hundreds of feet north of the Quetico Shear structure, which in this area separates Archean metavolcanic series to the north from Seine metasedimentary series to the south. The impact of metamorphism in the area is low.

Concentrations of Iron-Copper mineralization occur in tabular deposits up to 3000 feet long and 50-250 wide. Examples are: The Atikokan Mines-, Sapawe Lake-, Archibald-, Pattison-Roberts and Mark prospects. In detail the mineralization consists of lenses dominated by 1) massive-or disseminated magnetite with minor sulphide veinlets and 2) massive-or disseminated pyrrhotite, lesser amounts of pyrite-chalcopyrite (.3-.6% Copper) and trace amounts of Nickel-Cobalt bearing sulphides. The mineralized lenses are characterized by a banded structure with concordant intercalations of the ultrabasic-basic host rock. Within pinch-out zones the mineralization and the host rocks become heavily interbanded with the surrounding volcanic rocks. Geometrically the magnetite-and sulphide lenses are arranged in a complex en-echelon structure, sometimes with the sulphide rich zones confined to the footwall side; this feature may be a possible indicator of stratigraphical tops. Preliminary microscopic work reveals the presence of primary magmatic textures in both the oxide-and sulphide phases.

Origin of mineralization: Available data suggest 1) the mineralization forms an integrating part of the ultrabasic-basic host rocks. 2) there is no evidence to indicate a possible relationship to the bedded iron formations contained within the Steep Rock-and Caland deposits nearby. 3) Wall rock alteration is lacking apart from minor quartz-carbonate veining of the host rock. 4) There is no direct relation between the mineralized ultrabasic-basic series and the Quetico shear structure. A synvolcanic intrusive/extrusive origin is proposed for the stratabound ultrabasic-basic series and its associated mineralization.

## GEOCHRONOLOGY OF PRECAMBRIAN ROCKS IN EASTERN WISCONSIN

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

Recent geochronological studies by the author, in conjunction with other published and unpublished data, now permit the delineation of major chronologic units for Precambrian rocks in eastern Wisconsin.

The oldest rocks in the eastern part of the state are the metavolcanics, gneisses, and intrusive rocks in the northeastern corner, including the Quinnesec Fm., Dunbar Gneiss, Hoskin Lake Granite, Newingham Granodiorite, and Athelstane Quartz Monzonite. These rocks are about 1850 to 1900 m.y. old based on Rb-Sr whole-rock data and published U-Pb zircon data.

Apparently the bulk of the state is made up of meta-volcanics and granitic rocks that yield ages of 1650 to 1700 m.y. The author has analysed such rocks in Waushara Co. (granites) and to the south (rhyolites), and other workers have reported similar ages from near Monico, Wausau, and Baraboo.

Intrusive into the 1650-1700 m.y. old complex is a large plutonic assemblage that is about 1450 to 1500 m.y. old and is now referred to as the Wolf River Batholith. It includes a wide variety of rocks from Mountain, to Wausau, to Steven's Point, to Waupaca and apparently is the last major plutonic or metamorphic event in the state, except for the Keweenawan rocks in the far northwest.

Not yet absolutely dated are gneissic and related rocks in the Steven's Point-Wisconsin Rapids area. Published mineral ages from these rocks suggest they may be related to the northeastern Wisconsin complex, or older. Resolution of this problem, plus extending our knowledge westward and northwestward, is currently in progress.

## "FRAMBOIDAL" CHALCOCITE FROM WHITE PINE, MICHIGAN

Thomas A. Vogel and Nancy Alyanak, Geology Department,  
Michigan State University, East Lansing, Michigan 48823

### ABSTRACT

Chalcocite with nuclei occurs throughout the mineralized zone at White Pine, Michigan. They are more abundant in the well-laminated, black, fine-grained lithologies than in the massive lithologies. In polished section these nuclei are either circular, ellipsoidal or conform to the shape of the grain, with a median circular diameter of four microns and a median ellipsoidal long axis of eight microns. Microcrysts at least as small as 0.2 microns are found in each nucleus. The nuclei are similar to the framboidal texture commonly observed in pyrite associated with sediments. The chalcocite nuclei can only be observed after the polished section has been etched and stained with a weak hydrochloric acid and potassium ferrocyanide solution--a stain very sensitive to low concentrations of iron.

