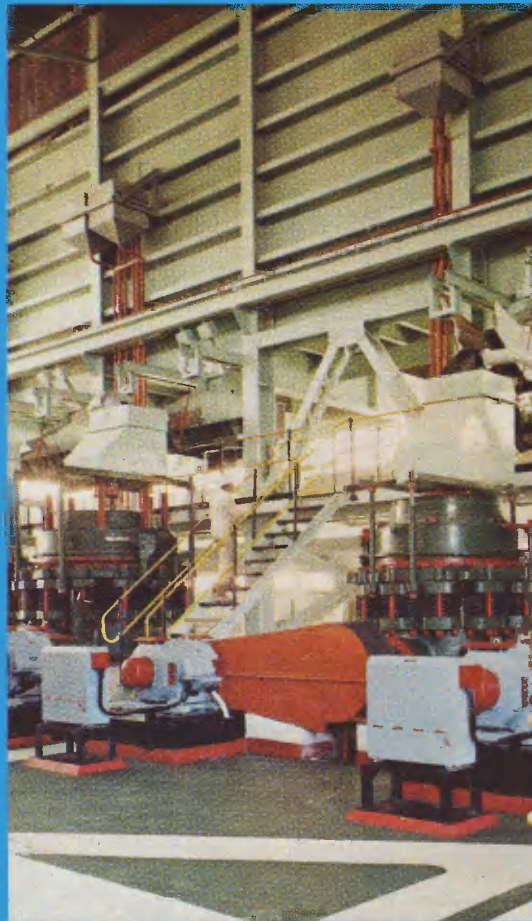
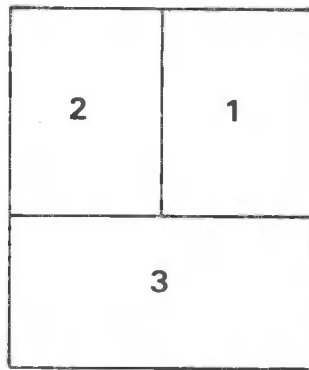




Abstract and Proceedings

24th Institute on Lake Superior Geology
Milwaukee, Wisconsin, May 9-14, 1978





1. THREE SYMONS 5 1/2' SHORT-HEAD, AND TWO SYMONS 4 1/4' STANDARD CONE CRUSHERS OPERATING AT BLYVOORUITZICHT GOLD MINE, CARLETONVILLE, TRANSVAAL, REPUBLIC OF SOUTH AFRICA.
2. P & H MINING SHOVELS, BUILT IN MILWAUKEE BY HARNISCHFEGGER, HAVE BEEN WORKING YEAR-ROUND REMOVING OVERBURDEN AND MINING IRON ORE AT DOFASCO'S ADAMS MINE AT KIRKLAND LAKE, ONTARIO, CANADA SINCE IT BEGAN OPERATIONS IN 1964.
3. ROTARY KILN COMPLETES INDURATION OF IRON ORE PELLETS AT 2400°F IN THIS GRATE-KILN PELLETTIZING PLANT IN MINNESOTA.

PROCEEDINGS

Twenty Fourth Annual Meeting

INSTITUTE ON LAKE SUPERIOR GEOLOGY



HELD AT THE

PFISTER HOTEL

MILWAUKEE

WISCONSIN

MAY 9-14, 1978

SPONSORED BY THE

DEPARTMENT OF GEOLOGICAL SCIENCES
UNIVERSITY OF WISCONSIN-MILWAUKEE
MILWAUKEE, WISCONSIN 53201

G. MURSKY, C.A. SALOTTI, AND W.H. SCHRAMM

GENERAL EDITORS

SALES

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GENERAL INFORMATION

24TH ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

PFISTER HOTEL

MILWAUKEE, WISCONSIN

MAY 9-14, 1978

SPONSORED BY THE

DEPARTMENT OF GEOLOGICAL SCIENCES

UNIVERSITY OF WISCONSIN-MILWAUKEE

MILWAUKEE, WISCONSIN

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FIELD TRIPS

Chairman, R.A. Paull, Department of Geological Sciences, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Trip I - Southwestern Wisconsin Zinc - Lead District

W.A. Broughton, University of Wisconsin-Platteville, Platteville, Wisconsin.

A.V. Heyl, U.S. Geological Survey, Reston, Virginia.

M.G. Mudrey, Jr., Wisconsin Geological and Natural History Survey, Madison, Wisconsin.

W.S. West, U.S. Geological Survey, Platteville, Wisconsin.

Trip II - Mineral Extraction and Processing Equipment Manufacturers in the Greater Milwaukee Area

C.A. Salotti, Department of Geological Sciences, University of Wisconsin-Milwaukee, Milwaukee Wisconsin.

Trip III - Precambrian Rhyolite and Granite Inliers in South-Central Wisconsin.

E.I. Smith, Division of Science, University of Wisconsin-Parkside, Kenosha, Wisconsin.

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P.K. Sims, U.S. Geological Survey, Denver, Colorado.

M.S. Walton, Director, Minnesota Geological Survey, Minneapolis,
Minnesota.

ANNUAL BANQUET KEYNOTE SPEAKER

Congressman James Santini, House of Representatives, Washington,
D.C. Member, Committee on Interior and Insular
Affairs; Subcommittee on Oversight of Public Lands
Mines and Mining.

ACKNOWLEDGEMENTS

The organizing committee for the 24th Annual Meeting on Lake
Superior Geology gratefully acknowledges the support of the follow-
ing corporations in the Milwaukee area:

Allis-Chalmers Corporation
Harnischfeger Corporation
Rexnord Corporation

CALENDER OF EVENTS

AND PROGRAM

Tuesday
May 9, 1978

Pre-Institute Field Trip I - Southwestern Wisconsin Zinc-Lead District, departs from Madison, Wisconsin to Platteville, Wisconsin at 12:30 P.M., and return to Milwaukee, Wednesday May 10, 1978 about 6:00 P.M.

Wednesday
May 10, 1978

Pre-Institute Field Trip II - Mineral Extraction and Processing Equipment Manufacturers in the Greater Milwaukee Area, departs from the Pfister Hotel about 8:30 A.M., and return about 4:30 P.M.

1:00 - 3:30 P.M.
and
6:00 - 9:00 P.M.

Early Registration, near the Imperial Ballroom, Pfister Hotel

7:30 - 10:00 P.M.

Conference "Smoker", Henry & Louis Room, Pfister Hotel.

Thursday
May 11, 1978

7:00 - 8:00 A.M.

Early Registration near the Imperial Ballroom, Pfister Hotel.

8:00-11:55 A.M.

Morning Session, Imperial Ballroom, Pfister Hotel.

9:00 A.M. - 4:50 P.M.

Poster Session, Henry and Louis Room, Pfister Hotel

1:30 - 4:50 P.M.

Afternoon Session, Imperial Ballroom, Pfister Hotel.

6:00 P.M.

Cocktail Hour (cash bar), Henry and Louis Room, Pfister Hotel.

7:00 P.M.

Annual Banquet, Imperial Ballroom, Pfister Hotel. Keynote speaker: Congressman James Santini.

Friday
May 12, 1978

8:10 A.M. - 12:10 P.M. Morning Session, Imperial Ballroom,
Pfister Hotel.

1:30 - 4:10 P.M. Afternoon Session, Imperial Ballroom,
Pfister Hotel.

6:30 P.M. Post-Institute field trip III -
Precambrian Rhyolite and Granite Inliers
in South-Central Wisconsin departs from
the Pfister Hotel, for Oshkosh, Wisconsin.
This field trip will return to Milwaukee,
Saturday, May 13, 1978 about 6:30 P.M.

TECHNICAL PROGRAMS

Thursday, May 11, 1978

8:00 - 11:55 A.M.

Morning Session - Co-Chairmen: Rachel K. Paull and Paul K. Sims

8:00 Opening Remarks

8:15 Smith, E.I. A New Precambrian Surface Contour Map for South-Central Wisconsin.

8:35 Zietz, I. A New Detailed Aeromagnetic Map Covering Most of the Precambrian Shield in Wisconsin.

8:55 Sims, P.K. Precambrian Geologic Framework of Northern Wisconsin.
Peterman, Z.E.

9:15 Cannon, W.F. A Middle and Late Precambrian Fault System in Northern Wisconsin and Northern Michigan.

9:35 Jones, D.G. Geology of the Iron Formation and Associated Rocks of the Jackson County Iron Mine, Jackson County, Wisconsin.

9:55 - 10:15

COFFEE BREAK

10:15 Van Schmus, W.R. Geochronologic Relationships in the Carney Lake Gneiss and other Basement Gneisses in Dickinson County, Upper Michigan.
Woronick, R.E.
Egger, N.L.

10:35 DuBois, J.F. Petrology and Geochronology of Archean Gneiss in the Lake Arbutus Area, West-Central Wisconsin.
Van Schmus, W.R.

10:55 Hammond, R.D. Geochronology of Archean Rocks in Marquette County, Upper Michigan.
Van Schmus, W.R.

11:15 Peltonen, D.R. Relations Between Soil Geochemistry and Bedrock Geology, Iron County, Wisconsin.
Salotti, C.A.
Taylor, R.W.

11:35 Cummings, M.L. Petrology and Geochemistry of Amphibolites, Eau Claire River, Eau Claire County, Wisconsin.
Myers, P.E.

11:55 - 1:30

LUNCH

Thursday, May 11, 1978

1:30 - 4:50 P.M.

Afternoon Session - Co-Chairmen: A.T. Broderick and J. Kalliokoski

- | | | |
|------|--|--|
| 1:30 | Ojakangas, R.W. | Criteria for Alligator River Type Uranium Deposits in the United States. |
| 1:50 | Kalliokoski, J. | The Unconformity-Type Proterozoic Pitchblende Ore Body Model and Its Application to Northern Michigan. |
| 2:10 | Peterman, Z.E.
Sims, P.K. | Baseline Uranium and Thorium in Archean and Lower Proterozoic Rocks of the Marenisco-Watersmeet Area, Michigan. |
| 2:30 | Meineke, D.G.
Vadis, M.K.
Klaysmat, A.W. | Pilot Exploration Geochemical Survey of Uranium in Organic-Rich Lake Sediments, Northeastern Minnesota. |
| 2:50 | Trow, J. | Possibilities for Uranium-Gold Quartz-Pebble Ores in the Lake Superior Region in the Light of a New Model for Elliot Lake-Witwatersrand Genesis. |

3:10 - 3:30

COFFEE BREAK

- | | | |
|------|---|--|
| 3:30 | Meddaugh, W.S.
Salotti, C.A.
Mursky, G. | The Distribution of Uranium and Thorium in the Wolf River Batholith, Northeastern Wisconsin. |
| 3:50 | Heinrich, E.W. | Industrial Sand and Sandstone Resources of Michigan. |
| 4:10 | Nebrija, E.L.
Welkie, C.J.
Meyer, R.P. | Offshore Sand and Gravel Exploration in Western Lake Michigan. |
| 4:30 | Gere, M.A. Jr. | Economic Mineral Production in Michigan Past and Present. |

Friday, May 12, 1978

8:10 - 12:10 A.M.

Morning Session - Co-Chairmen: M.M. Kehlenbeck and M.S. Walton

- | | | |
|------|---|--|
| 8:10 | Molling, P.A.
Tyson, R.M.
Chang, L.L.Y. | A Petrographic Guide for Unit Identification of the Partridge River Troctolite, Duluth Complex, Minnesota. |
| 8:30 | Foose, M.P.
Cooper, R.W. | Faulting in Part of the Duluth Complex, Northeastern Minnesota. |
| 8:50 | Bauer, R.L. | Polyphase Deformation in Archean Schists of the Western Lake Vermilion Area, Minnesota. |
| 9:10 | Cambray, F.W. | Plate Tectonics as a Model for the Environment of Sedimentation the Marquette Supergroup and the Subsequent Deformation and Metamorphism Associated with the Penokean Orogeny. |
| 9:30 | Larue, D.K. | Problems in Paleogeographic Reconstruction of the Chocoma and Lower Menominee Group Sedimentation, Marquette Range Supergroup, Lake Superior Region. |

9:50 - 10:10

COFFEE BREAK

- | | | |
|-------|-------------------------------|--|
| 10:10 | Massey, N.W.D. | The Geochemistry of Keweenaw Lavas of the Mamainse Point Formation, Ontario. |
| 10:30 | Jirsa, M.A. | The Petrology and Tectonic Significance of the Interflow Sediments in the Keweenaw North Shore Volcanic Group of Northeastern Minnesota. |
| 10:50 | Westjohn, D.
Cambray, F.W. | Finite Strain in the Precambrian Kona Formation of the Marquette Synclinorium. |
| 11:10 | Strakele, A.E. | The Geology and Petrology of the Wine Lake Intrusion, Cook County, Minnesota. |
| 11:30 | Cambray, F.W. | The Origin and Timing of Cleavage Formation in the Siamo Slate of Precambrian X Age, Marquette County, Michigan. |
| 11:50 | Hughes, J.D. | A Post Two Creeks Buried Forest in Michigan's Northern Peninsula. |

12:10 - 1:30

LUNCH

Friday, May 12, 1978

1:30 - 4:10 P.M.

