

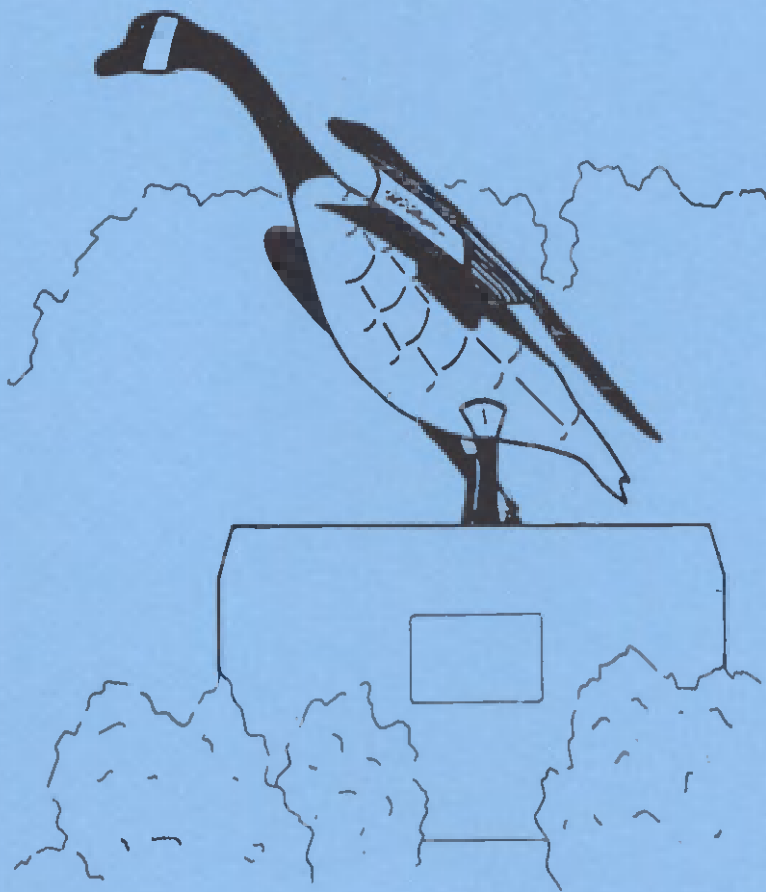


Institute on Lake Superior Geology
PROCEEDINGS and ABSTRACTS

Volume 33, Part 1

33rd Annual Meeting

May 12 and 13, 1987



Wawa, Ontario

ERRATA

with apologies to Muscocho Explorations and David Baxter.

xii - last line should read:

Muscocho Explorations Ltd. (Toronto) - coffee breaks

are quartz and carbonate, with lesser amounts of chlorite.
The chief accessory sulphide mineral is pyrite with lesser
amounts of pyrrhotite, chalcopyrite, and arsenopyrite.

INSTITUTE on LAKE SUPERIOR GEOLOGY

PROCEEDINGS and ABSTRACTS

Volume 33, Part 1

33rd ANNUAL MEETING

WAWA, ONTARIO

May 12 and 13, 1987

Organized by the Ontario Ministry of

Northern Development and Mines:

Wawa Resident Geologist Office

and the

Ontario Geological Survey

Program Chairmen and Editors: E.D. Frey and R.P. Sage

Vol. 33, Part 1: Proceedings and Abstracts

Part 2: Wawa Gold Field Trip

Part 3: Michipicoten Iron Formation Stratigraphy Field Trip

Part 4: Hemlo Gold Field Trip

Part 5: Kapuskasing Structural Zone Field Trip

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INSTITUTES ON LAKE SUPERIOR GEOLOGY

<u>NUMBER</u>	<u>DATE</u>	<u>PLACE</u>
1	1955	Minneapolis, MN
2	1956	Houghton, MI
3	1957	East Lansing, MI
4	1958	Duluth, MN
5	1959	Minneapolis, MN
6	1960	Madison, WI
7	1961	Port Arthur (Thunder Bay), Ont.
8	1962	Houghton, MI
9	1963	Duluth, MN
10	1964	Ishpeming, MI
11	1965	St. Paul, MN
12	1966	Sault Ste. Marie, MI
13	1967	East Lansing, MI
14	1968	Superior, WI
15	1969	Oshkosh, WI
16	1970	Thunder Bay, Ont.
17	1971	Duluth, MN
18	1972	Houghton, MI
19	1973	Madison, WI
20	1974	Sault Ste. Marie, Ont.
21	1975	Marquette, MI
22	1976	St. Paul, MN
23	1977	Thunder Bay, Ont.
24	1978	Milwaukee, WI
25	1979	Duluth, MN
26	1980	Eau Claire, WI
27	1981	East Lansing, MI
28	1982	International Falls, MN
29	1983	Houghton, MI
30	1984	Wausau, WI
31	1985	Kenora, Ont.
32	1986	Wisconsin Rapids, WI
33	1987	Wawa, Ont.
34	1988	Marquette, MI (tentative)
35	1989	Duluth, MN (tentative)

CONSTITUTION OF INSTITUTE ON LAKE SUPERIOR GEOLOGY

Article I Name

The name of the organization shall be the "Institute on Lake Superior Geology."

Article II Objectives

The objectives of this organization are:

- A. To provide a means whereby geologists in the Great Lakes region may exchange ideas and scientific data.
- B. To promote better understanding of the geology of the Lake Superior region.
- C. To plan and conduct geological field trips.

Article III Status

No part of the income of the organization shall inure to the benefit of any member or individual. In the event of dissolution the assets of the organization shall be distributed to _____ (some tax free organization).

[To avoid Federal and State income taxes, the organization should be not only "scientific" or "educational" but also "non-profit."]

Minn. Stat. Anno. 290.01, subd. 4

" " " 290.05(9)

1954 Internal Revenue Code s. 501(c)(3)

Article IV Membership

The membership of the organization shall consist of the board of directors. Any geologist interested shall be permitted to attend and participate in and vote at the annual meetings.

Article V Meetings

The organization shall meet once a year, preferably during the month of April. The place and exact date of each meeting will be designated by the board of directors.

Article VI Directors

The board of directors shall consist of the Chairman, Secretary-Treasurer and the last three past Chairmen; but if the board should at any time consist of less than five persons, by reason of unwillingness or inability of any of the above persons to serve as directors, the vacancies on the board may be filled by the annual meeting so as to bring the membership of the board up to five members.

Article VII Officers

The officers of this organization shall be a Chairman and a Secretary-Treasurer.

- A. The Chairman shall be elected each year by the board of directors, who shall give due consideration to the wishes of any group that may be promoting the next annual meeting. His term of office as Chairman will terminate at the close of the annual meeting over which he presides or when his successor shall have been appointed. He will then serve for a period of three years as a member of the board of directors.
- B. The Secretary-Treasurer shall be elected at the annual meeting. His term of office shall be two years or until his successor shall have been appointed.

Article VIII Amendments

This constitution may be amended by a majority vote of those persons who are personally present at, participating in, and voting at any annual meeting of the organization.

BY-LAWS

I. Duties of the Officers and Directors

A. It shall be the duty of the Chairman to:

1. Preside at the annual meeting.
2. Appoint all committees needed for the organization of the annual meeting.
3. Assume complete responsibility for the organization and financing of the annual meeting over which he presides.

B. It shall be the duty of the Secretary-Treasurer to:

1. Keep accurate attendance records of all annual meetings.
2. Keep accurate records of all meetings of, and correspondence between, the board of directors.
3. Hold all funds that may accrue as profits from annual meetings or field trips and to make these funds available for the organization and operation of future meetings as required.

C. It shall be the duty of the board of directors to plan locations of annual meetings and to advise on the organization and financing of all meetings.

II. Dues and Expenses

1. There shall be no regular membership dues.
2. Registration fees for the annual meetings shall be determined by the Chairman in consultation with the board of directors. It is strongly recommended that these be kept at a minimum to encourage attendance of graduate students.

III. Rules or Order

The rules contained in Robert's Rules of Order shall govern this organization in all cases to which they are applicable.

IV. Amendments

These by-laws may be amended by a majority vote of those persons who are personally present at, participating in, and voting at any annual meeting of the organization; provided that such modifications shall not conflict with the constitution as presently adopted or subsequently amended.

SAM GOLDICH MEDAL

Preamble

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

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

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

Award Guidelines

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

April 4, 1981

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

RECIPIENTS

1979 Sam Goldich, 1981 Carl Dutton, 1982 Ralph Marsden, 1984 Burton Boyum
1984 Richard Ojakangas, 1985 Paul Sims, 1986 G.B. Morey, 1987 Henry Halls

STUDENT TRAVEL AWARD

The 1986 Board of Directors established the ILSG Student Travel Award, to support student participation at the annual Institutes. The awards will be made from the accrued interest from a special fund set up for this purpose. This award is intended to help defray some of the direct travel costs to the Institute and includes a waiver of registration fees, but excludes expenses for meals, lodging, and field trip registration. The number and size will be determined by the annual Chairman in consultation with the Secretary-Treasurer and will be announced at the annual banquet.

The following general criteria will be considered by the annual Chairman, who is responsible for selection:

- 1) The applicants must have active resident (undergraduate or graduate) student status at the time of the Institute, certified by the department head.
- 2) Students who are the senior author on either an oral or poster paper will be given favored consideration.
- 3) It is desirable for two or more students to jointly request travel assistance.
- 4) In general, priority will be given to those in the Institute region who are farthest away.
- 5) Each travel award request shall be made in writing, to the annual Chairman, with an explanation of need, possible author status or other significant details.