The scanning electron microscope shows that the microcrysts within a well-defined circular or ellipsoidal nucleus are densely packed, with a few scattered microcrysts in the surrounding grain. However, the microcrysts are less densely packed where the nucleus occupies the entire grain. All gradations between dispersed and densely packed microcrysts are found. Preliminary microprobe data indicates that the nuclei are higher in iron, potassium and carbon than the surrounding grain.

Two origins are possible for the framboidal chalcocite: 1.) replacement of framboidal pyrite and 2.) formation of primary framboidal chalcocite. We are currently evaluating these alternative genetic models and their implications.

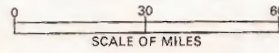
# LANDFORMS OF WISCONSIN

Geological and Natural History Survey

George F. Hanson, Director and State Geologist

UNIVERSITY EXTENSION, UNIVERSITY OF WISCONSIN

1971



Relief by David A. Woodward

Copyright © 1971 Regents, University of Wisconsin

# GEOLOGIC MAP OF WISCONSIN

Geological and Natural History Survey

George F. Hanson, Director and State Geologist

UNIVERSITY EXTENSION, UNIVERSITY OF WISCONSIN

1971

0 30 60  
SCALE OF MILES

## LEGEND

- |                   |  |                                                                          |
|-------------------|--|--------------------------------------------------------------------------|
| SILURIAN DEVONIAN |  | Devonian Formations (dolomite and shale)                                 |
|                   |  | Silurian Formations (dolomite)                                           |
|                   |  | Maquoketa Formations (shale and dolomite)                                |
| ORDOVICIAN        |  | Sinnipee Group (dolomite with some limestone and shale)                  |
|                   |  | Ancell Group (mainly St. Peter Fm.) (sandstone, shale and conglomerate)  |
|                   |  | Prairie du Chien Group (dolomite)                                        |
| CAMBRIAN          |  | Upper Cambrian Formations (sandstones with some dolomite and shale)      |
|                   |  | Upper Keweenaw Formations (sandstones with some shale and conglomerate)  |
| PRECAMBRIAN       |  | Quartzite, Slate and Iron Formations                                     |
|                   |  | Gabbro and Basalt                                                        |
|                   |  | Granite and Undifferentiated Igneous and Metamorphic Rocks               |
|                   |  | Granite and Undifferentiated Igneous and Metamorphic Rocks (sparse data) |
|                   |  | Border of Wisconsin (Cary) Drift                                         |
|                   |  | Border of Older Drift                                                    |

0 10 20 30 40  
HORIZONTAL SCALE IN MILES



## SHORT GEOLOGIC HISTORY OF WISCONSIN

The bedrock of Wisconsin is separated into two major divisions: (1) older, predominantly crystalline rocks of the Precambrian Era; and (2) younger relatively flat-lying sedimentary rocks of the Paleozoic Era.

The Precambrian Era lasted from the time the earth cooled, over 4,000 million years ago, until the Paleozoic Era which began about 600 million years ago. During this vast period of 3,400 million years sediments, some of which were rich in iron and which now form iron ores, were deposited in ancient oceans; volcanoes spewed forth ash and lava; mountains were built and destroyed, and the rocks of the upper crust were intruded by molten rocks of deep-seated origin. Only a fragmentary record of these events remains but, as tree stumps attest to the presence of former forests, the rocky roots tell the geologist of the presence of former mountains. Nowhere does any trace of the original crust remain, and the oldest rocks yet found in the state are about 2,000 million years old. With the exception of the Upper Keweenaw formations that outcrop in the northwest, all of these rocks have been extensively deformed, and in many areas they are so highly altered that their original nature and origin are extremely difficult to interpret.

In the north-central part of the state surface outcrops are so sparse, due to a cover of glacial deposits, that details of the bedrock are obscured. In such areas the only clues to the underlying rocks are obtained indirectly by such geophysical methods as airborne magnetics. In the past much high-grade iron ore was produced from the Precambrian rocks of northern Wisconsin, and much low-grade ore ("taconite") awaits development. Recent geologic work indicates that the area has a high potential for finding ores of other metals such as copper.