Afternoon Session - Co-Chairmen: J.D. Hughes and E.R. May

- | | | |
|-------------|--|---|
| 1:30 | Banaszak, K.J. | The pH of Ore Fluids of Mississippi Valley Type Deposits. |
| 1:50 | Cummings, M.L. | Stratigraphy and Mineralization, Quinnesec Formation, Northeastern Wisconsin. |
| 2:10 | Aaquist, B.E.
Hodder, R.W. | Microstylolites-An Indicator for an Early Stage of Native Copper Deposition in a Rhyolite Tuff, Keweenaw Peninsula, Michigan. |
| 2:30 | Scofield, N. | Native Copper Deposits Derived from Nearby Keweenaw Basalt by Combined Igneous, Deuteric, and Metamorphic Processes. |
| 2:50 - 3:10 | | <u>COFFEE BREAK</u> |
| 3:10 | Johnson, A.
Scofield, N.
Doane, V. | Geology and Mineralogy of Northern Michigan Phosphorites. |
| 3:30 | Shanabrook, D. | Precambrian X Paleopoles from the Upper Peninsula and a New Method for Remanent Vector Determination. |
| 3:50 | Luther, F.R. | The Geology of the Gore Mountain Garnet Deposit, Southeastern Adirondacks, Warren County, New York. |

END OF TECHNICAL SESSIONS

POSTER SESSION

Thursday, May 11, 1978

8:00 A.M. - 4:50 P.M.

- | | |
|--------------|---|
| Mudrey, M.G. | Aereomagnetic Map of Northern Wisconsin. |
| Sims, P.K. | Preliminary Geologic Map of Northern Wisconsin. |
| Cannon, W.F. | |
| Mudrey, M.G. | |
| Shaffer, N. | Possibility of Mississippi Valley-Type Ore Deposits in Indiana. |

ABSTRACTS

MICROSTYLOLITES-AN INDICATOR FOR AN EARLY STAGE OF
NATIVE COPPER DEPOSITION IN A RHYOLITE TUFF,
KEWEENAW PENINSULA, MICHIGAN

B.E. Aaquist, American Copper & Nickel Co., Milwaukee,
Wi. 53226 and R.W. Hodder, University of Western Ontario,
London, Ont. N6A 5B7

ABSTRACT

Microstylolites are contact surfaces between clasts in a rhyolite tuff hosting native copper in the Kingston mine. The microstylolites conform to Pettijohn's (1949) definition: "a stylolite seam is a surface of contact marked by interlocking or mutual interpenetration of the two sides. The teeth-like projections of one side fit into the sockets of like dimensions on the other." The microstylolites are mostly chlorite grains with their long axis parallel to the contact surface. Some fine grained hematite is also present. Quartz and feldspar phenocrysts terminated by a microstylolite are neither fractured, nor stressed. Fluid inclusions in phenocrysts are similarly terminated by microstylolites.

Depth of burial is the single most important factor in microstylolite development. In sandstones, microstylolites have been recorded at depths of burial of 1250 to 1650 meters (Trurnit, 1968). Tuff in the Kingston mine is overlain by about 1700 meters of lavas and sedimentary rocks of the Portage Lake Lava Series, sufficient weight to induce formation of microstylolites.

In the tuff, native copper is common in white rims on reddish rhyolite clasts. These rims are white where potash feldspar grains in clasts are clear and lack disseminated hematite of reddish grain interiors. Microstylolites terminate the white, copper-bearing rims. This suggests deposition of native copper and whitening of the rims of clasts prior to microstylolite formation and, hence, before lithification of the tuff.

References

- Pettijohn, F.J. (1949); Sedimentary rocks: Publ. by Harber and Brothers, New York, 526 p.
- Trurnit, P. (1968); Pressure solution phenomena in detrital rocks: Sed. Geol., vol. 2, p. 89-114.

The pH of Ore Fluids of Mississippi Valley Type Deposits

by

Konrad J. Banaszak

Department of Geology
Indiana/Purdue University at Indianapolis
925 W. Michigan, Indianapolis, Indiana 46202

The pH of the ore solutions responsible for Mississippi Valley type ore deposits is a critical chemical variable in the discussion of the origin of these deposits. This pH must have been acid, based on zinc dispersion curves, equilibrium relations with silicate minerals of "modern ore fluids", and the absence of magnesium silicates in the paragenetic sequences of the deposits. Zinc dispersion curves were recreated in the laboratory by Lavery and Barnes (1971) with model ore solutions buffered to a pH of 6 at 100°C. The model ore solutions that were basic did not reproduce the curves. Modern "ore fluids" appear to have both a low partial pressure of carbon dioxide and an acidic pH, and are probably in equilibrium with silicate rocks. The composition of fluid inclusions in an assumed equilibrium with K-spar, albite, quartz, muscovite, and montmorillinite indicates an approximate pH of 5 for brines at 150°C to 200°C. Other evidence is the absence of silicate minerals in the paragenetic sequence (See Drever, 1974.). In Mississippi Valley type deposits, the absence of sepiolite, an easily crystallized phase (Christ and others, 1973), especially restricts the pH of the ore solution to acidic values. In the presence of a silica phase, either quartz or opalline silica, and at the magnesium activities indicated by fluid inclusions, the pH of the ore fluid must have been no greater than 6 at 100°C and 5 at 150°C.

Christ, C. L., Hostetler, P. B., and Siebert, R. M., 1973, Studies in the system MgO - SiO₂ - CO₂ - H₂O (III): The activity product of sepiolite: Amer. Jour. Sci., v. 273, p. 65-83.

Drever, J. I., 1974, Geochemical model for the origin of Precambrian banded iron formations: Bull. Geol. Soc. Amer., v. 85, p. 1099-1106.

Lavery, N. G., and Barnes, H. L., 1971, Zinc dispersion in the Wisconsin zinc-lead district: Econ. Geol., v. 66, p. 226-242.

POLYPHASE DEFORMATION IN ARCHEAN SCHISTS OF THE WESTERN LAKE VERMILION AREA, MINNESOTA*

Robert L. Bauer, Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minnesota 55455, and Department of Geology, Macalester College, St. Paul, Minnesota 55105

ABSTRACT

A detailed petrologic and structural study has been initiated in the Norwegian Bay quadrangle and parts of adjacent quadrangles in the western Lake Vermilion area. The rock exposures consist of Archean schists and lamprophyres metamorphosed to the middle amphibolite facies and intruded by a quartz monzonite stock (Wakemup Bay stock). The stock and adjacent schists are bounded on the north by the Vermilion fault, on the southeast by the Frazer Bay fault, and on the south by the Haley fault. The structural studies reported on here indicate the schists have undergone four periods of deformation

The most evident structural feature in the area is a prominent foliation which wraps around the Wakemup Bay stock. This foliation (S_1) is axial planar to rare isoclinal F_1 folds and is parallel to bedding (S_0) in the schist. Numerous thin lamprophyre and granitic veins cutting the schist are boudinaged or folded by the flattening normal to S_1 .

F_2 folds are the most common minor structures preserved and are commonly accompanied by a weak to strong axial plane foliation (S_2). The distribution of minor F_2 folds indicates the presence of a major southwest-plunging F_2 antiform partially exposed south of the stock. The axes of the minor F_2 folds show a systematic variation in orientation to the west, northwest and north of the intrusion as a result of refolding (F_3) of the major F_2 structure around the western end of the Wakemup Bay stock. Despite the large-scale F_3 folding around the stock, minor F_3 folds are rare and occur only along the western margin of the intrusion. These folds are open, westward-plunging warps of the foliation with near vertical axial planes.

The shallow dips of the schist near the contacts of the stock and the presence of a flat-lying roof pendant of schist and lamprophyre near the center of the stock's exposure, suggest the surface exposures are very near the top of the stock.

Evidence for an F_4 deformation is restricted to kink bands, up to 5 cm wide, which deform the S_2 foliation.

A similar sequence of structural events has been recognized north of the Vermilion fault. Further study of the area is in progress which may lead to the correlation of major structural features across the fault.

*Research supported by the Minnesota Geological Survey

PLATE TECTONICS AS A MODEL FOR THE ENVIRONMENT OF SEDIMENTATION
THE MARQUETTE SUPERGROUP AND THE SUBSEQUENT DEFORMATION AND
METAMORPHISM ASSOCIATED WITH THE PENOKEAN OROGENY

CAMBRAY, F. William, Department of Geology, Michigan State
University, East Lansing, Michigan 48824

The Marquette Supergroup of Precambrian X age has been divided into three groups. This sequence can be compared to the one which forms on a passive plate margin such as the Atlantic. The Chocolay Group represents an epicontinental shallow sea followed by the initiation of rifting at the beginning of Menominee times. The doming associated with rifting would account for the unconformity between the two groups and the separate basins in which the banded iron formations and turbidites were deposited formed as a result of rifting producing local depressions such as the Marquette, Republic and Iron River/Crystal Falls Troughs. This extensional phase was accompanied by intrusion of tholeiite dykes parallel to the Marquette Trough and by the intrusion of sills into the sediments within the troughs. Subsequently the area underwent subsidence and accumulated the large thickness of Baraga Group sediments which compare favourably with the turbidites which formed on the subsiding shelf edge of the modern Atlantic Ocean.

In this interpretation it is proposed that the Iron River/Crystal Falls area succession, which includes the Riverton Iron Formation, is contemporaneous with the Menominee Group of the Marquette Range and that the Badwater Greenstones represent submarine extrusions related to the rifting which is proposed at this time. Each of the troughs referred to are likened to those which are found today on constructive plate margins.

Subsequent to deposition the area was compressed and metamorphosed in the Penokean Orogeny (1.85 - 1.9 Ga B.P.). It is proposed that during this episode deformation of the underlying Archean Basement occurred by ductile shears along pre-existing weaknesses, particularly the mafic dykes referred to above, producing east-west folding in the overlying Marquette Supergroup. During this phase troughs are thought to have been the locii of greater strain and that weaknesses developed during the earlier rifting were utilised to narrow them and produce a more intense folding. The seemingly anomalous orientations of folds in the troughs such as the Republic Trough are thought to have been controlled by the stress distribution across troughs with variable initial orientations.

The deformation was accompanied by metamorphism. The history of the region has many features in common with a plate tectonic cycle involving a continental rift followed by subsidence at the margin of an expanding ocean followed by reversal of plate movement, subduction, compression and metamorphism. The fact that all the evidence cited is situated on older Archean crust does not negate the hypothesis. All the more recent examples such as the Appalachian and Alpine Orogeny are underlain by continental crust. All this means is that the supposed ocean was completely subducted and continental collision resulted. The suture zone associated with this event has not been located and we are left to debate whether it is present but cryptic or that Proterozoic tectonics was similar in all other respects to plate tectonics.

THE ORIGIN AND TIMING OF CLEAVAGE FORMATION IN THE SIAMO SLATE OF
PRECAMBRIAN X AGE, MARQUETTE COUNTY, MICHIGAN

CAMBRAY, F. William, Department of Geology, Michigan State
University, East Lansing, Michigan 48824

In the previous work (Powell, C. McA; 1969, Bull. Geol. Soc. America) it has been suggested that the cleavage formed penecontemporaneously with the emplacement of sandstone dikes and the origin of both was ascribed to dewatering during late diagenesis or low grade metamorphism.

In the outcrop referred to by Powell the dikes can be shown to have been emplaced before deformation and to have undergone rotation as rigid bodies prior to the formation of the cleavage. The cleavage cuts across the boundary between the dikes and the host sediment, and it is not deformed by folds in the bedding which are related to the rotation of the dikes. The sense of this rotation is consistent with the shear couple on the limbs of the major fold. The magnitude however is greater than that predicted if one assumes the dikes originated normal to bedding and were deformed by flexural slip or flexural flow folding. This can be explained by "additional strain" introducing a flattening across the bedding as the fold develops. The flattening can be demonstrated by the variation in bed thickness as a function of distance from the rigid sandstone dikes.

The cleavage is defined by thin laminae of optically irresolvable material separated by broader areas containing quartz, chlorite, muscovite and a carbonate. The quartz, chlorite and muscovite show features which suggest the cleavage originated by recrystallisation, possibly in conjunction with pressure solution.

All the evidence points to cleavage forming late in a sequence of deformation and metamorphism which involved rotation of the sandstone dikes, flattening and recrystallisation.

A middle and late Precambrian fault system
in northern Wisconsin and northern Michigan
by

W. F. Cannon
U. S. Geological Survey
Reston, Virginia 22092

Interpretation of aeromagnetic and gravity maps of northern Wisconsin and northern Michigan suggests that major regional faults are much more abundant than previously believed. The newly identified faults appear as abrupt linear truncations of aeromagnetic patterns on a newly compiled 1:250,000 scale aeromagnetic map (U.S.G.S. map MF 888). Some faults also coincide with steep gravity gradients. Many faults produce lateral offset (some as much as 20 km) of magnetic anomalies caused by middle Precambrian supracrustal and Penokean intrusive rocks; this evidence indicates that large-scale lateral adjustment took place in the area after the Penokean orogeny ($\sim 1,800$ m.y. ago). Other faults, especially in northern Michigan, are known to have had large vertical displacements during the Penokean orogeny. Some faults cut rocks of the Wolf River batholith ($\sim 1,500$ m.y. old) and Keweenaw intrusive and flow rocks ($\sim 1,100$ m.y. old). Some east-trending faults and fractures contain lower Keweenaw diabase dikes.