REPORT OF THE CHAIRMAN
32ND INSTITUTE ON LAKE SUPERIOR GEOLOGY
1986

The 32nd meeting of the Institute on Lake Superior Geology was hosted by the Wisconsin Geological and Natural History Survey and held from April 29 to May 4, 1986 in central Wisconsin. Meeting headquarters was the Mead Inn in Wisconsin Rapids where technical sessions took place on May 1 and May 2. Conference registrants numbered 207 with students comprising just over one third of these. Two-day field trips were held both before and after the meeting. The pre-meeting trip 1, which was led by Jeff Greenberg and Gordon Medaris, visited exposures of plutonic rocks associated with the Wolf River batholith on April 29 and exposures of Baraboo interval metasedimentary and igneous rocks on April 30. There were 38 participants on trip 1. Field trip 2 leader Randy Maass was joined by 24 people on May 3 and May 4 to observe structural complexities of Archean gneisses and Early Proterozoic metavolcanic units in central Wisconsin. Separate guidebooks were published for each trip.

Sixty papers were presented, forty-two in the technical sessions and eighteen as posters. The morning of May 2 featured a special symposium on the Precambrian basement of the north-central U.S. Ray Anderson and Eva Kisvarsanyi were co-chairs of the symposium. Two best student-paper awards of \$100 each were provided by donations from Exxon Minerals Co. and Nekoosa Papers Inc. These generous contributors also made it possible to award eight student grants covering registration and luncheon expenses. The student-paper awards were presented by Wayne Zwickey to K. W. Klewin of Northern Illinois University for his paper, "The Petrology and Geochemistry of the Potato River Intrusion (Eastern Mellen Complex), Northern Wisconsin" and to A. D. Maharidge of Bowling Green State University for his paper "Tectonic Evolution of the Felch Trough."

On May 1 the Institute's annual banquet featured excellent food, an award ceremony, and the guest speaker. The Goldich Medal was presented by the ever-entertaining Dick Ojakangas to G. B. Morey of the Minnesota Geological Survey. Through the midst of some technical adversity, John Rogers of the University of North Carolina shared his insights into the "Precambrian of Peninsular India."

The Institute Board of Directors met at noon on May 1. Board members present included Jeff Greenberg (Chairman), Bruce Brown (Co-chair), J. Kalliokoski (Secretary-Treasurer), Gene LaBerge, Ted Bornhorst, Charlie Blackburn, and Dave Southwick. Ron Sage was also present as the 33rd I.L.S.G. Chairman. The Board took the following action:

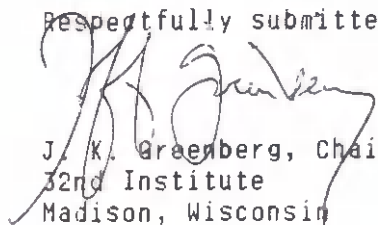
- 1) As of April 22, 1986, the U.S. accounts of I.L.S.G. total \$2592.34 and include \$890 in the Goldich Medal Fund account. The Canadian account stands at \$CAN 6,209.34. The 32nd I.L.S.G. turned over an additional \$1200.00 to the U.S. account.
- 2) In view of its relatively healthy financial status, the Institute will use most of the interest income for student travel awards. A primary objective of the awards will be to attract Canadian students. A committee (M. M. Kehlenbeck, C. E. Blackburn, T. J. Bornhorst) will submit the guidelines to the Board.

- 3) I.L.S.G. abstracts are now submitted to the American Geological Institute for inclusion in GEOREF.
4. Starting in 1987, the title of the I.L.S.G. publication will be Institute on Lake Superior Geology Proceedings and Abstracts. This title will appear on the cover and on the title page. The publication will also appear under a volume designation, the 33rd I.L.S.G. at Wawa will publish volume 33. These standardizations will enable the Institute to apply in 1988 for an ISBN number and thereby to become a recognized periodical.
5. Meeting notices for those meetings to be held in the U.S. should include the statement: "This Institute is recognized as a non-profit scientific and educational organization under the 1954 IRS Revenue Code S.501(c)(3) (Employee Indent. No. 23-7326054). Therefore, all gifts to the Institute are tax deductible."
6. R. W. Ojakangas is the new member (1986-1989) on the Goldich Medal Committee, replacing M. M. Kehlenbeck.
7. To be eligible for consideration for the Best Student Paper Award the student must be senior author and must present the paper. Starting in 1987 the prize will consist of both a check and a certificate. Gene LaBerge agreed to prepare the sample certificate.
8. Ron Sage reported that the 1987 Institute in Wawa Ontario will take place May 11 to May 15 and include several exciting field trips.
9. Although there were no clear offers of sponsorship for the 34th I.L.S.G. (1988), Gene LaBerge mentioned the possibility of a proposal to hold the meeting in Michigan's Upper Peninsula in the vicinity of the Gogebic Range. The Board also discussed the possibility of a meeting in Sudbury Ontario for 1989 or beyond.

As in the previous thirty-one years, this year's completed chairmanship has been an educational experience. It is indeed wonderful to see how so many people from different organizations can work together for the Institute's success. Perhaps the only problem of note for the 32nd I.L.S.G. was the poor pre-meeting response to the mailed registration forms. It is very difficult to estimate participation in meals, field trips and technical sessions (seating), etc. without reasonable early notice of two weeks or so before the meeting. I suggest that future local committees consider increasing the differential between pre-meeting registration fees and fees for on-site registration. This should encourage more people to preregister.

My thanks again to all who make the I.L.S.G. (and the 32nd Institute in particular) a priceless gathering of the friends of the Precambrian.

Respectfully submitted,


J. K. Greenberg, Chairman
32nd Institute
Madison, Wisconsin
July, 1986

INSTITUTE BOARD OF DIRECTORS

- R.P. Sage (with E.D. Frey, Mineral Dev. Br., Wawa), Ontario Geological Survey, Ministry of Northern Development and Mines, 77 Grenville St., Toronto, Ontario M7A 1W4 (1987)
- J.K. Greenberg (with B.A. Brown), Wisconsin Geological and Natural History Survey, 3817 Mineral Point Rd., Madison, Wisconsin 53705 (1986)
- C.E. Blackburn, Mineral Development Branch, Ministry of Northern Development and Mines, P.O. Box 5160, Kenora, Ontario P9N 3X9 (1985)
- G.L. LaBerge, Department of Geology, University of Wisconsin-Oshkosh, Oshkosh, Wisconsin 54901 (1984)
- J. Kalliokoski, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931 (Secretary-Treasurer)

LOCAL COMMITTEE

Ed Frey: Conference Co-chairman, Program and Abstracts Editor
Ron Sage: Conference Co-chairman, Program and Guidebooks Editor
Terri-Ann Hoffmann (MNDM, Wawa): Mailing and Registration
Barbara Leschishin (MNDM, Wawa): Mailing and Registration
Wendy Wing (MNDM, Wawa): Drafting and Registration
Delio Tortosa (MNDM, Wawa): Field Trip Assistance
Gerry Bennett (MNDM, Sault Ste. Marie): Field Trip Assistance
Ken Card (GSC, Ottawa): Field Trip Assistance
Mike Lockwood (Univ. Western Ontario): Field Trip Assistance
Dave Walker (MNDM, Toronto): Drafting and Guidebook Preparation
Krystyna Gil (MNDM, Toronto): Graphics

BEST STUDENT PAPER COMMITTEE

A.J. Andrews, Ontario Geological Survey, Toronto, Ont.
J.J. Brummer, Consulting Geologist, Toronto, Ont.
P.K. Sims, United States Geological Survey, Denver, CO

GOLDICH MEDAL COMMITTEE

W.A. Bodwell, Resource Exploration, Inc., Marquette, MI
K.D. Card, Geological Survey of Canada, Ottawa, Ont.
R.W. Ojakangas, Dept. of Geology, University of Minnesota-Duluth, Duluth, MN

FIELD TRIP LEADERS

E.D. Frey, Mineral Development Branch, Ministry of Northern Development and Mines, Wawa, Ont.
T.L. Muir, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, Ont.
J.A. Percival, Geological Survey of Canada, Ottawa, Ont.
R.P. Sage, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, Ont.

TECHNICAL SESSION CHAIRMEN

- T.J. Bornhorst, Department of Geology and Geological Engineering,
Michigan Technological University, Houghton MI
- K.D. Card, Geological Survey of Canada, Ottawa, Ont.
- A.M. Goodwin, Department of Geology, University of Toronto, Toronto, Ont.
- J.S. Kijasner, Department of Geology, Western Illinois University, Dekalb, IL
- G.L. LaBerge, Department of Geology, University of Wisconsin-Oshkosh,
Oshkosh, WI
- F.R. Luther, Department of Geology, University of Wisconsin-Whitewater,
Whitewater, WI
- R.J. Rupert, Citadel Gold Mines Inc., Wawa, Ont.
- R.H. Sutcliffe, Ontario Geological Survey, Toronto, Ont.

GOLDICH MEDAL RECIPIENT

- Henry C. Hall, Department of Geology, University of Toronto-Erindale,
Toronto, Ont.

BANQUET SPEAKER

- K. Howard Poulsen, Geological Survey of Canada, Ottawa, Ont.

ACKNOWLEDGEMENTS

In addition to those cited on the Local Committee, the Co-chairmen wish to thank other individuals and organizations whose efforts and cooperation have contributed to the operation of the 33rd ILSG. Our appreciation also goes to many others who will aid the Wawa ILSG after this writing.