At the close of the Precambrian Era most of Wisconsin had been eroded to a rather flat plain upon which stood hills of more resistant rocks as those now exposed in the Baraboo bluffs. There were still outpourings of basaltic lava in the north and a trough formed in the vicinity of Lake Superior in which great thicknesses of sandstone were deposited.

The Paleozoic Era began with the Cambrian Period, the rocks of which indicate that Wisconsin was twice submerged beneath the sea. Rivers draining the land carried sediments which were deposited in the sea to form sandstone and shale. Animals and plants living in the sea deposited calcium carbonate and built reefs to form rocks which are now dolomite—a magnesium-rich limestone. These same processes continued into the Ordovician Period during which, as indicated by the rocks, Wisconsin was submerged three more times. Deposits built up in the sea when the land was submerged were partially or completely eroded at times when they were subsequently elevated above sea level. During the close of the Ordovician Period, and in the succeeding Silurian and Devonian Periods, Wisconsin is believed to have remained submerged.

The youngest rocks outcropping in Wisconsin are of Devonian age and are about 350 million years old. Absence of younger rocks makes interpretations of post-Devonian history in Wisconsin a matter of conjecture. If the dinosaurs roamed Wisconsin, as well they might have some 200 million years ago, no trace of their presence remains. Available evidence from neighboring areas, where younger rocks are present, indicates that towards the close of the Paleozoic Era, perhaps some 250 million years ago, a period of gentle uplift began which has continued to the present. During this time the land surface was carved by rain, wind and running water.

The final scene took place during the last million years when glaciers invaded Wisconsin from the north and sculptured the land surface. They smoothed the hill tops, filled the valleys and left a deposit of debris over all except the southwest quarter of the State where we may now still see the land as it might have looked a million years ago.

**WISCONSIN GLACIAL DEPOSITS**  
after Thwaites, 1956

0 40 80  
SCALE OF MILES

**LEGEND**

- End Moraines
- Ground Moraine
- Outwash, unpitted
- Outwash, pitted
- Lake Basins
- Drumlin Trends

0 40 80

SCALE OF MILES

|                                                                                     |                   |
|-------------------------------------------------------------------------------------|-------------------|
|  | End Moraines      |
|  | Ground Moraine    |
|  | Outwash, unpitted |
|  | Outwash, pitted   |
|  | Lake Bosins       |
|  | Drumlin Trends    |

Wisconsin Geological and Natural History Survey

**George F. Hanson, Director and State Geologist**

## SHORT HISTORY OF THE ICE AGE IN WISCONSIN

The Pleistocene Epoch or "Ice Age" began about 1,000,000 years ago which, in terms of geologic time, is a very short time ago. There were four separate glacial advances in the Pleistocene each followed by an inter-glacial period when the ice receded. The fourth glacial stage is called the Wisconsin Stage because it was in this State that it was first studied in detail.

The glaciers were formed by the continuous accumulation of snow. The snow turned into ice which reached a maximum thickness of almost two miles. The ice sheet spread over Canada and part of it flowed in a general southerly direction toward Wisconsin and neighboring states.

The front of the advancing ice sheet had many tongues or "lobes" whose direction and rate of movement were controlled by the topography of the land surface over which they flowed and by the rates of ice accumulation in the different areas from which they were fed.

The ice sheet transported a great amount of rock debris called "drift". Some of this was deposited under the ice to form "ground moraine" and some was piled up at the margins of the ice lobes to form "end moraines". "Drumlins" are elongated mounds of drift which were molded by the ice passing over them and hence indicate the direction of ice movement.

The pattern of end moraines, in red, shows the position that was occupied by four major ice lobes. One lobe advanced down the basin of Lake Michigan, another down Green Bay, a third down Lake Superior and over the northern peninsula of Michigan and yet a fourth entered the state from the northwest corner. The well-known "Kettle Moraine" was formed between the Lake Michigan and Green Bay lobes. As the ice melted the drift was reworked by the running water. Large amounts of sand and gravel were deposited to form "outwash plains"; pits were formed in the outwash where buried blocks of ice melted and many of these are now occupied by lakes.