Although the age at which it began is unknown, the faulting is at least as old as the Penokean orogeny, and it continued until at least 1,100 m.y. ago, probably episodically. Some, and perhaps most, lateral movement is of Keweenaw age. Much of the map pattern in northern Wisconsin reflects major lateral fault movements; it may be a reflection of intraplate tectonics during the opening of the Keweenaw rift, as the older Precambrian rocks in Michigan and Wisconsin were caught between the somewhat opposed opening directions of the midcontinent and mid-Michigan arms of the rift system. A pre-Keweenaw fault and fracture system probably controlled the location and orientation of the Keweenaw rift and associated transform faults, so that some segments of pre-existing faults behaved as transform faults during rifting, whereas other segments shifted so as to alter the shape of the Wisconsin-Michigan plate as it moved generally southward.

Regardless of its origin and history, the fault system is important geologically because of its control on the regional map pattern. Additional faults having displacements too small to resolve by means of existing aeromagnetic data probably are also abundant and will be important in interpreting the map pattern on a larger scale.

Petrology and Geochemistry of Amphibolites, Eau Claire River,
Eau Claire County, Wisconsin

M. L. Cummings, Dept. of Geology and Geophysics, UW - Madison
P. E. Myers, Dept. of Geology, UW - Eau Claire

Precambrian amphibolites, mica schists, and intrusives crop out for 12 km along the Eau Claire River in north-central Eau Claire County.

Massive and banded mafic amphibolites, with more than 40 percent hornblende, have local mineral assemblages: hornblende-garnet-plagioclase-quartz, and hornblende-cummingtonite-garnet-plagioclase-quartz with accessory apatite, sphene, biotite, and opaques as sulfides and oxides. Feldspathic amphibolites, with 10 to 25 percent hornblende, are characterized by dominant plagioclase. Accessory epidote, quartz, sphene, and garnet show variable abundance. Banding and hornblende lineation are indistinct. Hornblende analyses from amphibolites show Al_2O_3 between 9.8 and 15.7 weight percent with Al in 1.05 to 1.81 tetrahedral sites. 100 Mg/(Mg + Fe) vary from 20 to 70 with values below 50 dominant.

Mica schists with assemblages: biotite-hornblende-epidote-plagioclase-quartz, and muscovite-biotite-epidote-plagioclase-quartz and subordinate amphibolite layers composed of hornblende, biotite, plagioclase and quartz underlie the eastern half of the area. 100 Mg/(Mg + Fe) of hornblende in these amphibolites ranges from 47 to 52. Epidote in both assemblages contains 11.5 to 13.0 weight percent Fe_2O_3 .

An intrusion breccia 0.75 km south of Big Falls contains amphibolite xenoliths in strongly foliated granodiorite(?) composed of biotite, muscovite, epidote, plagioclase, and quartz. A second intrusion breccia at county highway K 1.5 km east of Big Falls contains mafic amphibolite xenoliths in a coarse-grained, flow-laminated tonalite(?) matrix. The rocks described above are cut by granite pegmatite and diabase dikes.

The following, tentative chronology is based on petrochemistry, structure, and regional geology. The oldest rocks - mica schists and amphibolites - representing volcanic sediments and mafic flows(?) were intruded by a gabbro which differentiated into mafic and anorthositic layers. Metamorphism of these rocks to garnet amphibolite grade accompanied intrusion of tonalite, trondhjemitic and adamellite north of the area. A second metamorphism produced coarse hornblende and plagioclase in the amphibolites, while compositional layering was transposed by strong compressional stresses. Synkinematic intrusion of tonalite (1850 $\pm$ 50 m.y.) produced the breccias east and west of Big Falls, and was followed by postkinematic intrusion of granite pegmatite dikes. Shearing with contemporaneous formation of epidote and chlorite was followed by prolonged erosion after which east-northeast-trending olivine diabase dikes were intruded (1100-900 m.y.). Weathering and erosion continued until marine deposition of Upper Cambrian sandstones.

This chronology implies an Archean age for the mica schists and layered gabbro sequence.

Stratigraphy and Mineralization, Quinnesec Formation, Northeastern Wisconsin

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Volcanogenic semi-massive to massive sulfide zones occur at several stratigraphic levels in the Quinnesec Formation in Marinette County, Northeastern Wisconsin. The Quinnesec Formation includes basic to felsic flows, tuffs, iron formation and clastic sediments, that were intruded by quartz diorite to quartz monzonite at about 1850-1900 m.y.

Two types of conformable massive sulfide deposits occur in the Quinnesec Formation. 1) 2 to 10 cm beds with up to 70% sulfide in iron formation, and 2) 3 to 20 meter sulfide zones characterized by subangular quartz clasts and rounded graphitic muscovite-chlorite clasts supported in a sulfide matrix. Two main zones have been defined at stratigraphic levels separated by approximately 300 meters of basalt flow, tuffs and iron formation. The lower deposit overlies graphitic, sulfide-bearing felsic tuff and is overlain by garnetiferous iron formation and biotite-amphibole metasediments. The upper deposit overlies a 30 to 60 meter iron formation and is capped by thinly laminated, graphitic, siliceous sediments that grade upward into fine grained, well-bedded siltstones. Both main sulfide deposits overlie and are interbedded at the base with tremolite and anthophyllite-bearing assemblages, possibly representing alteration zones. The sulfide mineralogy of the massive sulfide deposits is simple, with monoclinic pyrrhotite predominant. Sphalerite and chalcopyrite occur throughout the deposits with sphalerite forming localized thin beds. Pyrite is generally secondary, associated with fractures, however, some pyrite may be part of the metamorphic sulfide assemblage. Highest Zn and Cu concentrations are 1.0% and 0.1% respectively.

Iron formation is represented by the assemblage grunerite-quartz, grunerite-ferro-actinolite-quartz, grunerite-ferro-hornblende-ferro-actinolite-quartz, grunerite-ferro-hornblende-garnet-quartz and grunerite-stilpnomelane-quartz. All assemblages can contain calcite. Grunerite-ferro-actinolite-garnet-quartz occurs in high Mn bulk compositions. Pyrrhotite is the main opaque phase with magnetite and ilmenite locally abundant. Sphalerite occurs with either magnetite or pyrrhotite, chalcopyrite tends to be restricted to pyrrhotite-bearing samples. The iron formation that underlies the upper main massive sulfide zone is divided into upper and lower units separated by a sulfide rich zone containing 0.5% Cu and 0.5% Zn. The lower unit is characterized by numerous thin sulfide-rich beds. The upper unit is characterized by garnetiferous beds, some of which are highly graphitic. Base metal ions were available periodically during iron formation deposition with precipitation controlled by local Eh-pH conditions and intensity of hydrothermal activity.

Metamorphic conditions were in the epidote amphibolite facies of amphibolite facies. Primary textures are well preserved with penetrative deformational features weakly developed.

PETROLOGY AND GEOCHRONOLOGY OF ARCHEAN GNEISS IN
THE LAKE ARBUTUS AREA, WEST-CENTRAL WISCONSIN

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The basal gneiss of central Wisconsin crops out along the Black River in Clark and Jackson counties and is particularly amenable to detailed study at a series of exposures below Arbutus Dam near Hatfield, Wisconsin. The gneiss has a heterogeneous composition, ranging from granite to tonalite, and contains interlayered amphibolite units.

There is considerable scatter of the Rb-Sr geochronologic data, but an upper age limit can be defined by a 2.8 b.y. isochron. This age presumably dates the time of upper amphibolite to granulite facies metamorphism. Later open system conditions are probably due either to Rb metasomatism or to loss of radiogenic Sr. The former may be explained as an effect from intrusion of Penokean granite (1830 m.y. old) 3 k.m. north of the study area. Two models are proposed for the structural relationships between the gneiss and granite. The granite may be a small body intruding continuous and extensive gneissic terrane, or the gneiss may be present as a roof pendant within a large Penokean batholithic complex. Due to limited exposure it may be difficult to prove either model.

U-Pb data on zircon from the gneiss yield a concordia intercept corresponding to an age of 2.9 b.y. The lower concordia intercept of 1.0 b.y. is too high to be interpreted by a simple diffusion model. It may, however, be explained by U and Pb diffusion affected by a second metamorphic event about 1.8 b.y. ago.

FAULTING IN PART OF THE DULUTH COMPLEX, NORTHEASTERN MINNESOTA

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Intense faulting and fracturing in part of the Duluth Complex, northeastern Minnesota, has been documented by detailed field mapping. Faulting is recognized principally by the displacement of mappable, mineral graded layers that were probably formed in a manner analogous to that of sedimentary turbidites. Recognition of the faulting, fracturing, and depositional environment establishes a basic geologic style that may have significant regional implications.

The area mapped is in Lake County, approximately 23 km southeast of Ely, Minn., near the basal part of the Duluth Complex. It is between Birch Lake, the Tomahawk Road, and Minnesota Highway 1. Two distinct rock sequences were identified. The lower sequence is predominantly medium-grained troctolites that contain 3 to 10 percent intercumulus pyroxenes and/or oxides; the upper sequence is medium- to fine-grained troctolites that contain little or no intercumulus pyroxenes or oxides. Well-defined and mappable layering is best developed in these upper troctolites. Most common are layers that have abundant cumulus olivine at the base and decreasing amounts of olivine upward. Contacts of layers are sharp, but inclusions of olivine-poor clasts occur within the olivine-rich basal part of overlying layers. The olivine-poor top of one layer is approximately 10 m thick and provides a distinctive marker horizon that can be traced through much of the study area. Layers appear to have been formed by density currents carrying olivine and plagioclase grains.

Faults and fractures are the most abundant and important structures recognized in the area. They are identified principally by the off-setting of mappable layers, but also by variations in the orientation of mineral laminations, the occurrence of gouge, and the presence of marked topographic lineaments. In the study area are three major directions of faulting. The principal direction trends N30-40E, and less prominent faults are usually oriented N-S and N35W. However, virtually any direction of faulting may be observed locally. Rarely, minor folds are observed in association with some major faults.

Previously, only a few faults have been identified by ground-controlled mapping, largely owing to the great difficulty of detailed field mapping in the Duluth Complex. However, the intense faulting documented in this small area defines a structural style that may be common to much of the region. Certainly, the possibility of intense faulting and fracturing must be considered in any further work and interpretation of the Duluth Complex.

ECONOMIC MINERAL PRODUCTION IN MICHIGAN
PAST AND PRESENT

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ABSTRACT

Michigan's mineral production statistics have been compiled either in whole or in part from 1845 to the present. In 1877 Act 9 was passed which created the position of Commissioner of Mineral Statistics. The duty of the Commissioner was to give the governor an annual report about the yearly mineral production statistics and the development of the mining and smelting industries. Part of Act 9 required all mining companies to submit their production figures to the Commissioner. In 1911 the duties of the Commissioner were transferred to the Geological Survey, now a Division of the Michigan Department of Natural Resources.

Presently, the Geological Survey receives most of the yearly mineral production statistics, exclusive of petroleum and natural gas, through a memorandum of understanding with the U.S. Bureau of Mines. Company data submitted to the U.S.B.M. is sent on to the State. Oil and gas production is collected by the State Survey directly. Copper, silver and iron ore figures are also received separately for taxation as well as through the U.S.B.M.

Tabulations of the value of nonmetallic, metallic, and fuel minerals from 1910 to present show that until 1977, the fuel minerals were always the smallest group with the metallics and nonmetallics switching leading places several times. In 1977 the fuels formed the middle group for the first time.

Michigan's 1977 mineral production value, according to the U.S.B.M. annual, preliminary report, was \$1.51 billion. The 1976 total value set a record at \$1,543.5 million. In 1910 it was \$80.5 million.

Everyone of the 83 counties in the State contribute to the total mineral value. However, all of the metallic minerals and a large amount of the high value for nonmetallic minerals is produced in the Upper Peninsula. The balance of the nonmetallics and all of the fuel minerals are derived from the Lower Peninsula.

GEOCHRONOLOGY OF ARCHEAN ROCKS IN
MARQUETTE COUNTY, UPPER MICHIGAN

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According to Morey and Sims (1976) the Archean basement of the Lake Superior region is composed of two different terranes, a gneiss terrane and a granite-greenstone terrane, which differ in age, rock type, structural style, and metamorphic grade. They extend the boundary between these two terranes through the central part of Marquette County, Michigan, beneath the middle Precambrian rocks of the Marquette Range Supergroup. Locally, the Archean rocks north of the boundary, which are part of the granite-greenstone terrane, are known as the Northern Complex and those south of the boundary, which are part of the gneiss terrane, are known as the Southern Complex. If Morey and Sims' model is correct, rocks older than 3,000 m.y. should be present in the gneiss terrane, and the rocks of the granite-greenstone terrane should not be older than about 2,800 m.y. A geochronologic study was done on the rocks of the Northern Complex and on a granite body of the Southern Complex which had yielded anomalous Rb-Sr age systematics with one sample giving a 3,200 m.y. model age (Van Schmus and Woolsey, 1975), to verify or revise Morey and Sims' model.

The Northern Complex consists of granitic to tonalitic gneisses, with lesser amounts of granites, amphibolites, and volcanics, that extend approximately 80 kilometers east-west and 40 kilometers north-south. The eastern part of the Complex includes a greenstone belt. U-Pb isotope studies on zircons from samples of the gneisses and volcanics do not indicate an age any greater than 2,750 m.y. for rocks of the Northern Complex.