Pam Aurora (MNDM-Toronto) - manuscript preparation

Ann Wilson (Wawa) - circulars

Ann May (Wawa) - banquet

Larry Robinson and others of the Wawa and District Chamber of Commerce - conference assistance

Grant Southwell and staff of the Leisure Services Department of the Township of Michipicoten - conference facilities

Township of Michipicoten Council - use of conference facilities

Algoma Ore Division of Algoma Steel Corporation Ltd. (Wawa) - field trip assistance

Bridget Lake Resources Inc. (Wawa) - property access

CANAMAX Resources Inc. (Timmins) - coffee breaks

Citadel Gold Mines Inc. (Wawa) - field trip assistance

Dunraine Mines Ltd. (Toronto) - property access

Monk Gold and Resources Ltd. (Toronto) - property access

Muscogcho Explorations Ltd. (Toronto) - property access

TECHNICAL PROGRAM

One Asterisk Identifies Student Papers.

Two Asterisks Identify Dual (Oral & Poster) Presentations.

Speaker/Presenter Underlined

SESSION ONE

Tuesday Morning - May 12, 1987

Co-chairmen: Allan M. Goodwin and Ted Bornhorst

- 8:00 Opening Welcome - Conference Co-chairmen
- 8:05 Greetings from the Ontario Ministry of Northern Development & Mines
- 8:20 K.D. Card Superior Province: the product of Archean convergent plate tectonism
- 8:40 A. Turek The meaning of U-Pb and Rb-Sr ages in the Wawa area
- 9:00 T.A. Vandall & D.T.A. Symons Paleomagnetism of Archean granites in the Wawa area: further definition of the apparent polar wander path
- 9:20 R.I. Thorpe,
R.P. Sage, &
J.M. Franklin Lead isotope evidence for an old crustal source for many ore leads in the Wawa region
- 9:40 F. Corfu &
R.P. Sage A precise U-Pb zircon age for a trondhjemite clast in the Dore conglomerate, Wawa, Ontario
- 10:00 coffee
- 10:40 G.E. McGill &
C.H. Shradly Sequence of faulting and folding, southwest Michipicoten greenstone belt, Ontario
- 11:00 * C.H. Shradly &
G.E. McGill Nature of cleavage, folding and strain in the Michipicoten greenstone belt, near Wawa, Ontario
- 11:20 R.P. Bowen Geology of the Mishibishu Lake area
- 11:40 ** K.B. Heather Gold mineralization of the Mishibishu Lake greenstone belt
- 12:00 lunch

SESSION TWO

Tuesday Afternoon - May 12, 1987

Co-chairmen: John Klasner and Gene LaBerge

- | | | |
|------|---|--|
| 2:00 | ** E.C. Grunsky | Geology of the Batchawana area, Ontario |
| 2:20 | W.T. Jolly | Rhyolite and basaltic volcanism from the Huronian of the Thessalon area, central Ontario |
| 2:40 | * C.T. Barrie | Geology and structural history of the Kamiskotia igneous complex, western Abitibi Subprovince, Ontario |
| 3:00 | J.A. Percival | "Basement-uplift" tectonics in the Kapuskasing Structural Zone, central Superior Province |
| 3:20 | | coffee |
| 3:40 | R.J. Shegelski | Imprint of Archean Abitibi tectonics on the Proterozoic Lake Superior basin |
| 4:00 | R.H. Sutcliffe | Contemporaneous late Archean mafic and granitoid magmatism in the Lac des Iles area, Wabigoon Subprovince, Ontario |
| 4:20 | H.R. Williams | Fluid induced structures in Quetico metasediments, northern Ontario |
| 4:40 | ** W. Cannon,
J. Behrendt, M. Lee,
D. Hutchinson, A. Green,
C. Spencer, B. Milkereit,
P. Morel, A. Davidson, &
D. Teskey | A brief look at GLIMPCE |

SESSION THREE

Wednesday Morning - May 13, 1987

Co-chairmen: Roy Rupert and Richard Sutcliffe

- 8:15 Announcements - Conference Co-chairmen
- 8:20 • D.A. Baxter, Geology, structure, and associated
 T.J. Bornhorst, & precious metal mineralization of Archean
 J.L. Van Alstine rocks in the vicinity of Clark Creek,
 Marquette County, Michigan
- 8:40 R.C. Johnson, Geology and precious metal mineraliza-
 T.J. Bornhorst, & tion of the Hill's Lakes area,
 J.L. Van Alstine Marquette County, Michigan
- 9:00 T.J. Bornhorst & Geochemical character of Archean rocks
 D.A. Baxter from the east half of the northern complex,
 upper Michigan: a progress report
- 9:20 R.L. Bauer Refolding and fold reorientation during
 pluton emplacement in a regional stress
 field, Vermilion granitic complex,
 northeastern Minnesota
- 9:40 • M.E. Bidwell & A two-stage simple shear model for high
 R.L. Bauer flattening strains in shear zones of the
 central Vermilion district, northeastern
 Minnesota
- 10:00 coffee
- 10:40 D.C. Stewart & The "Hagar Suite" and problems concerning
 J.M. Mancuso the nature and location of the northern
 boundary of the Wolf River batholith
- 11:00 I. Watkins, Rapakivi textures of central Minnesota
 G. Anderson, &
 P. Erickson
- 11:20 P.A. Nielsen Petrologic evolution of early Proterozoic
 supracrustal rocks from Florence County, WI
 and their bearing on the development of the
 Dunbar Gneiss
- 11:40 * J.A. Peterson & The Hardwood Gneiss, a basic two-pyroxene
 C.A. Geiger granulite
- 12:00 lunch

SESSION FOUR

Wednesday Afternoon - May 13, 1987

Co-chairmen: Ken Card and Frank Luther

- | | | |
|------|--|---|
| 2:00 | M.L. Cummings | Geochemistry of Proterozoic volcanic hosted formations in northern Wisconsin: prospects for gold mineralization |
| 2:20 | * D. Werbach | A review of the LaSalle Falls massive sulphide prospect |
| 2:40 | <u>R. Dahl,</u>
D.H. Watkinson, &
J.W. McGoran | Two Duck Lake intrusion, Coldwell alkaline complex, Ontario. 1. Geology and structure |
| 3:00 | <u>R. Dahl,</u>
D.H. Watkinson, &
J.W. McGoran | Two Duck Lake intrusion, Coldwell alkaline complex, Ontario. 2. Petrology and base-metal PGE geochemistry |
| 3:20 | coffee | |
| 3:40 | <u>A. Davidson</u> &
O. Van Breemen | Northeastern extension of the Proterozoic igneous terranes of mid-continental North America |
| 4:00 | * <u>J.F. Peterman,</u>
D. Droege,
A.M. Johnson, &
J.L. Van Alstine | Geological and geophysical investigation of graphite resources in upper Michigan |
| 4:20 | * <u>B.J. Prosen</u> &
A.M. Johnson | Natural brine contamination of groundwater in the Keweenaw rocks of northern Michigan |
| 4:40 | ** J.S. Springer | Mesozoic paleogeography: implications for economic deposits north of Lake Superior |

POSTER PRESENTATIONS

Monday, May 11	4:00 - 10:00 p.m.
Tuesday, May 12	8:00 - 5:00 p.m.
Wednesday, May 13	8:00 - 5:00 p.m.

- | | | |
|--|----|---|
| <u>C.D. Anglin,</u>
<u>J.M. Franklin,</u>
<u>I.R. Jonasson,</u>
K. Bell, & E. Hoffman | | Geochemistry of scheelites associated with
Archean gold deposits |
| E.N. Berdusco | | MacLeod Mine geology - a brief review |
| <u>W. Cannon,</u>
<u>J. Behrendt,</u> M. Lee,
D. Hutchinson, A. Green,
C. Spencer, B. Milkereit,
P. Morel, A. Davidson, &
M. Teskey | ** | A brief look at GLIMPCE |
| P.M. Eick | • | Geochemistry and petrography of selected Early
Proterozoic metadiabase dikes from Marquette
County, Michigan |
| <u>R.E. Ernst &</u>
<u>K. Bell</u> | * | The great Abitibi dyke - petrological overview |
| <u>R.J. Ferderer &</u>
<u>V.W. Chandler</u> | * | The utility of Werner deconvolution as a
geomagnetic mapping tool in east-central Minnesota |
| E.C. Grunsky | ** | Geology of the Batchawana area, Ontario |
| K.B. Heather | ** | Gold mineralization of the Mishibishu Lake
greenstone belt |
| M.A. Jirsa | | Stratigraphic evolution of part of the Archean
Itasca County metavolcanic belt, northern Minnesota |
| <u>M.J.P. Kuhns &</u>
<u>R.J. Kuhns</u> | | Applicability of a sediment-hosted copper deposit
model to the Keweenaw Solor Church Formation,
Minnesota |
| G.L. LaBerge | | Major lithological units in the Wisconsin magmatic
terrane: new data from drill cores |
| G.A. Lehman | | U-Pb datation of pitchblende from Dickinson County,
upper Michigan, suggests reactivation of
Precambrian structures during formation of the
Michigan Basin |
| D.S. McPhee | | Magnacbn Project - Mishibishu Lake greenstone
belt |