The action of the ice profoundly modified the landscape, smoothing off the crests of hills and filling the valleys with drift. In some places it changed the course of rivers forcing them to cut new channels such as that of the Wisconsin River at the Dells; elsewhere it dammed the valleys to create lakes such as those of the Madison area.

During recent years there have been intensive studies made of the polar ice caps, and methods have been developed for dating glacial events from the radioactivity of the carbon in wood, bones, etc. which are found in many of the deposits. The results of these studies are causing many previously accepted concepts to be changed or challenged.

We once thought that there were rather extensive glacial deposits older than Wisconsin age in the State, but age determinations do not support this. It was also thought that the ice left Wisconsin some 20,000 years ago but a forest at Two Creeks in Manitowoc County was buried under an advancing ice tongue only 11,000 years ago. Evidence is accumulating to indicate that ice may have occupied the so-called "Driftless Area" of the southwestern part of the State which hitherto has been held to be unglaciated.

Most scientists now believe that the cause of the Pleistocene "Ice Age" was due to variations in the solar energy reaching the earth, but how these may have occurred is still a matter of conjecture. We are still in the Ice Age and it is anybody's guess whether future millenia will see the melting of the ice caps and the slow drowning of our coastal cities, or the regrowth and once more the inexorable advance of the glaciers.