The rocks of the Southern Complex are primarily granitic gneisses with lesser amounts of granites, mafic gneisses, and amphibolites, which extend approximately 75 kilometers east-west and 50 kilometers north-south. One granite body, 1.5 by 4 kilometers in size, was mapped about 8 kilometers south of Ishpeming. It is a medium-grained granite which appears gray in outcrop in the western half and red in the eastern half. Parts of the granite body are quite porphyritic with aligned feldspar phenocrysts. Although no direct contacts were observed, the presence of gneissic inclusions suggest that the granite was intruded into the surrounding gneiss. Rb-Sr isotope data on whole-rock samples from the granite define a 2,400 m.y. isochron with a $\text{Sr}^{87}/\text{Sr}^{86}$ intercept of 0.7200. U-Pb isotope studies on zircon from the granite do not indicate an age any greater than 2,600-2,700 m.y. The granite is possibly remobilized crustal material as indicated by the high initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio.

Ages of the rocks studied from both these complexes conform with Morey and Sims' model, even though primary ages in excess of 2,800 m.y. have yet to be found from the Southern Complex.

INDUSTRIAL SAND AND SANDSTONE

RESOURCES OF MICHIGAN

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Michigan's silica, sand and sandstone deposits, which range in age from Middle Precambrian to Quaternary, embrace a considerable diversity of geological types and have a remarkable diversity of technological applications. Historically, Michigan sandstones were famous for two purposes: 1) the Jacobsville sandstone (Cambrian) used as a colorful dimension stone in the construction of larger buildings (churches, courthouses, breweries), mainly in the Upper Peninsula and 2) the Marshall sandstone (Devonian), utilized in the last half of the 19th century for abrasive wheels (Grind Stone City, Huron Co.). The spectrum of deposits and potential deposits, by formation, age and application, includes:

1. Middle Precambrian quartzites: Sunday, Sturgeon, Mesnard, Ajibik, and Goodrich quartzites: aggregate; the Ajibik may be of potential value for ferrosilicon.
2. Munising sandstone (Late Cambrian): glass-sand potential.
3. Sylvania sandstone (Lower Devonian): presently exploited near Rockwood as one of the premier glass-sands of the United States; also abrasive sand and silica flour.
4. Napoleon sandstone (uppermost Devonian): quarried near Jackson for flagging, riprap and sandstone-bituminous hot mix for pavement.
5. Pleistocene till, glaciofluvial deposits, and lakebeds: fill sands and aggregate.
6. Dune sands in southwestern Michigan (Quaternary): active mining for molding sands (considered the industry standard for such sands); also evaluated as glass-sand.

A POST TWO CREEKS BURIED FOREST
IN MICHIGAN'S NORTHERN PENINSULA

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ABSTRACT

In 1976-77, spruce and tamarack trees in growth position were exposed between six and eleven meters below the surface during construction of the Gribben tailings basin for the Cleveland-Cliffs Iron Company. The site, located sixteen kilometers southwest of Marquette, Michigan, lies within the outwash apron of the outer Marquette moraine. Throughout the excavation, there is no evidence that glacial override occurred following the period of growth such as the presence of distorted strata, sheared trees, or intercalated till.

The outer parts of two trees were dated at $9780 \pm 250^{14}\text{C.y.a.}$, W3904 and $9850 \pm 300^{14}\text{C.y.a.}$, W3866 (M. Rubin). Spruce needles from the upper part of the buried A₀ soil horizon were dated at $10,230 \pm 300^{14}\text{C.y.a.}$, W3896 (M. Rubin). The largest tree collected has a diameter of sixty centimeters and 150 growth rings. Most trees suffered a severely retarded growth rate during their final thirty or forty years of growth, a condition that is attributed to climatic deterioration accompanying the glacier's return.

Evidence in the Gribben tailings basin indicated a minimum period of plant growth of 150 years following recession of the Valdres (Great Lakean) Stadial. Tree growth in the basin was terminated by local ice-marginal ponding caused by glacial readvance into the area. Deposition of lacustrine sediment capped by outwash gravel and sand occurred during building of the Marquette-Munising moraine system. Similar dates have been obtained from detrital spruce and hemlock found in red till and red clay till in Michigan's westernmost county and near Ashland, Wisconsin at elevations 400 to 600 feet above present Lake Superior.

It appears that a glacial advance climaxed slightly less than 10,000 years ago, and at that time, almost all, if not all, of the Lake Superior basin was occupied by glacial ice. It is proposed that the name Marquette Stadial be adopted for the period of glacial advance and Gribben Interstadial for the preceding time of retreat.

THE PETROLOGY AND TECTONIC SIGNIFICANCE OF THE INTERFLOW SEDIMENTS IN THE
KEWEENAWAN NORTH SHORE VOLCANIC GROUP OF NORTHEASTERN MINNESOTA

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Interflow sediments occur as lenticular bodies between and crevice fillings, within, lavas of the North Shore Volcanic Group. Their structure, texture, and composition offer evidence of the depositional/erosional relationships between the volcanic and sedimentary accumulations and the surrounding borderland during Keweenawan rifting.

The majority of the 380 (total) of interflow sediments occur as bedded interflow sandstones, conglomerates, and minor shaly sediments. Tabular and trough cross-bedding, planar bedding and lamination, and ripple marks are the most prevalent primary structures. Other deposits include sediment-filled flow-top breccias, clastic dikes, and sedimentary/volcanic breccias. Nearly all interflow beds lie on uneroded flow tops. Most clastic dikes are the result of sediment filling fractures in upper lava surfaces; however, some were filled by sediment injected into lava fractures from underlying clastic deposits. Mud cracks, slump structures, and convolute laminations occur in most types of deposits.

These volcanogenic arkosic sediments are reddish-brown to buff, and consist of predominantly fine-to medium-grained, subrounded, well-sorted grains of plagioclase, clinopyroxene, magnetite, and various rock fragments. The dominant rock fragments are volcanic; however, agate, chert, shale, and glass shards also occur. Actual tuff beds are rare. Minor constituents are potassium feldspar, quartz, and accessory heavy minerals. Grains are fresh to altered, and in many cases, replaced by various zeolites, chlorite, calcite, and potassium feldspar. In addition to silica and hematite, these minerals form the major chemical cements.

Paleocurrent indicators show predominant current flow southward and southeastward towards the present Lake Superior Basin. These data imply a fluvial environment of deposition, and sedimentary structures support this implication. Several deposits may reflect influences of fluvio-lacustrine and eolian environments.

The response of the Keweenawan terrain to rifting and basinal development is interpreted from a combination of sedimentological, petrographic, and clastic dike orientation analyses. In general, sediment bodies are thicker and more variable in lithology in the area from Tofte to Grand Portage than in the area from Duluth to Tofte. This may suggest more ponding and/or longer periods of volcanic quiescence in the northeastern portions of the basin. Petrology indicates predominantly local (Keweenawan) sources for sediments; however, several deposits had variable sources which may include some pre-Keweenawan sediments and intrusions. The presence of agate fragments in some deposits implies mineralization of lava prior to erosion, and thus an earlier cycle of volcanism, burial, and uplift in the source area. Data obtained from clastic dike orientations is significant because sediment filling (by whatever process) occurred near the time of lava deposition, thus dating the stress patterns at that time. Although many of these orientations are scattered and reflect cooling fractures filled with sediment, some conjugate orientations occur which may reflect regional stresses.

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Geology and Mineralogy of Northern Michigan Phosphorites

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Widespread occurrences of Middle Precambrian phosphate-bearing strata in the central part of the Upper Peninsula of Michigan were first reported by Cannon and Klasner (1976). Surface exposures of the bedded phosphorites were found at margins of several sedimentary basins near the contact with older Archean crystalline rocks. The thickest known phosphorite section (100 m) is in Section 15, T49N R28W, on the eastern margin of the Dead River Basin 17 miles northwest of Ishpeming, Michigan. The rocks here strike NS and dip steeply to the west. Early in 1977, a bulk surface sample was collected for mineralogical study and preliminary beneficiation tests by the Institute of Mineral Research (IMR). During the summer of 1977, the upper, richest section was diamond drilled by IMR in cooperation with the Michigan and U.S. Geological Surveys.

Results of this work showed the apatite to be present as pebbles, oöids and as fine crystallites in a quartzitic matrix. Most of the apatite is in dark, elongate pebbles 1-30 mm in length. Aphanitic apatite comprises 75-80% of the pebbles. Submicron graphite, pyrite euhedra, quartz and stilpnomelane are also present. This apatite has been identified by XRD as francolite, the carbonate fluorapatite.

Some of the rich surface beds contained as much as 15% P_2O_5 , but the bulk surface sample averaged 6.95% P_2O_5 . However, in the drill core apatite decreased with depth, although intermittent richer zones were encountered. Calcite was observed to be more abundant with depth and may have replaced some apatite. Several pyrite-rich zones were encountered, but surface weathering had oxidized much of the pyrite in the upper 5 meters. The conglomerate containing the apatite pebbles appears to have a shale-pebble origin and the occurrence may be a channel deposit.

The best results of initial beneficiation tests using a standard fatty acid float produced a 27% grade P_2O_5 at 60% recovery.

Reference

Cannon, W. F. and Klasner, J. S. (1976), Phosphorite and Other Apatite-Bearing Sedimentary Rocks in the Precambrian of Northern Michigan, U.S.G.S. Circular 746, 6 p.

GEOLOGY OF THE IRON FORMATION AND ASSOCIATED ROCKS
OF THE JACKSON COUNTY IRON MINE, JACKSON COUNTY, WISCONSIN

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ABSTRACT

Precambrian magnetite iron formation crops out as low hills in Jackson County, Wisconsin. The Jackson County Iron Company's open pit taconite mine was opened in the largest of the hills. The ore body mined strikes northwest and dips 70-80 degrees southwest. The ore body is a lens 915 meters in length and 150 meters in width. It averages about 35% magnetite. Dominant mineral assemblages within the iron formation are:

1. magnetite-quartz-grunerite-ferroactinolite
 2. magnetite-quartz-cummingtonite-biotite
 3. magnetite-quartz-garnet-Ca-rich hornblende-ferroactinolite-grunerite
- Amphiboles commonly contain visible exsolution features. Ca-rich hornblende (hastingsite) replaces garnet.

Southwest of the iron formation is a highly weathered siliceous schist mapped as the hangingwall schist. It is composed of quartz, biotite, and sericite. Weathering decreases with depth. The footwall schist, northeast of the ore body, is identical to the unweathered hangingwall schist. Both are composed mainly of three assemblages:

1. quartz-chlorite-muscovite-andalusite
2. quartz-biotite-chlorite-staurolite-garnet-andalusite-muscovite
3. quartz-biotite-oligoclase-muscovite

Phase relations suggest that the rocks attained chemical equilibrium at staurolite-grade metamorphism. Texturally the footwall schist ranges from a highly foliated coarse-grained schist to a nearly granular schist. Interlayered with the pelitic schist are zones of grunerite-garnet-quartz iron formation and poorly foliated, dark green amphibolite.

A lenticular zone of talc schist about 350 meters long and 40 meters wide is situated within the iron formation in the eastern portion of the mine. The assemblages talc-garnet-andalusite, talc-biotite, and talc-cummingtonite are locally present.

Compositional banding of quartz and magnetite is prominent within the iron formation and provides the contrast necessary for viewing minor structure. The rocks have been isoclinally folded around nearly vertical axes and sheared into boudins. Features observed include: 1) small boudins and isolated and rotated fold hinges of minor isoclinal folds, 2) transposed, parallel bedding, 3) prominent lineation of amphiboles developed in the plane of compositional banding, and 4) distinct thickening and thinning of iron formation along strike.

Upper Cambrian Mount Simon Sandstone unconformably overlies the Precambrian terrane. Within the Mount Simon a basal conglomerate containing clasts of angular hematitic iron formation is well developed. The conglomerate grades rapidly upward into well sorted, poorly indurated sandstone.

The deposit has not been dated, but structural and metamorphic style indicate that it may be Archean.

The Unconformity-Type Proterozoic Pitchblende Ore Body Model
And Its Application to Northern Michigan

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Previous studies establish that this class of ore bodies has a characteristic setting: a short distance below an unconformity, in almost any kind of host rocks that have developed permeability through either physical or chemical ground preparation (or both). This chemical ground preparation is represented in the vicinity of the ore body also by various types of low temperature alteration, none of which need to be a direct effect or cause of the deposition of the pitchblende. The quantity and intensity of alteration cannot be related to the size of the pitchblende deposits. In a similar coincidental fashion, pitchblende ore bodies can adjoin also economic concentrations of nickel-cobalt arsenides and gold. By contrast, graphite and pyrite are interpreted to be related more directly to the ore body and to the mineralization process.

An evaluation of the geochemical system indicates there to be adequate uranium sources and uranium transport mechanisms. The major outstanding problem concerns the locus and manner in which uranium is deposited as pitchblende. There is some indirect geological evidence to suggest that the precipitation results from the mixing of oxidized uraniferous fluids with those containing large quantities of such reductants as methane and H_2S . These substances are capable of precipitating pitchblende within low temperature systems, with very little evidence remaining of their previous existence.

Applying the model to northern Michigan one can note that a very thick body of young Precambrian continental redbed Jacobsville sandstone rests unconformably on a floor of middle and lower Precambrian rocks. Thus, the first requirement of the model is met, that of an oxidized system situated above a more reduced one. The basement is cut by a series of easterly trending major faults and diabase dikes. These provide the second requirement, that of secondary permeability in the basement. The middle Precambrian low grade metasedimentary rocks below the Jacobsville are quite carbonaceous and pyritic. It is proposed that because of their low metamorphic grade these rocks could have provided the gaseous hydrocarbons or possibly H_2S that are required by the model to precipitate pitchblende in and along the permeable zones of mixing.