D.S. McPhee		Magino Project - Michipicoten greenstone belt
J.D. Miller, Jr.		Bedrock geology of Keweenaw rocks in the vicinity of Silver bay and Beaver Bay, northeastern Minnesota
T.L. Muir		Stratigraphic and structural considerations on the Hemlo gold deposit setting
P.A. Nielsen		On the failure of the midcontinent rift system to proceed to sea-floor spreading
W.I. Rose		Video field trip to the Keweenaw rift
R.J. Rupert		Structural and economic geology of Citadel Gold Mines Inc., Wawa, Ontario
<u>C.H. Shradly</u> & <u>G.E. McGill</u>	*	Structural geology of the southwestern portion of the Michipicoten greenstone belt, Ontario
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D. Tortosa		Reconnaissance geology of granitic and gneissic terrane, Wawa District
<u>R. Wunderman</u> & <u>C.T. Young</u>	*	Evidence for widespread basement decollement structures and related crustal asymmetry associated with the western limb of the midcontinent rift
G.R. Yule		Kremzar gold deposit, District of Algoma, CANAMAX Resources Inc. - Kremzar Gold Mines Ltd.
G.R. Yule		Structurally hosted vein type gold mineralization, Goudreau-Lochalsh gold camp, District of Algoma

ABSTRACTS

Geochemistry of Scheelites Associated with Archean Gold Deposits

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In the study of gold deposits, fundamental questions remain regarding the origin of the ore-bearing fluids and the absolute age of mineralization. If the timing of gold emplacement can be shown to be related to specific magmatic or metamorphic events, then very specific geological criteria for these events can be documented, and new or refined guidelines for exploration can be defined. To date, attempts to determine the absolute timing of emplacement of gold have been frustrated by the lack of suitable minerals for dating by conventional radiometric dating techniques.

This study was initiated to follow up a suggestion by Ludden et. al. (1984) that scheelite, a common constituent of gold-bearing veins, may be a suitable mineral for Rb/Sr and Sm/Nd isotopic analysis. In addition, scheelite may be suitable for U/Pb isotopic determination, and O-isotope analysis. Boyle (1979) has noted the close association of scheelite with gold mineralization, and pointed out that scheelite "occurs in [gold] deposits of all ages from Precambrian to Tertiary". For this reason, a preliminary examination of the trace element and REE contents of scheelites from gold deposits has been undertaken to determine if the levels of REE, U and Sr would be sufficient for isotopic study.

To date, more than 30 samples of scheelite have been collected from active or past producing gold mines or prospects. 19 samples were analyzed for their trace element and rare earth element (REE) contents by E. Hoffman, Nuclear Activation Services. All samples were associated spatially with gold, and several contained native gold.

The scheelite samples typically contain several tens of ppm of REE, very abundant strontium and, in some samples, abundant uranium. The variation in the content of strontium in scheelite from samples within a single deposit is generally very restricted, but samples from different districts show wide variations. At the Sigma Mine, Sr contents range between 100 and 200 ppm, whereas in Timmins scheelites typically contain 2400 ppm, those from Geraldton contain an average of 7500ppm and those from Yellowknife are highly variable and enriched over the other deposits. The contents of Sr in all cases are sufficient to permit

determination of initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, which may give an indication of the primary fluid composition, and of mantle versus crustal sources.

As with strontium, the REE contents within a single deposit or district are typically quite uniform, but significant variations exist between groups of deposits. Both the Geraldton and Sigma samples contain between 3 and 10 ppm (average of 9ppm) La, whereas the Timmins samples have 14 to 28 ppm (average 23 ppm) La. As with Sr, the REE contents of scheelite from Yellowknife are highly variable, and generally enriched over the other deposits.

Chondrite-normalized REE patterns illustrate two interesting features; 1) all samples have a significant positive Eu anomaly which may indicate that Eu was transported in the reduced state in the ore fluid; 2) the REE patterns may be separated into two groups: i) samples from Timmins, which have a relatively flat REE profile, with a distinctive positive Eu anomaly, and ii) samples from Sigma which display a pattern with a broad positive hump in the intermediate REE's. The Geraldton-Beardmore samples show both types of profile.

In both groups, the light and heavy rare earths (LREE and HREE) have approximately the same chondrite-normalized contents. Either the samples with the broad hump have incorporated the "middle" REE more efficiently than the other group, or else the REE compositions of the mineralizing fluids of each group were different. Ionic radius and charge conditions which controlled the REE distribution in scheelite should be constant (with the exception of Eu), and thus different fluid compositions seem a more likely explanation of the differences in shape of the patterns. However, possible temperature and pressure dependence of the REE partitioning need to be considered further.

From our preliminary data, it is clear that continued study of scheelite and other accessory minerals, will yield more information on the source of mineralizing fluids for gold deposits.

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Geology and structural history of the Kamiskotia
Igneous Complex, western Abitibi Subprovince, Ontario

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The Kamiskotia Igneous Complex (KIC), located 30 km west of Timmins, Ontario near the western margin of the Abitibi Subprovince, is composed of the Kamiskotia Gabbro (KG), a large (>200 km²) anorthositic gabbroic intrusion, and the overlying Kamiskotia Volcanics (KV), a bimodal, tholeiitic volcanic pile that hosts significant massive sulfide mineralization (>5 mil. tons Cu-Zn ore recovered). The KIC is underlain by a 2 m thick oxide-sulfide iron formation and a sequence of tholeiitic mafic volcanic rocks, and is intruded by four distinct tonalitic masses.

In order to unravel the structural history of the KIC, detailed structural mapping of penetrative and non-penetrative fabrics is presented, along with preliminary U-Pb geochronology to constrain the timing of deformation and magmatism. There are three prominent structural features in the region. 1) A broad regional monocline facing to the north and east has affected all lithologies except three late tonalitic intrusions. 2) Contact strain aureoles are present around three tonalitic intrusions, and extend up to two km to either side of their contacts. They are defined by a well-developed flattening fabric parallel to the contact accompanied by a strong elongation fabric locally. There is evidence for overprinting of one contact strain aureole on another. A fourth tonalitic body located at the center of the KG does not have an associated contact strain aureole. It is characterized by clear magma mixing textures between tonalitic and gabbroic material. 3) A predominately east-trending, non-penetrative fabric crosscuts stratigraphy and is pervasive throughout the region. This fabric is particularly well-developed in the felsic volcanics of the KV.

Preliminary precise U-Pb zircon and sphene geochronology* indicates that the voluminous tholeiitic and calc-alkalic magmatism and deformation in the Kamiskotia area occurred within a 15 Ma interval. Two samples from the KIC, a quartz pegmatitic gabbro from the KG and a flow-banded rhyolite from the KV are coeval at 2705 Ma. This agrees with field and geochemical evidence for the derivation of the KV from a supracrustal magma chamber that crystallized to form the KG. A foliated hornblende tonalite along the western

margin of the KG is 2697 Ma. One abraded sphene fraction from this sample is nearly concordant at 2692 Ma, suggesting a protracted cooling history, or a dynamic metamorphic event 5 Ma after crystallization to reheat the sphene past its blocking temperature. A foliated biotite tonalite from within the margins of the KG has two nearly concordant zircon fractions at 2692 Ma. A third abraded fraction has a 207/206 age of 2926 Ma and is 4.6% discordant. These data can be interpreted as defining a mixing line between 2692 Ma and approximately 3500 Ma, indicating inheritance of xenocrystic zircon from a much older crustal component. Further work is in progress to analyze older zircon populations, and better establish the evidence for very old crust in the Kamiskotia area.

The KIC intruded into previously existing crustal material composed of tholeiitic mafic volcanics and an older component, probably felsic intrusive rock. During the crystallization of the KG, a calc-alkalic tonalitic magma was injected into its center and mixed with the resident tholeiitic magma. Approximately 10 Ma later, a series of tonalitic intrusions were vertically emplaced into and along the margins of the KG, and subsequently expanded in situ to produce the well-developed flattening fabrics that characterize their contact strain aureoles. Between 2705 and 2695 Ma., a non-penetrative deformation event formed the large monoclinical structure across the Kamiskotia region. Later north-south compression formed the regional east-trending, non-penetrative fabric.

With its magmatic and structural history, the KIC is similar to several mafic intrusions that border granitoid terrane in northwestern Ontario, and appears to be comparable to the Bell River and Dore Lake Complexes in Quebec. Bedding attitudes and structural fabrics are comparable with predominately vertical movement of crustal material. There is little evidence that modern day plate tectonic processes played a role in the evolution of the KIC.

*All errors in age determinations are approximately +/-2 Ma. Ages and errors will be modified as geochronologic work progresses.

Refolding and fold reorientation during
pluton emplacement in a regional stress field,
Vermilion Granitic Complex, northeastern Minnesota

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Archean schists and migmatites along the southern margin of the Vermilion Granitic Complex, southeast of the Lac La Croix batholith (LLB), have undergone three periods of regional ductile deformation. Both F_2 and F_3 folds formed as a result of regional N-S compression. However, F_3 folds and local noncylindrical variations in F_2 are interpreted here to be an indirect result of country rock reorientation during the emplacement of the LLB.

F_2 folds along most of the southern margin of the LLB are generally cylindrical and have relatively constant SW-plunging hinges and east-striking axial planes. However, in the Burntside Lake area, along the southeast margin of the LLB, large-scale F_2 parasitic folds become noncylindrical, and F_2 fold hinges range from SW to NE plunging within the local F_2 axial planes. In this same area, local tonalite veins have undergone a counterclockwise rotation producing S-symmetry drag patterns in the S_1 foliation cut by the veins. Both the local F_2 noncylindricity and the drag patterns adjacent to veins are attributed to a counterclockwise rotation of the country rocks along the southeast margin of the LLB during its progressive emplacement in a continuing N-S compressional regime. As emplacement of the LLB continued, a doubly plunging F_3 synform developed parallel to the southeastern margin of the LLB, refolding both the earlier F_2 folds and the tonalite veins displaying adjacent drag patterns.