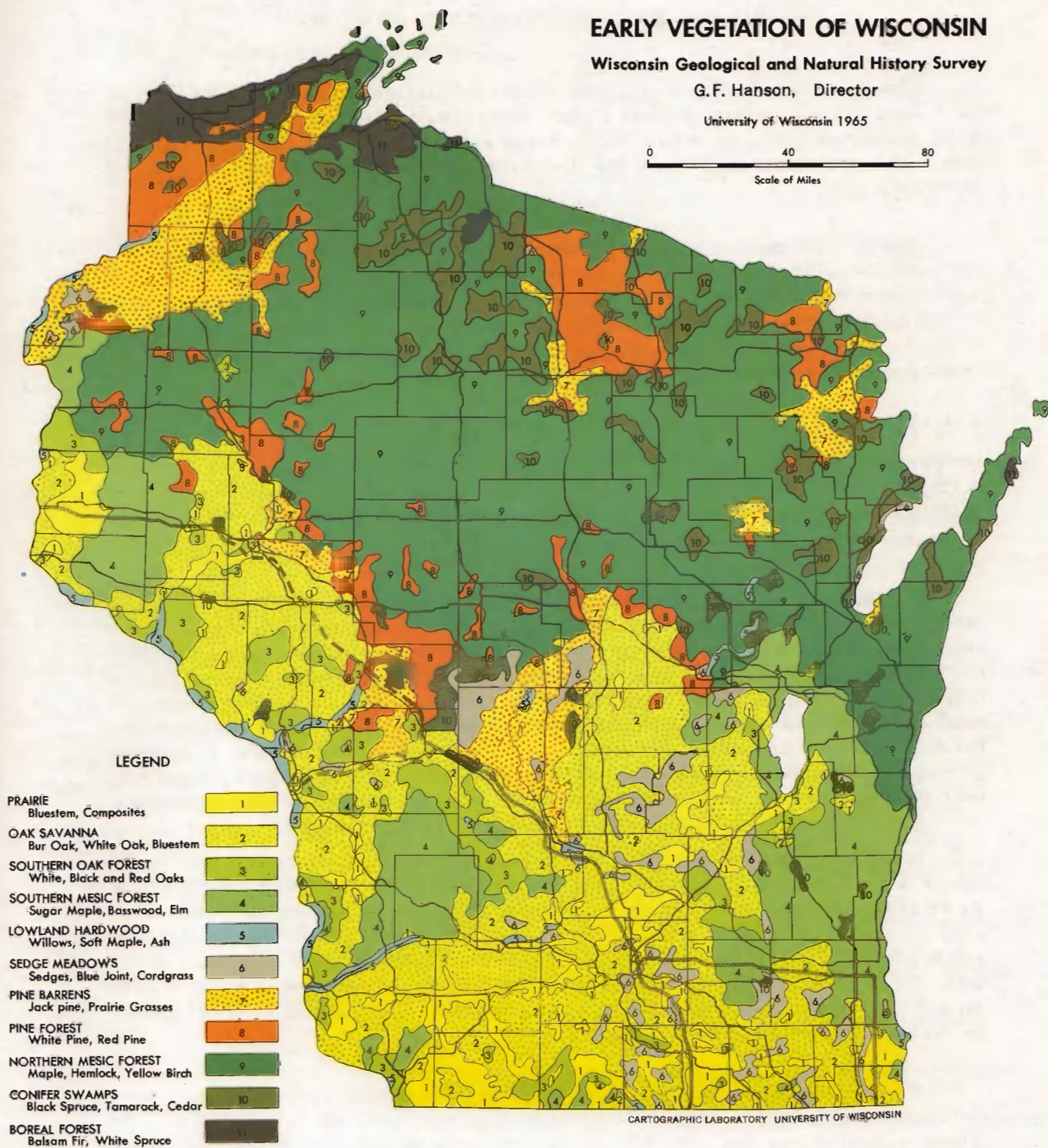
# EARLY VEGETATION OF WISCONSIN

Wisconsin Geological and Natural History Survey

G.F. Hanson, Director

University of Wisconsin 1965

0 40 80  
Scale of Miles



## INTERPRETATION OF THE VEGETATION OF WISCONSIN

This map is based on the original land survey conducted about the middle of the last century. Surveyors were required to place a stake each half mile, identified by notation of nearby trees, and to note briefly the general plant cover of each quarter section. These records have been used to reconstruct the presettlement distribution patterns of plant communities shown on the map.

The plant communities recognized, however, are based on systematic studies of present-day vegetation. The results of these studies are summarized in a recent book (J. T. Curtis, *The Vegetation of Wisconsin*, University of Wisconsin Press, 1959) in which each community, with its history, location, and relationship to other communities and to the environment, is considered in detail. Since some of the factors determining vegetation vary gradually, the vegetation itself varies gradually and boundaries on the map are somewhat arbitrary.

The vegetation of the state is divided into northern and southern floristic provinces by a line that runs in an S-curve northwest from Milwaukee to Hudson. North of this line the vegetation is a broadleaf forest containing conifers—pines, hemlock, spruces, and fir. Southwest of the line, conifers are much less important and are replaced by forests with several species of oaks, and by the prairies—areas dominated by grasses and tall herbs.

Fire has been important in determining almost all of the plant communities and their location. Before the coming of white man, the prairies (1) and the open woodlands burned almost every year. Thus most of the southern part of the state was covered with prairie or oak savanna (2), an orchard-like community with a few large bur or white oaks growing in fields of grass. Only in the more protected places did forests survive. Some of these were oak (3) but many were sugar maple-basswood-slippery elm forests (4). The lowlands were occupied by river bottom forest (5), and sedge meadow (6). With settlement, the fires were stopped, and the oak savannas grew up to the dense white oak-black oak forests found today. Most of the prairies have been cultivated, and at present, with the oak savannas, are among the rarest of our plant communities.

In the northern part of the state, a combination of fire and poor soil resulted in the development of pine barrens (7) on the sandy soils, and pine forests (8) on somewhat better soils. In the absence of fire, the white pine forests gradually changed to the northern equivalent of the sugar maple-basswood forests, a community containing sugar maple, yellow birch and hemlock, with beech added in the eastern counties (9). Also present in the north were large tracts of lowland, with tamarack and black spruce bogs in the wetter areas, and white cedar swamps in drier, but still very moist habitats (10). In the extreme north are local occurrences of the northern conifer forest (11) dominated by fir and spruce.

A comparison of this map with maps of climate, soil, and glacial deposits shows many correspondences, indicating many relationships between vegetation and the environment. The original vegetation was thus determined by the distribution of both climatic and soil factors, modified by fire.

G. Cottam, O. L. Loucks  
Department of Botany  
The University of Wisconsin