Problems in Paleogeographic Reconstruction of the Chocelay and lower Menominee Group Sedimentation, Marquette Range Supergroup, Lake Superior region

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Due to structural complications and few outcrops, little is known about the regional sedimentary facies and source areas of the Chocelay and Menominee Groups of the Marquette Range Supergroup and their Animikian equivalents. In structurally deformed areas isopachous and paleocurrent data are equivocal (Ramsay, 1961, 1966), but have been used in previous reconstructions (Taylor, 1972, Sims, 1976). Trends in regional mineralogy are employed by others (Morey, 1973, Gair, 1975).

Data bearing on paleogeographic reconstructions of the Chocelay Group include: 1) an increase in feldspar and grain size in basal quartzites toward the Lake Mary Quadrangle (Bayley, 1959, Gair and Weir, 1956); 2) strongly unimodal NW - SE to weakly unimodal NE - SW orientations of symmetric-ripple mark crests in quartzites; 3) regional decrease in basal quartzite thickness toward the west (excluding the poorly understood Trout Lake Formation) (Sims, 1976); 4) local westerly thinning of quartzite in the Gogebic Range; 5) restriction of large domal stromatolites to the Kona Dolomite (Marquette area); 6) greater volume of intercalated clastic silica in the Kona Dolomite than stratigraphic equivalents; 7) presence of subrounded quartzite and chert pebbles in channel deposits of the Randville Dolomite. Symmetric-ripple spacing in quartzite indicates short period waves. Evaporite mineral casts (Taylor, 1972) with mud cracks in dolomitic units indicate a semi-arid to arid environment with periods of subaerial exposure.

North - south facies transition in the lower Menominee Group continues into Iron Formation sedimentation (Gair, 1975). Available paleocurrent data suggest flow parallel to the trend of the transition (E - W).

These available data, though obviously scant, support the interpretation of a shallow basin deepening gently to the south, with a major detrital source to the north, and a local source for feldspar and subrounded pebbles near the Lake Mary Quadrangle. Shorelines possibly extended NW - SE during deposition of Chocelay sediments. Water depth varied from intertidal (possibly supratidal) to shallow subtidal for the entire area, thus the significance of the term "shoreline" for the dolomitic units is questionable. The Wewe Slate may represent a still deeper-water phase of sedimentation (Puffett, 1974, Gair and Thaden, 1968). Lower Menominee Group sedimentation was similarly influenced by a northern source (Morey, 1973) and by mean water depths increasing southward, but the contribution of local faulted uplifts is indicated (Gair, 1975, James, 1954).

THE GEOLOGY OF THE GORE MOUNTAIN GARNET DEPOSIT,
SOUTHEASTERN ADIRONDACKS, WARREN COUNTY, NEW YORK

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The garnet deposit, a garnet amphibolite, is located on the north slope of Gore Mountain in the southeastern Adirondack Highlands. The major rocks of the area are: 1) rocks of charnockitic affinity, 2) anorthosite, and 3) corona-bearing olivine gabbro; all of these rocks are metamorphosed to the upper amphibolite or hornblende granulite facies.

The garnet amphibolite contains euhedral to anhedral garnet porphyroblasts which are commonly 10-20 cm in diameter (some range up to 30 cm). These garnets are surrounded by a 1-2 mm rim of plagioclase (an₅₂) and biotite, a thick (up to 10 cm) shell of hornblende, and often a pressure shadow of plagioclase (an₄₀) and orthopyroxene (en₆₇). Electron microprobe analyses show the composition of the garnets to be remarkably uniform for garnets of this size. To the north, the garnet amphibolite grades through a 2 m transition zone into a layered gabbro containing igneous olivine, pyroxenes, and plagioclase and corona structures of metamorphic pyroxenes, garnet, and plagioclase. This contact is characterized by major changes in mineral proportions and texture while the change in bulk chemistry is small (an increase in H₂O and Fe⁺³/Fe⁺² toward the garnet amphibolite). Electron microprobe analyses show that compositional variations between minerals occurring in the garnet amphibolite and gabbro are very small; compositions are: plagioclase (pl)-an₃₉, garnet (g)-al₄₇py₄₀gr₁₂sp₁, orthopyroxene (opx)-en₆₈, hornblende (h)-paragasite, clinopyroxene (cpx)-augite, and magnetite (mt). These two rocks are surrounded by anorthosite on the west, north, and east. The gabbro contains xenoliths of deformed anorthosite. To the south, there is a sharp contact with syenitic granulite (mangerite); patches of anorthosite up to 5 m thick occur along this contact.

The following geologic history is proposed. A hot dry gabbroic magma was intruded along the contact of already deformed mangerite and anorthosite. The magma crystallized slowly without tectonic disturbance to produce the layered gabbro. Water from an external source was absorbed by the margin of the gabbro during subsolidus cooling causing a transformation from gabbro to garnet amphibolite following the reaction:

$19 \text{ pl} + 8 \text{ cpx} + 10 \text{ opx} + 4 \text{ ol} + 1 \text{ mt} + 6 \text{ H}_2\text{O} \rightarrow 6 \text{ h} + 9 \text{ pl} + 4 \text{ g} + 1 \text{ opx}.$
A petrogenetic grid suggests that a temperature of about 800°C and a load pressure of 7-8 kb is consistent with this reaction. Growth of large garnets consumed plagioclase yielding a hornblende shell around each garnet. Later deformation produced pressure shadows around the garnets and a weak foliation through the garnet amphibolite.

Reference

Luther, Frank R., 1976, The petrological evolution of the garnet deposit at Gore Mountain, Warren County, New York; unpublished dissertation, Lehigh University.

THE GEOCHEMISTRY OF KEWEENAWAN LAVAS OF THE MAMAINSE POINT FORMATION, ONTARIO

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The Mamainse Point Formation outcrops at Mamainse Point, about 80 km north of Sault Ste. Marie, Ontario. It consists of tholeiitic flood basalts with rhyolites and conglomeratic sediments, and spans the palaeomagnetic reversal normally regarded as the boundary between Lower and Middle Keweenawan. The flows consist of olivine-phyric melaphyres at the base which pass up into feldspar-phyric melaphyres and ophites. The thin Alona Bay sequence is also olivine-phyric and probably correlative with the basal section of the Mamainse Point sequence.

Low-grade, burial metamorphism has caused zeolite-grade secondary minerals to develop, both within the rock and in veins and vesicles. Although laumontite occurs throughout, a crude metamorphic zoning is developed with epidote occurring mainly in the basal section and stilbite in the upper parts. Heterogeneity, with the development of epidote-, chlorite- and albite-rich-metadomains, is restricted to feldspar-phyric melaphyres in lower parts of the section. The metamorphism was accompanied by increases in Na, K, Rb, Li, Ba, Fe_3/Fe_2 , $\text{H}_2\text{O}+$ and CO_2 , and increases or decreases in Ca, Sr and Cu. Al, ΣFe , Ti, P, Y, Zr, Nb, $?\text{FeO}_T/\text{MgO}$ and $?\text{MgO}$ appear to be immobile or little affected by the alteration. The immobile trace elements confirm the tholeiitic nature of the lavas and suggest an ocean-floor to within-plate character.

The occurrence of a suite of flows of distinctive chemical type beneath the "Great Conglomerate", but not repeated above, would suggest the triple reversal in the palaeomagnetic stratigraphy of Mamainse Point¹ is real and not due to strike fault repetition.

¹Palmer, H.C. (1970) Paleomagnetism and correlation of some Middle Keweenawan rocks, Lake Superior. Can. Jour. Earth Sci., 7, 1410-1436.

THE DISTRIBUTION OF URANIUM AND THORIUM
IN THE WOLF RIVER BATHOLITH, NORTHEASTERN WISCONSIN

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Measurements of outcrop radioactivity at over 175 locations and whole-rock uranium and thorium analyses by gamma spectroscopy have revealed significant differences in the radioactive character and radioelement distribution of several of the lithologic units that comprise the Wolf River Batholith. The batholith, dated about 1500 m.y., is a large epizonal anorogenic composite pluton consisting mainly of quartz monzonite and granite with much lesser amounts of monzonite, syenite, and rhyolite. For the purposes of this study the batholith has been arbitrarily divided into a southern section and a northern section.

In the southern section, the Red River quartz monzonite, the most radioactive unit of the entire batholith, is considerably more radioactive than either the Wolf River quartz monzonite or the Waupaca quartz monzonite. Two somewhat anomalous areas, one east of Tigerton and the other near Big Falls, have been located within the more radioactive interior region of the Red River quartz monzonite. Preliminary analyses of typical samples of Red River quartz monzonite yield average values of 37 ppm Th and 10 ppm U ($\text{Th/U} = 3.7$) while samples of mafic-rich material yield individual values as high as 150 ppm Th and 190 ppm U. Peripheral areas of the Wolf River quartz monzonite, particularly near its contact with the Tigerton anorthosite, are more radioactive than central areas. The Waupaca quartz monzonite and the Wolf River quartz monzonite have similar average outcrop radioactivities.

The Belongia granite, slightly more radioactive than the Wolf River quartz monzonite, is the most radioactive unit in the northern section of the batholith. Marginal regions of the granite tend to be more radioactive than inner areas. Typical samples of Belongia granite yield preliminary average values of 27 ppm Th and 6.3 ppm U ($\text{Th/U} = 4.3$). Average outcrop radioactivity of the Hager rhyolite is slightly less than that of the Belongia granite. Samples of the Peshtigo monzonite, the least radioactive unit of the entire batholith, yield preliminary values of 14 ppm Th and 2.6 ppm U ($\text{Th/U} = 5.4$). Average outcrop radioactivities of the Hager feldspar porphyry and the Hager syenite are intermediate between that of the Belongia granite and Peshtigo monzonite.

PILOT EXPLORATION GEOCHEMICAL SURVEY OF URANIUM IN
ORGANIC-RICH LAKE SEDIMENTS, NORTHEASTERN MINNESOTA

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ABSTRACT

As part of the National Uranium Resource Evaluation Program (NURE Program) of the U. S. Department of Energy (DOE), Union Carbide-Nuclear Division, the DOE contractor responsible for geochemical exploration surveys, decided to investigate the use of organic-rich lake sediments for the NURE Program in Minnesota. This study was done in conjunction with the Minnesota Department of Natural Resources (MDNR). The MDNR had previously applied organic-rich lake sediment to various areas of northern Minnesota for the evaluation of base metal potential. The observations and conclusions described here are those of the MDNR and do not necessarily represent those of Union Carbide-Nuclear Division.

Organic-rich lake sediment samples were selected to represent five major geologic formations from previous sediment surveys conducted by the MDNR in the Western Vermilion District of northeastern Minnesota. The objectives of this study were: 1) to determine whether or not uranium in the various rocks is reflected in the sediment, and 2) to determine if any treatment of the raw data was necessary in order to use this information for evaluation of uranium potential.

Results indicate that the uranium content of the bedrock is reflected in the sediment. The uranium concentrations in sediments over the Vermilion Massif are about twice those over other rocks; which compares with the difference in relative radioactivity levels of the same rocks as reported by Ojakangas (1976).

Examination of the data suggests that uranium may be concentrated in the inorganic fraction of the sediment. Although the reflection of the uranium content of the bedrock is discernible by basing the uranium concentration on the unignited (total) sample weight, the distribution of uranium based on the ignited sample weight (inorganic fraction) more clearly reflects the bedrock geology because of loss-on-ignition variation between samples. No significant relationships were observed for uranium and iron or manganese, which would suggest that uranium is not preferentially adsorbed by iron-manganese hydroxides and, therefore, does not create elevated uranium values unrelated to the bedrock geology.

REFERENCE

Ojakangas, R.W., 1976, Uranium Potential in Precambrian Rocks of Minnesota: Report to U. S. Energy Research and Development Administration, Contract AT(05-1)-1652, 259 pages.

A PETROGRAPHIC GUIDE FOR UNIT IDENTIFICATION OF THE PARTRIDGE RIVER TROCTOLITE, DULUTH COMPLEX, MINNESOTA

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The Partridge River Troctolite (PRT) has a lithology similar to that exhibited by the South Kawishiwi Intrusion (SKI). However, the units recognized in the SKI do not extend into the PRT (Bonnichsen and Tyson, 1975). The PRT does exhibit a cryptic-like layering as it becomes more mafic with depth. However, there is no distinct variability in the mafic mineral species which thus provides little aid in the definition of correlatable units. This study of one drill core has concentrated on the silicate and oxide mineralogy and their relationships with depth. Five specific petrographic relationships used in conjunction have been determined as indicators of units: (1) Some biotite grows epitaxially to augite. This epitaxial biotite is characteristic of the lower portion of the drill core studied. (2) Inclusions of biotite aligned in parallel arrays within augite are common in the upper half of the drill core. This occurrence is believed to be a replacement texture. (3) Oxide inclusions, reddish-brown rutile and opaque ilmenite, appearing in augite as minute blebs and rods are arranged in rows, locally throughout the drill core and may represent gradational contact zones. (4) The texture and amount of exsolved oxide inclusions in the plagioclase crystals varies consistently with depth and is believed to be the most diagnostic feature of differentiation. (5) A wormy, symplectitic intergrowth of plagioclase and orthopyroxene similar to Taylor's (1964) mymerkite is evident. This fine grained symplectite appears to have set up its own plagioclase domain wherein the opx blebs exist. Another symplectite, coarser in grain size, appears as an earlier phase relative to the fine grained symplectite and does not exhibit a separate domain.