Other F_3 folds with W- to WNW-trending axial planes occur to the southwest of the LLB where they noncylindrically refold regional F_2 folds (Bauer, 1985, 1986). The F_2 folds in this area are interpreted to have been reoriented to the NW during emplacement of the LLB and then refolded by F_3 during continued N-S regional compression.

These variations in fold geometry suggest that emplacement of the LLB caused late-stage modifications in the regional fold geometries but was not responsible for the N-S compression which caused the F_2 and F_3 folds.

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Geology, structure, and associated precious metal
mineralization of Archean rocks in the vicinity
of Clark Creek, Marquette County, Michigan

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The Clark Creek region lies within the Ishpeming Greenstone Belt in the northern portion of Marquette County. This area is currently being tested by several mining companies for the presence of economic gold mineralization. The oldest rocks observed in the area are part of a succession of steeply dipping Archean metavolcanics known as the Metavolcanics of Silver Mine Lakes. This group was named originally by Owens and Bornhorst in 1985 (Michigan Geological Survey Division Report OFR-85-2; 1985 ILSG) in an area immediately east of the Clark Creek region and was subdivided into Pillowed Basalt, Pyroclastic, Iron Formation, and Laminated Schist members. In 1986, Johnson and others (Michigan Geological Survey Division Report OFR-86-2; 1986 ILSG) reported on an area immediately to the west which contained foliated, non-foliated, and highly altered basalts of unknown stratigraphic relationship to the Metavolcanics of Silver Mine Lakes.

This study allows correlation between the two areas and revision of the members within the Metavolcanics of Silver Mine Lakes to (from oldest to youngest): Lower Pillowed Basalt Member, Willow Creek Pyroclastic and Iron Formation Member, and Upper Pillowed basalt Member. The Upper Pillowed Basalt Member is subdivided into highly altered, foliated, non-foliated, and laminated schist varieties. Numerous pillow structures in the basalts consistently showed the top of beds to be towards the south-southwest. Where visible, bedding and lithologic contacts strike between N60°W and N75°W and dip from 70° to vertical, generally to the southwest. The metavolcanics are intruded by the Archean Metagabbro of Clark Creek, which roughly parallels bedding. During the Late Archean the area was subjected to a period of intense deformation and metamorphism. Most field evidence for this event comes from the presence of mappable faults based on lithologic contact discontinuities, highly sheared intrusive contacts, and zones of highly foliated to schistose basalts, many of which we interpret as shear zones. Most foliations have strikes of between N60°W and N75°W with dips between 60° and vertical. The Archean Rhyolite Intrusive of Fire Center Mine intrudes pre-existing rocks in a dike to sill-like manner. Field relationships suggest that these rhyolites are syn- to post-tectonic. The Archean rocks are unconformably overlain by quartzites and slates of the Lower Proterozoic Michigamme Formation. The Michigamme Formation was metamorphosed and faulted near the end of the Lower Proterozoic by the Penokean orogeny. This orogeny was also responsible for reactivation of Archean faults and minor secondary metamorphic overprinting within the Archean rocks. Middle Proterozoic (Keweenawan) diabase dikes, typically east-west trending, cut all of the older rock units and structures. Additional stratigraphic details will be published in a 1987 Michigan Geological Survey Division Open File Report.

Mineralization in the region exists in two forms: 1) epigenetic quartz-carbonate-sulphide veins, and 2) disseminated sulphides within altered country rocks. The epigenetic quartz veins are often associated with shear zones and faults. The most common gangue minerals in these veins are quartz and carbonate, with lesser amounts of pyrrhotite, chalcopyrite, and arsenopyrite. Disseminated mineralization is most prominent in the highly altered variety of the Upper Pillowed Basalt Member but also occurs to a much lesser degree in other Archean rock types. This mineralization consists of disseminated pyrite accompanied by minor amounts of pyrrhotite and chalcopyrite. The gangue minerals in the altered country rocks are primarily sericite, quartz, chlorite, and carbonate. Locally, galena and sphalerite are the dominant disseminated sulphide minerals.

A limited number of gold assays was completed, some of which yielded anomalous values. The highest values were from the highly altered variety of the Upper Pillowed Basalt Member. Additional anomalous values for gold were obtained from the Willow Creek Pyroclastic and Iron Formation Member. Owens and Bornhorst (1985) also found anomalous gold in this member which we interpret to represent a chemically favorable host for gold mineralization. An anomalous silver assay was obtained from an area with shear zone associated galena mineralization.

MacLeod Mine Geology - A Brief Review

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The MacLeod iron ore (siderite) mine is located 235 kilometers by highway, north of Sault Ste. Marie, 4 kilometers north of Wawa and lies within the Wawa Belt of the Canadian Shield's Superior Province. It is a downward extension of the depleted Helen and Victoria orebodies which all together formed a single orebody in the Helen Iron Range (Goodwin, 1964). The siderite-pyrite, banded chert iron formation is conformable within underlying felsic tuffs, agglomerate, and overlying intermediate flows and pillow lavas. This continuous uninterrupted sequence forms the south limb of a syncline that is overturned to the north, strikes east-west, dips south an average of 60° and plunges 35° east.

MacLeod Mine siderite, which extends from 180 to 730 meters below the shaft collar, averages 2 kilometers in length, 60 meters in width and in the east half of the mine, which widens to a maximum 150 meters, contains a low iron high chert central silica rib from 3 to 20 meters in width. An average in situ grade of siderite is: 35.3% Fe, 3.86% S, 6.89% SiO₂, 2.85% CaO, 5.60% MgO, 0.70% Al₂O₃, 2.02% Mn.

In descending order from the siderite footwall contact, the rocks may grade into a few meters each, of any or all of the following - interbanded chert and siliceous siderite, pyrite-argillite, fuchsite bearing felsic intrusive sill or dike, siliceous siderite, before encountering 60 to 90 meters of carbonated felsic pyroclastics. Chloritoid is common in the underlying volcanics. The massive siderite grades upwards into a high pyrite zone from 3 to 15 meters in width and then into several hundred meters of banded chert topped by upper volcanics. Some zones in the upper banded chert member contain thin bands of jasper, magnetite and pyrrhotite. The latter two minerals are also not uncommon in siderite and they frequently occur with pyrite, ankerite and calcite in narrow quartz veins. Large irregular masses of metadiorite generally strike northeast and intrude all rock types. Minor intrusions of lamprophyre dikes, sills, and quartz-feldspar porphyry are also present. Four steeply dipping diabase dikes from 10 to 20 meters in width traverse the orebody. Two in the centre and one at the east boundary strike northwest while a west boundary dike strikes northeast.

The orebody is offset 107 meters north at the east central diabase dike; relative displacement is east side northward. This dike divides the mine into MacLeod West and East.

Vugs of all sizes are frequently intersected especially in the hangingwall banded chert of MacLeod East where in one area they are interconnected for 250 meters along strike. Several vugs are 10 to 30 meters in height and width. Most were water filled, coated with various assemblages and forms of calcite, marcasite, pyrite and very rarely with minute amounts of chalcopyrite, marmatite, galena or selenite.

The MacLeod Mine has been in production since 1961 and 58 million tons of ore have been mined to 1986. Total ore from all three mines in the same orebody since siderite mining began in 1939 has been 8 million tons by open pit, 1939 - 1950, and 79.3 million tons from underground since 1949. A diamond drill hole from surface intersected siderite 1,200 meters below the shaft collar.

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A two-stage simple-shear model for high flattening strains in shear zones of the central Vermilion district, northeastern Minnesota

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Large-scale anastomosing shear zones up to 600 meters wide deform basalt, tuff, lamprophyre, and graywacke in the central Vermilion district just north of the town of Ely. Mylonites in the shear zones have a relatively consistent C foliation orientation of $N72^{\circ}E$, $68^{\circ}S$ and contain numerous mineral lineations and striations with high concentrations at $S27^{\circ}E$, 69° and $S44^{\circ}W$, 56° and a more dispersed concentration at $N74^{\circ}E$, 33° . Small-scale kinematic indicators, including actinolite porphyroblast fish, S-C fabric relationships, shear bands, and extension fractures, indicate non-coaxial deformation with a dextral sense of shear.

Finite strain measurements from variolitic pillow basalts, agglomerate clasts, and phenocrysts indicate large flattening strains in the shear zones (Fig. 1). Values of k range from a nearly plane strain value of 0.94 to highly oblate values of 0.06; r values ($=X/Y + Y/Z + 1$) are locally greater than 15. This range in strain, along with the abundant kinematic shear indicators, argues against generation of the high flattening strains via coaxial deformation. In addition, the flattening strains cannot reasonably be accommodated by a combination of simple shear and volume loss. Excessive volume loss - greater than 70% - is required to attain the measured strains; however, no evidence of diffusive mass transfer was observed either on a microscopic or a mesoscopic scale.