Of the petrographic relationships used, only two appear to be representative of the primary conditions of the magma; the oxide inclusions in augite and in plagioclase. The others appear to be due to later stages of crystallization or deuteric alteration. The use of these relationships will allow for the definition of crystallization units which heretofore have not been described for the Partridge River Troctolite.

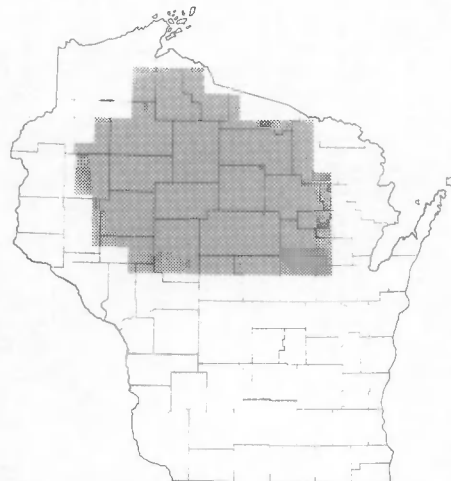
AEROMAGNETIC MAP OF NORTHERN WISCONSIN
(Poster Session)

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ABSTRACT

In 1973, the Geological and Natural History Survey and the Department of Physics, University of Wisconsin-Oshkosh, initiated a detailed aeromagnetic survey of northern Wisconsin with primary funding from the Upper Great Lakes Regional Commission. The map on display is a color compilation at 1:250,000 by Zeitz, Karl and Ostrom (1977) published as U. S. Geological Survey Open-file Report 77-598, and is available in black and white as U. S. Geological Survey Miscellaneous Field Study MF-888.

The map is derived by photographic reduction of 86 aeromagnetic survey maps published at a scale of 1:62,500 by the Geological and Natural History Survey with a standard line spacing of 0.8 kilometers flown north-south at an elevation of 150 meters (48,000 square kilometers of coverage). The process of construction of the maps consisted of removing the regional magnetic variation of the earth's total magnetic field as determined by Fabiano and Peddie (1969), and contouring the residual at 20 gammas. If the regional variation is not removed, a severe banding effect, which is not related to the geology, subdues the magnetic pattern caused by the geology. An additional 3,400 square kilometers were flown in 1977.



An obvious correlation when the map is compared to a geological map (Sims, Cannon and Mudrey, 1978, and presented at this Institute on Lake Superior Geology meeting) in addition to the parallelism of magnetic and geological trends is that the broad magnetic "low" areas coincide very well with regions of predominantly metasedimentary and metavolcanic rocks, and their gneissic equivalents. The magnetically "high" areas, on the other hand, correlate well with more extensively granitized terranes. The Gogebic Iron Range, other iron formations, and Middle and Late Precambrian gabbroic plugs are readily discerned as magnetic highs of over 7,000 gammas.

OFFSHORE SAND AND GRAVEL EXPLORATION
IN WESTERN LAKE MICHIGAN

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Offshore sand and gravel deposits are potentially important resources, especially near high-use urban centers which usually lack nearby land sources and, thus, require transport of this low-cost, high-bulk commodity from a distance. Conventional acoustic profiling and coring of these deposits is difficult, however, because the high acoustic impedance of sands and gravels inhibits sound penetration and because conventional coring is generally inapplicable.

At three test areas in Western Lake Michigan - off Kewaunee, Manitowoc, and Rawley Point - experiments to determine the lateral extent and thicknesses of sands and gravels were conducted using combined acoustic and Schlumberger resistivity profiling, resistivity sounding from the water surface, and selective surficial sediment sampling. Previous detailed sediment sampling by other workers showed temporally changing sediment patterns off Kewaunee, and laterally uniform, well-sorted, fine sands off Rawley Point. Knowledge of the apparent resistivities obtained over these sediments was used to determine offshore extensions of known onshore gravels at Manitowoc.

Initial testing of this integrated geological-geophysical approach shows that:

(1) Where surficial sediments are thin, there is low correlation between the observed apparent resistivity and the sediment type inferred from acoustic profiles or physical samples. Instead, the contours of apparent resistivity reflect the trends in the till and glaciolacustrine clays beneath the thin sediments and point to prospective areas, such as probable buried channels or ancient shorelines.

(2) In areas where acoustic profiles show thick sediments, the observed apparent resistivity is correlatable with the type and distribution of the sediment. The lateral uniformity of the acoustically-impenetrable sands off Rawley Point, for example, is reflected in the relatively constant apparent resistivity over most of the area.

(3) Given the water depth from acoustic profiles, the water resistivity from independent specific-conductance measurements, and the resistivity ranges of the sands and underlying till from resistivity profiling elsewhere, then, resistivity sounding yields a resistivity-depth structure which is helpful in estimating thicknesses. The electrical pseudo-section also aids in interpreting the lateral changes in sand thickness.

(4) The offshore extensions of the thick onshore gravel deposits are mappable on the basis of their relatively high resistivity and potential subsurface deposits undetectable from surficial samples are inferred from the resistivity data.

CRITERIA FOR ALLIGATOR RIVER TYPE
URANIUM DEPOSITS IN THE UNITED STATES

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Three geologically similar uranium subprovinces--Rum Jungle, South Alligator River Valley, and Alligator Rivers--are present in the top end of the Northern Territory of Australia. Pitchblende deposits, with minor secondary minerals, are found in a specific, generally carbonaceous and chloritic horizon of Lower Proterozoic metasedimentary rocks. This horizon consists of the presumably equivalent Golden Dyke, Koolpin, and Cahill Formations in the three respective subprovinces. In the Rum Jungle and Alligator Rivers subprovinces, Archean basement rocks are also exposed.

The ore bodies generally occur at relatively shallow depths, and most intersect the eroded Lower Proterozoic surface. The grade of ore generally ranges from 0.25 to 0.40 percent U_3O_8 , with short lengths of core as rich as 72 percent. Structural preparation of the host rocks is evident in each deposit. Remnants of a hematite-quartz breccia are associated with many ore deposits, and may represent a Proterozoic regolith.

Throughout the eastern part of the region, the Middle Proterozoic (1500 m.y.?) Kombolgie Formation of conglomerates, quartzose sandstones and volcanics, overlies the Lower proterozoic metasedimentary rocks with angular unconformity. All ore bodies in the Alligator Rivers subprovince occur near this unconformity. In the South Alligator River Valley subprovince, the Edith River Volcanics and the overlying Kombolgie Formation overlie the Lower Proterozoic rocks, and all ore deposits occur near this unconformity. In the Rum Jungle subprovince, the Depot Creek Sandstone of Upper Proterozoic age (<1400 m.y.) may have had essentially the same relationship to the Lower Proterozoic and to the ore deposits as do the Kombolgie and Edith River Volcanics in the other subprovinces.

Evidence can be amassed for both syngenetic and supergene origins. Most Australian workers seem to prefer a syngenetic origin with initial deposition of uranium in Lower Proterozoic geosynclinal rocks during sedimentation. Additional enrichment is attributed to anatexis and metamorphism, with later local supergene enrichment. The original sources of the uranium are generally thought to be the Archean complexes. Some workers suggest the Edith River Volcanics as the source rock in the South Alligator subprovince. Alternatively, a strong case can be made for a dominant supergene origin, with oxidizing waters having carried uranium along the eroded Lower Proterozoic surface either before, during or after deposition of the overlying rock units.

What is the applicability of these criteria to exploration in the United States? Regardless of the hypothesis of origin, the major field criteria remain essentially the same. The presence of a major unconformity is of primary importance, as is the reducing nature of the structurally prepared host rocks. The significance of the relative ages of the rock units beneath and above the unconformity is not clear.

Relations Between Soil Geochemistry and Bedrock Geology,
Iron County, Wisconsin

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A heavy metal geochemical soil (B horizon) and biogeochemical (aspen twigs) survey was completed over approximately 100 square miles directly south of the Gogebic Range in a granite-greenstone terrain in Iron County, Wisconsin. Soil samples were dry sieved, the -80 mesh fraction collected and taken into solution using a lithium metaborate fusion technique. The twigs were ashed and dissolved in 2M HCl. Nearly 3000 elemental analyses were made using atomic absorption spectrophotometry. These results were processed by computer and statistical parameters assigned to all anomalous values.

Geochemical data indicates there is communication between the B soil horizon in the glacial till and the underlying bedrock. Nickel and copper are distinctly lower in soils overlying "granites" than in soils overlying greenstones, and allow the underlying rock types to be distinguished with greater than a 97.5% confidence level. In two areas where Zn concentrations are known to be greater than 0.1% in parts of the bedrock, anomalous values of Zn in the overlying soil samples occur.

BASELINE URANIUM AND THORIUM IN ARCHEAN AND LOWER PROTEROZOIC
ROCKS OF THE MARENISCO-WATERSMEET AREA, MICHIGAN

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Radiometric dating in the Marenisco-Watersmeet area, northern Michigan, has delineated a lower Archean (Precambrian W) gneiss terrane at least 3,400 m.y. old adjacent to and south of a greenstone-granite terrane (2,600 to 2,700 m.y. old). Both terranes formed the basement for the lower Proterozoic (Precambrian X) sedimentary and volcanic rocks of the Marquette Range Supergroup. The gneisses were involved in folding and metamorphism during the Penokean orogeny ($1,750 \pm 50$ m.y. in this area). Analyses of U and Th in samples collected for radiometric dating provide baseline data for evaluating radioelement mobility, and possibly enrichment, during reactivation of the ancient basement rocks. The lower Archean gneiss at Watersmeet contains 1.4 to 14 ppm U and 9 to 35 ppm Th. The available data suggest U and Th enrichment in more highly cataclasized facies of the gneiss. A leucogranite dike in the gneiss, provisionally related to the late Archean event, contains 18 ppm U and 68 ppm Th, and field scintillometer measurements suggest that these high values are common in the dikes. The granite near Thayer of Fritts (1969), also thought to be reactivated Archean gneiss, has U and Th contents similar to those of the gneiss at Watersmeet. A leucocratic phase of this rock contains 21 ppm U and 29 ppm Th. The Puritan Quartz Monzonite, a late Archean intrusion in the greenstone-granite terrane, is higher than average in Th content and Th/U ratio. Uranium ranges from 2.5 to 8 ppm and Th from 17 to 62 ppm. In all the crystalline rocks, K and U vary independently, a feature suggesting post-crystallization movement of U. Metagraywackes of the Marquette Range Supergroup are consistently low in both U and Th, with averages of 2.6 ppm U and 6.6 ppm Th. These values are similar to those of other graywackes and may reflect a high volcanic component in the detritus.

NATIVE COPPER DEPOSITS DERIVED FROM NEARBY
KEWEENAWAN BASALT BY COMBINED IGNEOUS,
DEUTERIC, AND METAMORPHIC PROCESSES

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ABSTRACT

A thick (60 m) basalt flow (Scales Creek flow) from the middle of the Portage Lake Volcanics was intensively studied petrographically and its constituent minerals analyzed by electron microprobe techniques. In the interior of the flow, which is nearly unaltered chemically: 1) whole rock Cu abundance is 110-150 ppm; 2) microscopically-visible native Cu is present within pseudomorphs after olivine; and 3) Cu concentrations in oxidized titanomagnetite (2-3 modal %) are 2000-2500 ppm. With increasing degree of deuteric and metamorphic alteration, Cu was released from primary minerals, disseminated, and incorporated into secondary minerals. Dominant mechanisms of Cu concentration after extrusion are: 1) igneous differentiation by gaseous transfer within the flow, 2) release of native Cu during deuteric oxidation of Fe-Ti oxides and Fe-Mg silicates, and 3) mobilization and redistribution by later metamorphic fluids.

Extrusion of the flow onto a wet surface produced a basal zone of high oxygen and volatile activity, accompanied by gaseous transfer downward of Cu, Fe, and Ti. This zone, enriched to 420 ppm Cu by this gaseous transfer, was immediately above the vesicular top of the underlying flow, and provided a source of Cu for later circulating metamorphic fluids which followed the permeable flow-top channelways. If this process was repeated elsewhere within the volcanic pile, channelways below the basal zones of thick flows may, in some cases, have unusually high Cu concentrations.

POSSIBILITY OF MISSISSIPPI VALLEY-TYPE ORE DEPOSITS IN INDIANA
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The midwestern United States is recognized as a lead-zinc metallogenic province due to the occurrence there of low-temperature ore deposits of the Mississippi Valley-type. Such deposits commonly occur within Paleozoic dolomite host rocks on the flanks of structurally high areas far from regions of igneous activity. They are characterized by simple mineral suites, usually sphalerite, fluorite, galena, or barite, that are believed to have formed at moderate temperatures from strong brines. One explanation of the origin and characteristics of Mississippi Valley-type deposits suggests that they formed as a natural consequence of basin development when sedimentary connate waters, the metal-bearing brines, migrated updip from the basin and precipitated ore minerals upon encountering sources of reduced sulfur.

Indiana lies near this general province and contains many geologic features that appear suitable for the development of Mississippi Valley-type deposits. A structurally high region collectively known as the Cincinnati and Kankakee Arches, crosses Indiana and separates the Michigan and Illinois Basins. Paleozoic carbonates occur in the Knox Dolomite (Cambrian and Ordovician); Black River and Trenton Limestones (Ordovician); Salamonie, Louisville, and Wabash Formation (Silurian); Muscatatuck Group (Devonian); and Salem, St. Louis, and Ste. Genevieve Limestones (Mississippian). Unconformities exist at the tops of Knox, Trenton, and Wabash Formations. Numerous occurrences of sphalerite, fluorite, barite, and galena have been noted in Indiana in the past, and more than 60 new but generally minor occurrences have been found during this recent study, many in the Black River-Trenton section, especially in northern Indiana where extensive dolomitization has occurred. The dolomitized reef facies of the Wabash Formation had many mineral occurrences in northern Indiana as did the overlying Devonian limestones. Limestones of the Salem and Ste. Genevieve also had occurrences of sphalerite and fluorite in southern and southwestern Indiana.

Limited information from fluid inclusions in sphalerite, barite, and fluorite indicates that some samples have formed from brines in the range of temperatures reported from Mississippi Valley-type deposits. Minor elements in 80 sphalerite specimens from Indiana included cadmium (.03 to 6.9 percent), iron (.01 to .61 percent), and lesser amounts of gallium, germanium, copper, and manganese. Silver was not detected in sphalerite samples.

Due to favorable geology, occurrence of minor amounts of ore minerals, and tentative evidence that fluids of the ore-forming type passed through suitable host rocks, a real possibility exists that undiscovered Mississippi Valley-type ore deposits may occur in Indiana.

PRECAMBRIAN X PALEOPOLES FROM THE UPPER PENINSULA AND A NEW METHOD FOR REMANENT VECTOR DETERMINATION

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A method will be described which makes it possible to use the three-dimensional magnetic modeling program of Whitehill modified so as to take the remanent magnetic vector into account so that it is possible to determine the declination and inclination of a body's remanent vector directly from observed magnetic data. This is done by using a computer program named SHALOCI written by William Ciolek, Mark Locher, and the author to calculate the induced field due to the body. This induced field is then subtracted from the observed data to yield the magnetic field due to the body's remanent vector. SHALOCI is then used again to calculate the magnetic fields due to various vectors in order to match the observed anomalies. This method is accurate to within 10 degrees of the vector's true declination and 4 degrees of its inclination. Because of this, the results of this method are often useful in determining the age of a body which is very helpful in Precambrian shield areas like the Upper Peninsula of Michigan where there are magnetic bodies of different ages. At present, this computer-oriented approach is limited to bodies with fairly strong remanent magnetic vectors and which have not been metamorphosed very severely, but future work may be able to alleviate these problems.

Paleomagnetic work done on samples from a metadiabase dyke of of supposed Precambrian X age in connection with the magnetic-modeling described above has yielded some interesting results. Thermal demagnetization has established a paleopole that falls on the apparent polar wandering curve for North America either at 2.04 bybp or 1.84 bybp depending on whether it is normal or reversed. Further work is being undertaken to clarify the situation, but it is clear that the long held idea that the many positive magnetic anomalies in the Upper Peninsula of Michigan were due to "normally" magnetized Precambrian X metadiabases will have to be revised in light of the fact that they yield north-seeking paleopoles in the Southern Hemisphere.

Precambrian geologic framework of northern Wisconsin

by

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Northern Wisconsin contains rocks belonging to each of the three major subdivisions of the Precambrian. Lower Precambrian (Archean or Precambrian W) rocks constitute the basement. Except for the Gogebic Range and vicinity, which is underlain by 2,700-m.y.-old greenstone-granite complexes, the basement rocks are dominantly gneisses and amphibolite. Minimum ages for the gneisses of 2,800-3,000 m.y. have been obtained at a few localities in central Wisconsin (by W. R. Van Schmus) and near Morse, south of Mellen. Middle Precambrian (Precambrian X) supracrustal rocks occur on the Gogebic Range, in a 75-km-wide east-trending belt across northern Wisconsin, and in Marathon County and vicinity in central Wisconsin. The proportion of volcanic rocks increases southward relative to that of sedimentary rocks; these volcanic rocks contain the valuable massive sulfide deposits known at Crandon, Ladysmith, and Pelican River, near Monico. Abundant granitic rocks (1,800-1,850 m.y. old) intrude the volcanic rocks. As known previously, the youngest rocks are local platform quartzite deposits more than 1,500 m.y. old, the large 1,500-m.y.-old Wolf River batholith and associated syenite, and the approximately 1,100-m.y.-old (Keweenawan) volcanic and sedimentary rocks related to the midcontinent rift system.

The middle Precambrian rocks that overlie Archean gneisses, together with the basement, were folded and metamorphosed about 1,800 m.y. ago, and were cataclastically deformed locally about 1,600 m.y. ago. In contrast, strata overlying the greenstone-granite basement on the Gogebic Range were not deformed during this interval.

At least three major high-angle fault sets have been recognized. The youngest, related to the midcontinent rift system, consists of N. 50-55 E. faults that were formed in late Keweenawan time; they probably produced most of the northward tilting of strata on the Gogebic Range. North-northeast-trending faults that had repeated movements and that typically have wide zones of mylonite bound the middle Precambrian rocks in the Marathon County area, as described earlier by G. L. LaBerge. Probably the oldest set consists of long, northwest-trending faults that were repeatedly reactivated and have apparent right-lateral movements; the major fault, the Mineral Lake fault, is interpreted to off-set Archean rocks about 160 km and middle Precambrian rocks, 10-15 km.

A NEW PRECAMBRIAN SURFACE CONTOUR MAP FOR SOUTH-CENTRAL WISCONSIN,

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A new surface contour map for the buried Precambrian basement of south-central Wisconsin was constructed using data from 200 deep water and oil test wells, geophysical studies, and previously published Precambrian surface contour maps of Wisconsin. The new map shows that (1) the Precambrian surface slopes gently to the east, southeast and south off the Wisconsin arch. Standing above this surface are numerous ridges and knobs of resistant rhyolite, granite and quartzite, many of which protrude through the Paleozoic and Pleistocene cover as inliers (e.g., at Waterloo, in the Fox River Valley, and at Baraboo). Buried knobs of Precambrian rock occur at Ripon (granite), Brothertown (quartzite), Waupun (quartzite), Whitewater (quartzite) and Rosendale (rock type unknown). Both the exposed and buried knobs rise abruptly from the peneplained Precambrian surface; for example, the rhyolite knob at Berlin stands over 600 feet above this surface, and that at Marcellon, 470 feet. The change in elevation in both cases occurs over a lateral distance of less than 1 mile. Other knobs have similar relief. (2) The eastward plunging Waterloo syncline is revealed by an arcuate ridge that in places stands 700 feet above the level of the surrounding Precambrian surface. This ridge is only exposed in the area to the east of Waterloo, near Portland. The nose of the Waterloo fold is in the Portland area. The north limb extends as a ridge from Portland to near Hartford in Washington County, a distance of 30 miles. The south limb extends as a continuous (?) ridge as far as Fort Atkinson and then continues as a series of quartzite knobs into central Walworth County, a distance of 45 miles (a buried quartzite knob is located at Whitewater, and quartzite is found beneath Delavan). (3) The subsurface data is supportive of a northeast trending fault extending from near Sheboygan to central Walworth County (as shown on maps by Thwaites, and Dutton and Bradley), but the presence of other faults in the Precambrian basement of south-central Wisconsin is uncertain.

THE GEOLOGY AND PETROLOGY OF THE WINE LAKE INTRUSION, COOK COUNTY,
MINNESOTA

by
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Exposures of granophyric granite and associated felsic intrusive rocks of the eastern part of the Duluth Complex form an east-west trending belt which parallels the northern or basal contact of the North Shore Volcanic Group in Cook County, Minnesota. Along the western limit of this belt, where it begins to trend southwestward near the county line, there exist several bodies of medium-grained diorite and quartz diorite. The largest body of these dioritic rocks and some smaller satellite bodies, together with an adjacent unit of recrystallized rhyolite and granite have been informally designated as the Wine Lake Intrusion by Grout, Sharp, and Schwartz in 1959.

Coarse-grained gabbroic anorthosite underlies this general area to the north and west, being locally overlain by a fine to medium-grained gabbro. The dioritic rocks also occur above the gabbroic anorthosite as bodies of 1 to 5 km² in area. Both gradational and intrusive contacts appear to exist between these three rock units. The rhyolite and granite unit of the Wine Lake Intrusion has an outcrop pattern suggestive of a subhorizontal sheet. The granite locally contains both irregular cusped and sometimes angular inclusions of fine-grained quartz diorite near the granite-diorite contact. Large xenoliths of amygdaloidal basalt and some late-stage basaltic dikes have also been observed in the Wine Lake area.

Field relationships, petrography, chemistry, and modelling of chemical trends by a least squares approximation program for crystal fractionation and magma mixing support the derivation of gabbro by fractionation of plagioclase from gabbroic anorthosite. The gabbro was apparently altered by the addition of the components of albite, quartz, orthoclase, and H₂O to produce the diorite and quartz diorite phases. The evidence also suggests that the granitic mineral components were derived from the remelting of xenoliths of rhyolite composition. This model is in conflict with the model of Weiblen and Morey (1975) which states that the felsic series rocks were produced by the differentiation of gabbroic anorthosite.

POSSIBILITIES FOR URANIUM-GOLD QUARTZ-PEBBLE ORES IN THE LAKE SUPERIOR
REGION IN THE LIGHT OF A NEW MODEL FOR ELLIOT LAKE-WITWATERSRAND GENESIS

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East Lansing, Michigan 48824

Gibbs free-energy calculations support a new model for the formation of quartz-pebble ores: 1) a typically granitic, alkaline, or metamorphic source area was exposed to 2) oxygenated atmospheres during major glacial CO₂-impoverished episodes since the Early Precambrian. Lower P_{CO2} and related higher pH of rain and runoff inhibited the dissolving of oxidized uranium as UO₂OH⁺, UO₂CO₃⁰, and UO₂(CO₃)₂(H₂O)₂⁼ to produce some clastic hydrated uranyl oxide pseudomorphs after uraninite, some water-soluble UO₂(HPO₄)₂⁼ complex ions, and possibly (if not exposed too long) some uraninite clasts 3) which were transported by streams along with magnetite and hematite clasts, ferric hydroxide hydrosols, gold nuggets, and ilmenite clasts, among others. 4) These materials were carried to a steep Eh gradient where hydrated uranyl oxide clasts were re-reduced to uraninite pseudomorphs, where UO₂(HPO₄)₂⁼ complex ions were reduced to interstitial uraninite, where magnetite and hematite clasts were reduced to pyrite "clasts", where ferric hydroxide hydrosols were reduced to interstitial pyrite, and where gold nuggets lost their clastic character by dissolving as AuS⁻ (to precipitate much later as non-clastic gold), all by reactions paradoxically requiring O₂ as well as anticipated H₂S or HS⁻, the latter two from interbedded and underlying sulfidic basalts or from the reaction of botanic sugars upon SO₄⁼. Quartz pebbles indicate the vigor of the sedimentary environment and imply the availability of reactant air. Sulfurization of clastic ilmenite resulted in iron sulfide (later to become pyrrhotite) and TiO₂; the latter then joined UO₂ to form brannerite. 5) To endure as ore, the reduced system was sealed and preserved from renewed oxidation under post-glacial higher P_{CO2} climates. A 55,000-miles Jeep reconnaissance in the Basin and Range, the Rocky Mountains, and the Appalachians has discovered five targets worthy of further study, of Late Precambrian and Eocambrian ages. Additional glacially-related terranes to be reconnoitered include Late Ordovician-Early Silurian, Permocarboniferous, and Pliocene-Fleistocene. Late Precambrian possibilities in the Lake Superior region inviting examination include 1) the parent ledge from which the Mt. McCaslin (Wisconsin) pyritic-quartz-pebble conglomerate boulder was wrenched during the Pleistocene, 2) conglomerates at the base of the Keweenaw, including the Bessemer Conglomerate (Wisconsin), Nopeming and Puckwunge Conglomerates (Minnesota), and correlatives along the northern and eastern shores of Lake Superior (Ontario), and 3) the southwestward continuation of the pyritic quartz-pebble conglomerate at the base of the Fond du Lac Formation (Minnesota) particularly where it overlies the St. Cloud Granite, and the correlative top of the Copper Harbor Conglomerate (Michigan). A Pleistocene possibility beneath lake-bottom clays near Sault Ste. Marie (Michigan), suggested by 37 ppb U in well water, may have been derived from the same source as Elliot Lake ores.

GEOCHRONOLOGIC RELATIONSHIPS IN THE
CARNEY LAKE GNEISS AND OTHER BASEMENT GNEISSES
IN DICKINSON COUNTY, UPPER MICHIGAN

W. R. Van Schmus, R. E. Woronick, and N. L. Egger

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The Carney Lake Gneiss and other granitic gneisses exposed in the Felch trough region, Dickinson County, have generally been assumed to be Archean (Lower Precambrian) in age. According to the model of Morey and Sims (1976), these gneisses belong to a terrane that is in part older than 3.0 b.y. We are carrying out total-rock Rb-Sr and zircon U-Pb analyses from these rocks in order to determine their primary age and to evaluate effects of post-Archean metamorphic events.

Data for the Carney Lake Gneiss indicate that this unit has a primary age of about 2.8 b.y. and has undergone extensive redistribution of Rb and Sr during a metamorphic event about 1.8 b.y. ago. This event was probably regional metamorphism associated with emplacement of the northeastern Wisconsin plutonic complex during the Penokean Orogeny about 1.83 b.y. ago.