Although a strain path involving a combination of progressive simple shear and pure shear may be called upon to explain the strain values in Figure 1, we consider the possibility that the differential clustering of lineations and striations on the C foliation and the distribution of major and intermediate strain axes in Figure 2 is a result of superimposed simple shear. Possible strain paths consistent with the observed distribution of flattening strains were calculated using a two-stage model in which two simple shear events with different displacement vectors and slightly different displacement planes are superimposed. A difference in the orientation of the displacement planes is required because superimposed simple shear, with different shear displacement vectors but parallel displacement planes, results in finite plane strains regardless of the angle between displacement vectors.

Relatively low-magnitude, near plane-strain values obtained from three samples collected adjacent to the mylonitic shear zones are taken to represent strains attained during the initial simple shear event. An angle as small as 5° between the shear displacement planes of the first and second events will produce large finite flattening strains. The best fit strain paths (Fig. 1) were obtained using initial strain values (γ_1) of 1.0 and 2.5, respectively, overprinted by a second simple shear with a

10° shear plane angle from the first event and a 75° angle between the two displacement vectors. γ_2 values as high as 8.0 are required to produce the observed finite strains.

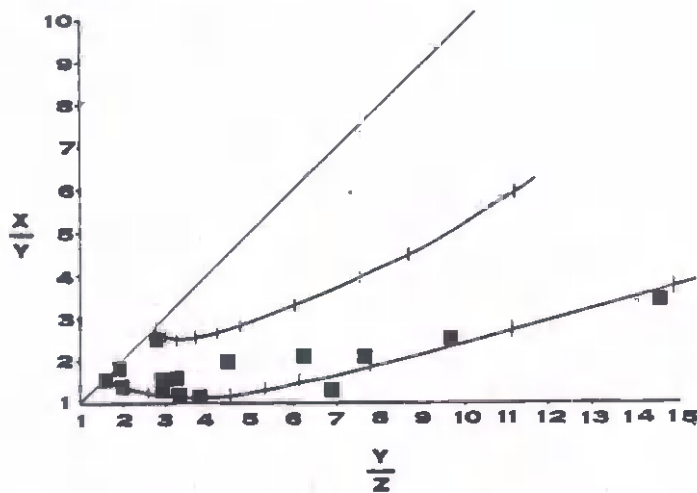


Figure 1. Flinn plot of finite strain analyses with two strain paths for γ_1 of 1.0 and 2.5 and γ_2 intervals 0.2, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 6.0, and 8.0.

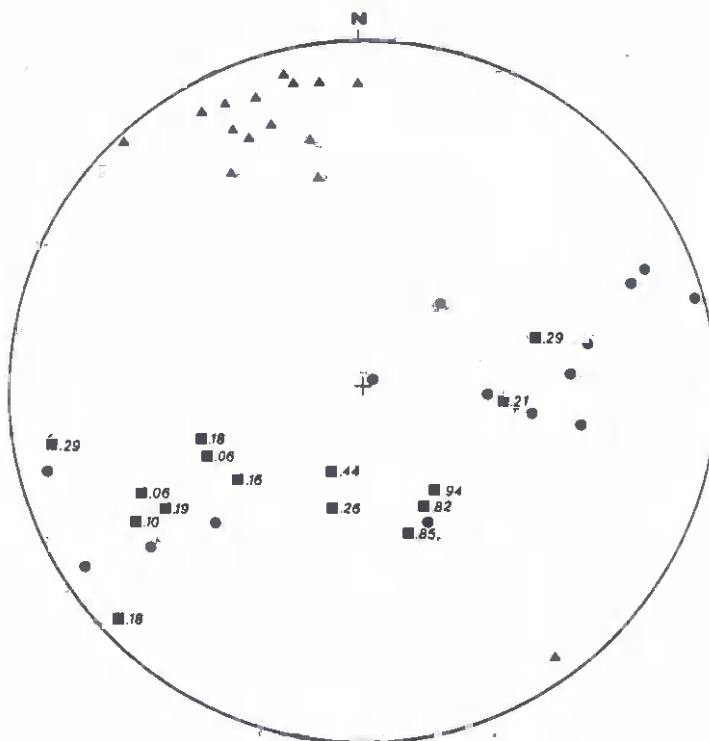


Figure 2. Orientation of minor (triangles), intermediate (circles) and major (squares) axes of finite strain ellipsoids. Numbers are k values.

Geochemical Character of Archean Rocks from the East Half
of the Northern Complex, Upper Peninsula, Michigan:
A Progress Report

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The northern complex is an Archean granite-greenstone terrane located in Marquette and Baraga Counties. As a whole, it consists of more granitoid and gneissic rocks than greenstone. In the eastern half of the complex there are about 1000 km² of exposed Archean rocks, one-third greenstone, which are unconformably overlain by Proterozoic sediments. The Archean of the east half consists of thousands of meters of dominantly subaqueous, mafic to felsic volcanic flows, pyroclastics, and volcanoclastic sediments that are intruded by gabbro and rhyolite dikes and sills, and granitoid plutons. An 8x1 km Archean peridotite body was also emplaced structurally within the volcanic rocks. All of these rocks have been subjected to intense deformation and metamorphosed to at least greenschist facies.

Histograms of geochemical data, weighted for exposed area, illustrate that the greenstone belt, excluding granitoid plutons, is weakly bimodal in character. Basaltic lava flows are, by far, the dominant rock type. Pyroclastic volcanic rocks of andesitic to dacitic composition are the second mode in the histograms, rhyolites are lesser in abundance. On a Jensen cation diagram the basaltic flows and gabbroic intrusives are tholeiitic whereas andesitic pyroclastic rocks and rhyolite intrusives are calc-alkalic. The granitoid rocks are calc-alkalic and on the basis of modal mineralogy range from quartz diorite to trondhjemite.

Within two sections of basalt, where structural repetition may be low, we looked for stratigraphic geochemical variations but no coherent trends were found. Basalts and the gabbros which intrude them cannot be distinguished from one another geochemically, suggesting that they are from genetically similar or possibly the same magma source. A few INAA data for the basalts show relatively flat to slightly LREE depleted patterns, 5 to 9x chondrites.

The last Archean magmatic event in the greenstone belt was the intrusion of relatively tabular rhyolite bodies and granitoid plutons. There is a textural continuum between the rhyolites and granitoid rocks which is further expressed by excellent chemical continuity on variation diagrams. Thus, a close genetic link exists between the rhyolite and granitoid intrusives. The rhyolites are interpreted as the late-stage, generally more-evolved parts of the plutons. This investigation is an outgrowth of projects partially funded by the Michigan Geological Survey.

Geology of the Mishibishu Lake Area

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The Mishibishu Lake Area is located about 35 km west of Wawa and about 80 km southeast of Hemlo. The Mishibishu Lake supracrustal belt is about 55 km long and 16 km wide and is concave to the south, bounded on either end by Lake Superior, enclosed by felsic batholithic complexes and locally intruded by younger felsic plutonic rocks. The ratio of supracrustal to batholithic rocks is 2:3.

Proceeding upward stratigraphically, the supracrustal rocks consist of 15% mafic metavolcanic, massive and pillowed basaltic, and lesser andesitic flows and associated breccias and pyroclastic rocks. Chemically, these rocks are magnesium- and iron-tholeiitic basalts, tholeiitic andesites and calc-alkaline basalts. The iron tholeiite basalts predominate. Intermediate metavolcanic flows and pyroclastics make up about 4% of the supracrustal rocks and consist of tholeiitic dacites and calc-alkaline andesites. Felsic metavolcanic flows and pyroclastic rocks of calc-alkaline dacite to rhyolite composition make up about 5% of the supracrustal rocks. The intermediate and felsic metavolcanics increase in proportion west of Mishibishu Lake.

Chemical metasedimentary rocks make up less than 1% of the supracrustal rocks and are typically magnetitic chert or jasper interlayered with magnetitic iron-rich rocks and appear to be associated with the waning stages of a volcanic cycle. The cherty portions may be arkosic to wacke and sulfides are often associated with the oxide portions in varying degrees. These rocks often exhibit the effects of deformation rather dramatically.

Clastic metasedimentary rocks comprise 15% of the supracrustal rocks and range from mudstone to conglomerate. These rocks appear to have been deposited by turbidity currents along submarine fans.

Felsic hypabyssal, mafic plutonic, transitional migmatitic rocks bounding the supracrustal rocks and felsic stocks and batholiths make up most of the rocks underlying the map area.

A considerable range of mineralogy and chemical composition is evident in the granitoid rocks. The stocks intruding the supracrustal rocks tend to be fairly uniform in composition while the batholithic rocks bounding the supracrustal rocks exhibit a more varied composition and may be multiple intrusions or the product of a differentiated magma.

Metamorphic grade is mainly low to middle greenschist rank with some contact facies to amphibolite rank. Middle to Late Archean and Proterozoic diabase dikes of at least 3 different ages cut all Archean rocks in the Mishibishu Lake Area. Several diatremes and erosional remnants of Late Proterozoic lavas occupy topographically low areas near the shore of Lake Superior. These rocks do not appear to have undergone metamorphism or structural deformation.

The physiography is characterized by low to moderate relief, commonly broken by steep sided hills and ridges 30 to 200 m high. Elevations range from 183 m (Lake Superior) to 300 m above sea level. Pleistocene deposits are varved clays with lesser deposits of sandy outwash, till, gravel bars and deltas. Recent surficial deposits consist of a mantle of organic debris and recent erosional products from bedrock and glacial deposits.