Data from the Felch Trough region continue to reflect the complex geochronologic relationships reported on previously by Banks and Van Schmus (1971, 1972). There is clear evidence for a major event 2.1 b.y. ago that caused extensive Rb-Sr re-equilibration in the basement gneisses. Our preferred interpretation is that the event was high-grade metamorphism, perhaps with minor anatexis, affecting 2.8 b.y. old gneisses. Alternatively, it is possible that much of the gneiss has primary ages of about 2.1 b.y., but have incorporated substantial amounts of older radiogenic Sr^{87} .

Finally, even though the age systematics are quite complex, there is no clear evidence that any of the units studied to date are older than 2.8 b.y.

FINITE STRAIN IN THE PRECAMBRIAN KONA FORMATION OF THE MARQUETTE SYNCLINORIUM

WESTJOHN, David and CAMBRAY, F. William, Department of Geology,
Michigan State University, East Lansing, Michigan 48824

Slates in the Precambrian Kona Formation of the Marquette Supergroup contain ellipsoidal reduction spots and deformed veins. Each feature has been used independently in other areas as a means of measuring finite strain induced in rocks during tectonic deformation. However, the strain values obtained from either of these indicators are open to questions because the following assumptions must be made; the reduction spots were predeformational and initially spherical, and the veins were predeformational and initially had a wide range of planar orientations. The presence of these features in the same lithology provided an opportunity to test the validity of such assumptions. Both indicators occur in the same strain domain, and should show the same strain state if the assumptions are valid.

In this study, reduction spots and deformed veins from the same strain domain are used to determine the orientation and dimensions of the minimum finite strain ellipsoid.

In using the two methods it is possible to test if it is valid to use them independently as a measure of finite strain.

Preliminary work suggests that there are some differences which indicate that the veins may have developed after some increment of strain and that they record only part of the strain history and that the reduction spots provide a more complete record.

If this is the case it may be possible to plot part of the incremental strain history of the region and to record both magnitude and orientation of strain at separate times during the Penokean Orogeny.

The reduction spots indicate a minimum finite strain in which

	Axial Ratios X : Y : Z	k value (a-1/b-1)	Extensions			Orientations of Principle Axes		
			X	Y	Z	X	Y	Z
Reduction Spots	1.5:1.1:0.6	0.50	+58%	+7%	-43%	82°/093°	80°/273°	1°/003°

A new detailed aeromagnetic map covering
most of the Precambrian shield in Wisconsin

by

Isidore Zietz
U.S. Geological Survey, National Center, Reston, Virginia 22092

ABSTRACT

A detailed aeromagnetic survey, having a flight separation of $\frac{1}{2}$ mile and a flight altitude of 500 feet, has been made over most of the Precambrian shield in Wisconsin. The survey was under the direction of John H. Karl of the University of Wisconsin at Oshkosh. An aeromagnetic map, published by the U.S. Geological Survey in 1977, was prepared at a scale of 1:250,000 by photographically reducing and compiling 86 aeromagnetic maps that cover areas shown on standard U.S. Geological Survey 15' quadrangles. In addition, a colored aeromagnetic map of the same area and at the same scale (1:250,000) has been prepared and placed on open-file by the U.S. Geological Survey.

By using these two aeromagnetic maps, together with the existing regional gravity data, available outcrops, and existing isolated, sparse geologic mapping, Paul Sims and William Cannon have prepared a regional geologic map.

In the main, the uncolored aeromagnetic map was used for structural analysis, whereas the colored version of the map on which the differences of magnetic intensity are conspicuous was used for inferring lithologic variations.

FIELD

TRIPS

FIELD TRIP I

SOUTHWESTERN WISCONSIN ZINC-LEAD DISTRICT

LEADERS: M.G. Mudrey, Jr., Wisconsin Geological and Natural History Survey, W.A. Broughton, University of Wisconsin-Platteville, Walter S. West, U.S. Geological Survey, and Allen V. Heyl, U.S. Geological Survey.

DATE: May 9 - 10, 1978.

This trip will visit the Wisconsin part of the historic Upper Mississippi Valley Zinc-Lead District. Stops at quarries and roadcuts will provide a background on the ore-bearing Paleozoic rocks before going underground at a historic mining site, and a producing zinc-lead mine.

1. Assemble in Madison, Wisconsin, at 12:30 p.m. on Tuesday, May 9, 1978, and proceed to Platteville, Wisconsin for overnight lodging. Tour southwest Wisconsin, and journey to Milwaukee on Wednesday, May 10, for the evening festivities.
2. The cost is \$40.00 and includes:
 - a) Overnight accommodations (double occupancy) at Platteville.
 - b) Bus transportation from Madison to Platteville with a return trip to Milwaukee.
 - c) An evening banquet in Platteville on Tuesday, May 9, and lunch on Wednesday, May 10.
 - d) Guidebook.
3. Limited to a maximum of 36 participants.
4. The guide materials designed for this field trip are:
 - a) Geology of Upper Mississippi Valley Zinc-Lead District, Information Circular Number 16, 1970. (\$3.00)
 - b) Upper Mississippi Valley Base Metal District, Field Trip Guidebook Number 1. (\$4.00)
 - c) If purchased together, the cost is \$6.00.
 - d) Available from:

Wisconsin Geological and Natural History Survey
1815 University Avenue
Madison, Wisconsin 53706
608-262-1705

FIELD TRIP II

MINERAL EXTRACTION AND PROCESSING EQUIPMENT MANUFACTURERS IN

THE GREATER MILWAUKEE AREA

LEADER: Charles A. Salotti, University of Wisconsin-Milwaukee.

DATE: May 10, 1978

This tour will visit a number of major manufacturing plants where mineral and solid fuel extraction and processing equipment is fabricated. Milwaukee is a world center for this activity, and much of the equipment used in the Lake Superior Region originated in southeastern Wisconsin. Increased coal utilization, coupled with rapidly changing technologies in mineral and solid fuel processing, are reflected in the dynamic character of this industry.

1. Depart from the Pfister Hotel, downtown Milwaukee, on Wednesday morning about 9:00 a.m., May 10, 1978.
Return to the Pfister Hotel about 4:00 p.m.
2. There is no guidebook for this trip.

FIELD TRIP III

PRECAMBRIAN RHYOLITE, GRANITE, AND QUARTZITE INLIERS IN

SOUTH-CENTRAL WISCONSIN

LEADER: Eugene I. Smith, University of Wisconsin-Parkside.

DATE: May 12 - 13, 1978

This field trip will visit rhyolite ash-flow tuff and granite of Middle Precambrian age (1765 ± 20 m.y.), which are inliers on the southern margin of the Precambrian shield. These rocks are younger than granite and rhyolite in the Wausau area of central Wisconsin (1900 m.y.), and older than the Wolf River batholith of northeastern Wisconsin (1500 m.y.). Stops are designed to illustrate stratigraphic and structural relations in this interesting province.

1. Depart Milwaukee on Friday evening, May 12, 1978, at 6:30 p.m., and proceed to Oshkosh, Wisconsin for overnight lodging. Tour south-central Wisconsin on Saturday, May 13, and return to Milwaukee about 6:30 p.m.
2. The cost is \$35.00 and includes:
 - a) Overnight accommodations (double occupancy) at The Pioneer in Oshkosh, Wisconsin.
 - b) Bus transportation from Milwaukee to Oshkosh and return to Milwaukee.
 - c) Lunch on May 13.
 - d) Guidebook.
3. No limit on number of participants.
4. The guide materials designed for this trip are:
 - a) Introduction, Geochronology, and Engineering Geology of Precambrian Rocks in South-Central Wisconsin, Geosciences Wisconsin Number 2. (\$4.00).
 - b) Precambrian Inliers of South-Central Wisconsin, Field Trip Guidebook Number 2. (\$5.00).
 - c) If purchased together, the cost is \$8.00.
 - d) Available from:

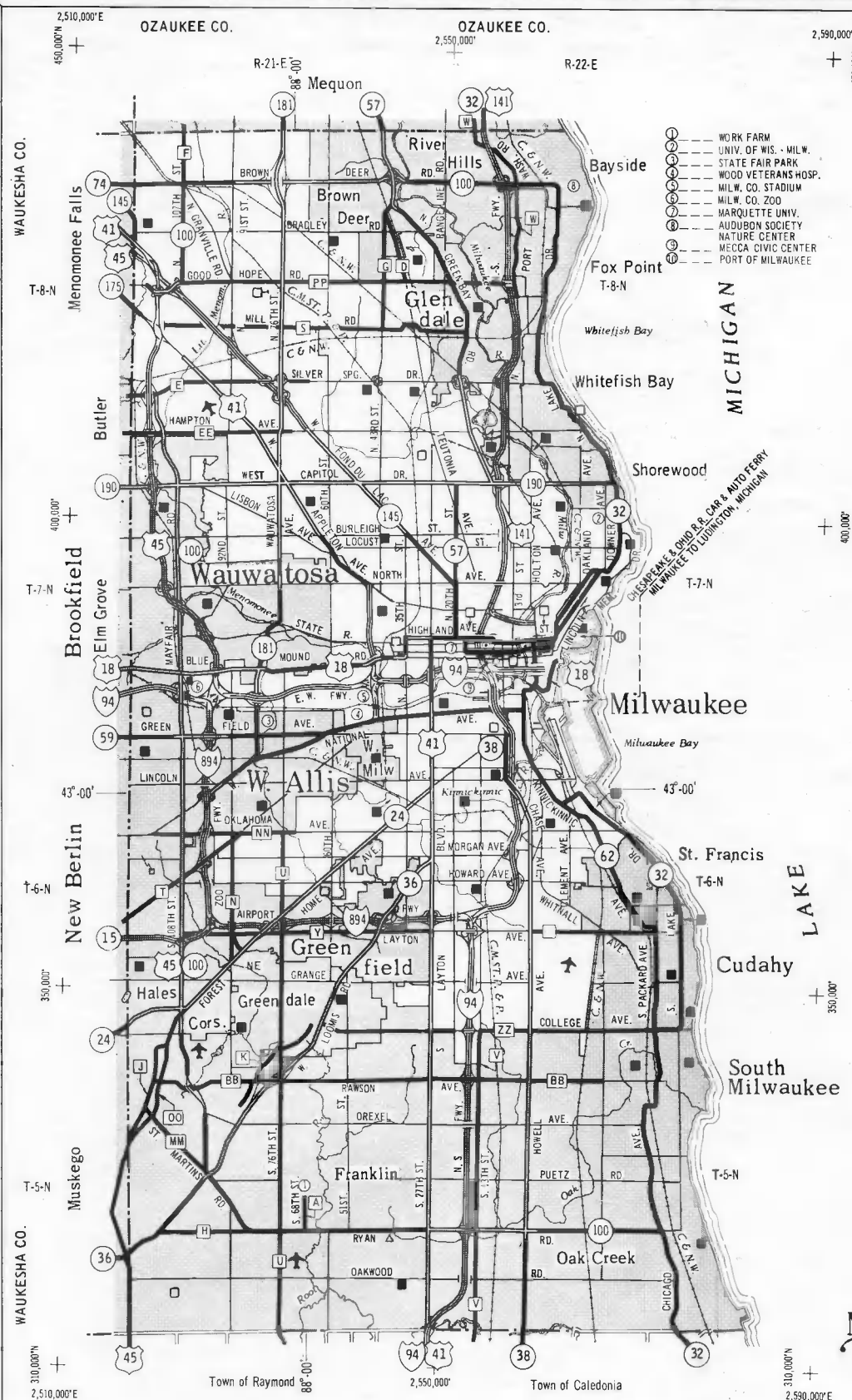
Wisconsin Geological and Natural History Survey
1815 University Avenue
Madison, Wisconsin 53706
608-262-1705

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TWENTY-SEVEN FIRMS IN THE GREATER
MILWAUKEE AREA EITHER MANUFACTURE
OR SUPPLY COMPONENTS FOR MINERAL
EXTRACTION AND PROCESSING MACHINERY.
THEIR AGGREGATE SALES IN 1977 WAS
9.5 BILLION DOLLARS.



LEGEND

- Portland Cement or Bitum. Concrete
- Gravel
- Earth
- Town Road
- Fire Lane
- Multilane Divided
- Freeway
- Interchange
- Highway Separation
- Interstate Highway No.
- U.S. Highway No.
- State Highway No.
- County Hwy. Letter
- Railroad
- Dam
- State Boundary
- County Boundary
- Civil Town Boundary
- Corporate Limits
- Nat. & State Forests
- Airport
- Fish Hatchery
- Game Farm
- County Seat
- Unincorp. Village
- Schools
- Public Hunt. or Fish. Grds.
- Hospital
- Ranger Station
- Public Camp & Picnic Grds.
- State Park
- County Park
- Wayside



MILWAUKEE CO. DEPARTMENT OF TRANSPORTATION

DIVISION OF HIGHWAYS
STATE OFFICE BUILDING
Madison, Wisconsin

SCALE 0 1 2 MILES

Corrected for
JAN. 1976

Compiled from U.S.G.S. Quadrangles
Based on Aerial Photographs

MILWAUKEE 40-9

Land Area 239 Sq. Mi.
Population 1,046,268
Co. Seat Milwaukee

MILES OF HIGHWAY as of Jan. 1, 1975
STATE 254
COUNTY 83
LOCAL ROADS 2278
OTHER ROADS 0
TOTAL FOR COUNTY 2615

Grid based on Wisconsin coordinate system, south zone