The supracrustal rocks have been folded into an isoclinal synformal shape about an east-trending axis with several subparallel parasitic fold axes on either side. Faults and lineaments with varying degrees of movement displayed along them cut all Archean lithologies, both parallel and transverse. Shearing is most intense near the late stage intrusive bodies. The main Mishibishu Deformation Zone is a composite of several shear zones. Shearing is characterized by an increase in the penetrative fabric, examples of which are kink banding including conjugate kink sets, compositional banding and three dimensional chevron folds.

Mineral exploration in the area has been recorded in assessment file records since 1907 and is reported to have begun before the turn of the century. Early exploration was for iron ore and was concentrated near the David Lakes area. Gold exploration occurred between 1937 and the beginning of World War II. After the war gold exploration resumed and with only brief breaks continued until the present. Some base metal exploration projects occurred from time to time, however, these programs were not of a very large scale. The area is presently undergoing relatively intense exploration for gold with several companies involved in property evaluation and feasibility studies on previously discovered showings.

A Brief Look at GLIMPCE

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The Great Lakes International Multidisciplinary Program on Crustal Evolution (GLIMPCE) was conceived in November 1985 to coordinate multidisciplinary research on fundamental problems of crustal evolution of the Great Lakes region. Participants include U.S. and Canadian federal geological surveys, state and provincial geological surveys, and many university geoscientists. GLIMPCE has the following principal aims:

1. To promote cooperative research and communication among researchers in the region,
2. To advocate funding of research in the region, and
3. To cooperatively fund large geophysical surveys.

During the first year of GLIMPCE, three large data sets were acquired. Seismic reflection profiles totalling 1350 km were obtained by marine seismic surveys in Lake Superior, Lake Huron, and Lake Michigan; preliminary results are displayed in posters throughout this meeting. During the reflection survey, a large data set of refraction and wide-angle reflection data also was recorded at on-land recording sites placed strategically around the lakes and with lake bottom seismometers. Data were recorded by teams from the University of Wisconsin-Madison, University of Wisconsin-Oshkosh, Southern Illinois University, Western Ontario University, University of Saskatchewan, the Geological Survey of Canada (GSC), and the U.S. Geological Survey (USGS). Funding for all seismic work was provided by the GSC through the Lithoprobe Program and by the USGS. Logistical support was provided by the Ontario Geological Survey and the U.S. Coast Guard.

In another cooperative survey, a new aeromagnetic map of Lake Huron was produced. With funds from the GSC and the USGS, the GSC conducted the survey and produced the preliminary map on display in the poster session.

Seismic reflection data from Lake Superior reveal a remarkable image of the asymmetric Keweenaw Rift basin with strong reflections from the intercalated rift volcanic and sedimentary horizons extending to two-way travel times (T) of ≈ 7 s (≈ 20 km). Beneath the western end of the lake, the crust-mantle transition is represented by the base of a prominent band of reflections that dips to the south from $T \sim 11.5$ s (~ 38 km) to $T \sim 14$ s (~ 40 km) and beneath the center of the lake it could be as deep as $T \sim 17$ s (~ 56 km). The Grenville Front at the western end of Georgian Bay is imaged as a spectacular series of easterly dipping reflections that truncate a nearly flat horizon that lies to the west beneath Lake Huron at $T \sim 6$ s (~ 20 km). A less prominent band of sub-horizontal reflections at $T \sim 10$ s (~ 35 km) to $T \sim 12$ s (~ 40 km) may delineate the base of the crust in this region.

Superior Province: The product of Archean convergent plate tectonism

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Models proposed for the tectonic evolution of the Archean Superior Province (SP) can be characterized as fixist (1,2,3) involving deposition of volcanics and sediments in rifts of older sialic crust, followed by gravity driven vertical tectonism; or mobilist (4,5,6) with convergent plate tectonism, such as in the NW Pacific where ongoing accretion is the result of subduction beneath Eurasia (7,8).

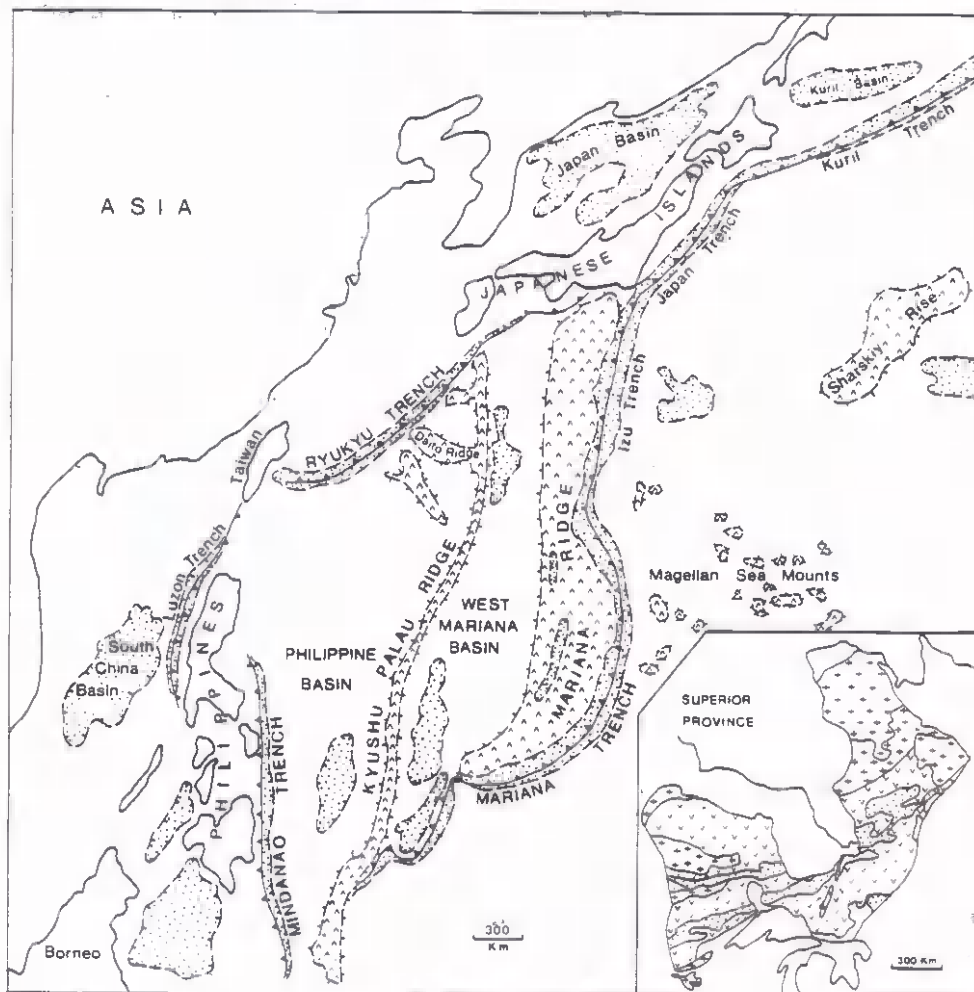
SP greenstone belts, from 3.0 to 2.7 Ga (9) consist of lower, extensive, submarine plain tholeiitic pillow basalts and komatiites, and upper, partly subaerial, chemically diverse central complexes of calc-alkaline and tholeiitic volcanics with turbiditic sediments that also form the large, intervening metasedimentary belts (10). Late shoshonitic/alkalic volcanics and alluvial/fluvial sediments unconformably overlie older volcanics in some belts. SP greenstone sequences do not resemble the fill of continental rifts, which commonly begin with alluvial sediments and end with volcanics (11,12), nor do they resemble Proterozoic greenstones deposited on rifted sialic crust which commonly begin with terrigenous sediments and end with submarine volcanics. They do resemble sequences of island arcs that vary from immature to mature and from ensimatic to ensialic (13,14). SP submarine plain accumulations may represent the lower parts of accreted arcs, seamounts, or upper oceanic crust, whereas the complexes are the upper parts of mature arcs or oceanic islands. Bimodal cycles may represent back-arc volcanism on stretched continental crust and late cycles in polycyclic belts may be the products of back-arc rifting and intra-arc wrench faulting. Superior turbidite belts may represent the fill of trenches, intra-arc and back-arc basins, and transported deep-sea fans.

SP plutonic rocks, including early, in part synvolcanic, sodic suites and later, in part syntectonic, potassic suites, are generally similar to those of Phanerozoic orogens. They range in age from 3.0 to 2.65 Ga and, like the volcanics, display little evidence of isotopic inheritance from appreciably older (>3.0 Ga) crustal sources (15). Plutonic-supracrustal contacts are mainly intrusive or tectonic; unconformities are rare.

SP structural trends and metamorphic zonation may be partly attributable to early orogenesis, but are mainly the products of late, polyphase events that occurred at about 2.73-2.7 Ga in the north and 2.7-2.68 Ga in the south. Major north-south compression and transpression resulted in early, ductile, isoclinal folds and later, increasingly brittle shear zones and wrench faults. Major recumbent folds, thrusts, and deformation zones have been mapped in some belts (16,17,18). In the NW Pacific, terrains of lithological, structural, and metamorphic complexity such as the Philippines (8) and Japan (19) are variably deformed and metamorphosed subduction complexes, arc, back-arc and trench sequences with abundant plutonic rocks accreted over a period of about 300 Ma through a complex sequence of thrusting, rifting, wrench faulting, and isoclinal folding. It is evident that Superior Province and the NW Pacific have many features in common, including similar assemblages, structural and metamorphic styles, scales, and time frames. Differences such as the absence of komatiites in the NW Pacific and the lack of paired metamorphic belts and abundance of plutonic rocks in the SP can probably be attributed to hotter Archean mantle and the relatively shallow level of erosion in the NW Pacific.

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A precise U-Pb zircon age for a trondhjemite clast in the Dore conglomerate, Wawa, Ontario.

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Trondhjemite clasts and boulders, set in a matrix composed predominantly of volcanic detritus, are a characteristic component of the Dore conglomerate in the Michipicoten greenstone belt, Wawa Subprovince. The Dore conglomerate and associated sedimentary rocks are laterally interfingered with felsic volcanic rocks belonging to the second cycle of volcanism in the belt. These units are overlain by a third cycle comprising intermediate to mafic volcanic rocks. The distribution of the clasts in the conglomerate suggests a provenance from a source in the west of the belt. Blue anatase is a unique feature, that may help in locating the source of the trondhjemite.

A previous attempt to date a trondhjemite clast by analysing bulk zircon fractions was hampered by the highly metamict, U-rich nature of the zircons which yielded very discordant analyses (Turek et al. 1984). A different approach based on the analysis of 20-1 μg samples of the subordinate, carefully selected and strongly abraded, clear zircons provided concordant and nearly concordant data which define an age of 2698 ± 2 Ma. The various fractions analyzed comprised long-prismatic, euhedral crystals, subrounded grains and apparent cores and single zircons from the matrix of a clast. All these analyses yield indistinguishable results indicating that the trondhjemite does not contain any older, inherited component.

The 2698 ± 2 Ma age for the trondhjemite is similar to U-Pb dates of 2696 ± 2 and 2698 ± 11 Ma reported by Turek et al. (1982, 1984) for felsic volcanic rocks within cycle 2. Since the Dore conglomerate is stratigraphically associated with these volcanic rocks the overlapping U-Pb ages indicate a very rapid sequence of volcanism and plutonism, uplift, erosion and sedimentation spanning only a few Ma.

The source of the trondhjemite detritus is unknown. The U-Pb age indicates that it was not derived from older sialic crust documented in the belt by U-Pb ages of about 2800-2900 Ma (Turek et al., 1984). A possible source may be the granitoid terrain to the west, one unit of which was dated by Turek et al. (1984) at 2698 ± 1 Ma. Alternatively the trondhjemite may have represented the rapidly uplifted magma chamber of cycle 2 volcanic rocks.

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Geochemistry of Proterozoic Volcanic Hosted Iron Formations in
Northern Wisconsin: Prospects for Gold Mineralization

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Iron formation units were selectively sampled in drill cores at the Wisconsin Core Repository in Milwaukee, Wisconsin during exploration for possible gold-bearing units. The rocks contain grunerite + quartz as the common mineral assemblage. Ferro-hornblende, ferro-actinolite, stilpnomelane, and sulfide minerals are present in varying proportions. Most units are well-bedded and contain alternating iron silicate and quartz beds. The grade of metamorphism ranges from upper greenschist facies to amphibolite facies. Samples were collected from 9 cores from throughout the Northern Wisconsin volcanic belt. Ten elements, including Au, Ag, Cu, Pb, Zn, Co, Ni, As, Ba, Mn, B (ppm) and Fe (%), were determined for a set of 48 samples. Whenever possible, the samples were approximately 3 m lengths of core.

Gold was detected in concentrations $> .02$ ppm in cores from Marinette County (Duval Corporation) and Clark County (North Central Mineral Ventures). In Marinette County the iron formations are those associated with the Duval Deposit. Geochemical data indicate patterns that distinguish the gold-bearing iron formations from those in which gold was absent or below detection limits. These include: concentration of Cu, Zn, Pb are low in all iron formation samples (Cu $< 1,000$ ppm, ave. 208 ppm; Zn $< 1,350$ ppm, ave. 180 ppm; Pb < 50 ppm, ave. 9 ppm), however, gold-bearing iron formations contain Zn $>$ Cu, they also contain detectable concentrations of Pb; gold-bearing iron formations are not distinguishable on the basis of Co:Ni; Fe and Mn suggest that variations in the concentrations of both elements within the section are favorable for gold association, where the concentration of both do not vary gold was not detected; As concentrations ranged from 10 to 50 ppm and, as a group, were on the average higher in gold-bearing iron formations; B is elevated in gold-bearing iron formations (71 ppm ave. / 18 ppm ave.).

Fifty-three additional samples of the iron formation section in Marinette County were analyzed by instrumental neutron activation. Samples were prepared from sections of core containing 2 to 5 cm stratigraphic thickness. Twenty-eight samples contained Au concentrations greater than detection limits and ranged up to .15 ppm. The persistence of stilpnomelane in association with grunerite and quartz under conditions of the amphibolite facies of metamorphism suggests a high alkali content in the iron formation. Trace element concentrations show strong variability among samples. These differences are related to mineralogy of the sample and to the intensity of the hydrothermal system at the time of deposition.

Volcanic stratigraphy suggests that the iron formation in Marinette County was deposited within a local basin that may have been a caldera. Basalt dikes and sills within the iron formation were intruded while the sediments were unconsolidated. These basalts are chemically distinct from basalts within the local volcanic section.

Two Duck Lake Intrusion, Coldwell Alkaline Complex, Ontario

1. Geology and Structure

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The Coldwell Alkaline Complex, on the north shore of Lake Superior, is a Proterozoic composite intrusion of layered gabbroic to syenitic rocks. Along its eastern boundary occurs an arcuate belt of layered gabbroic rocks regarded as a single intrusive unit (CURRIE, 1980). A platinum-group-element (PGE) and copper deposit was outlined through recent exploration (DAHL et al., 1986; WATKINSON et al., 1986) in the same unit. Detailed mapping (1:200), structural analysis and logging of new drill core outlined a distinct coarse-grained gabbroic to monzonitic intrusion, the Two Duck Lake Intrusion, cross-cutting the layered gabbroic unit, and corresponding to the copper-PGE mineralization. Two Duck Lake Intrusion is a N-S elongated dyke-shaped unit, of 130m maximum width, continuously exposed for 1.5km. It is discordant to the large scale stratigraphy of the layered gabbro, and to its mesoscopic layering, and exhibits magmatic breccia and xenolithic zones along the eastern (bottom) and western (top) contacts. Along the eastern boundary, the coarse-grained gabbro intrudes foliated mafic and felsic Archean metavolcanics, the foliation of which is systematically subparallel to the intrusion, suggesting that it was intruded along a pre-existing major fault or shear zone. This early structure has then been reactivated. Steeply dipping to the west in the northern part, the intrusion becomes more flat southward. Several phases of faulting affected the coarse-grained gabbroic intrusion. They are of various intensity, and consist essentially of a major NNE subvertical fault, and a conjugate network of minor NE and SE trending faults and fractures. The relative offsets along these structures vary along strike, and are responsible for some of the discontinuities of the intrusion.

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Two Duck Lake Intrusion, Coldwell Alkaline complex, Ontario.
II. Petrology and base-metal/PGE geochemistry

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Detailed petrological and geochemical cross-sections have been carried out across Two Duck Lake Intrusion in order to identify any petrological and geochemical stratigraphy or zoning, their relationships, and to enlighten petrological and geochemical relationships with host Archean metavolcanics on the eastern margin, and Coldwell Eastern Gabbro on the western margin. Typical section consists from bottom to top of 3 main subunits.

1. A fine to **medium-grained hornblende gabbro to monzodiorite** of ophitic to poikilitic textures (plagioclase, K-feldspar, augite, olivine, hornblende, biotite, apatite, chalcopyrite, cubanite, pyrrhotite, ± [quartz, magnetite, pentlandite, prehnite, actinolite, chlorite, serpentine, calcite]) including numerous recrystallized and partially melted xenoliths of metavolcanic material, and numerous granophyric pods.

2. A **coarse to pegmatitic olivine ferrogabbro to ferrodiorite** of hypidiomorphic to pegmatitic textures (plagioclase, augite, olivine, Fe-Ti-oxides, biotite, apatite, ± [orthopyroxene, chalcopyrite, cubanite, pyrrhotite, pentlandite, serpentine, actinolite, prehnite, chlorite, calcite]), cross-cut by numerous pods of gabbro to monzodiorite pegmatites where granophyres may occur.

3. A **coarse to very coarse-grained olivine gabbro to diorite** with hypidiomorphic to poikilitic textures (plagioclase, augite, olivine, orthopyroxene, biotite, apatite, chalcopyrite, cubanite, pyrrhotite, pentlandite, Fe-Ti-oxides, ± [K-feldspar, sphene, epidote, chlorite, albite, prehnite, actinolite, calcite]), including numerous xenoliths and blocks of equigranular fine-grained olivine-biotite gabbro from the Eastern Coldwell Gabbro. Most of these inclusions did not suffer partial melting as did xenoliths in subunit 1.

The abundance of hydrous and volatile-rich minerals near the contacts of the intrusion and the common association of pegmatites with xenoliths suggest that assimilation took place at both east and west boundaries of the intrusion and through the xenolithic material. Base-metal and PGE geochemical distributions follow the petrographic zoning, in that they are concentrated assymmetrically along the boundaries. The asymmetry of ore concentration is attributed to partial withdrawal of assimilated material from the bottom by gravity and concentration of volatile/Cu+PGE-rich fluids toward the top of the intrusion.

Northeastern Extension of the Proterozoic Igneous Terranes
of Mid-continental North America

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Granites and rhyolites ranging in age from 1.8 to 1.34 Ga are known to underlie much of mid-continental North America west of the Phanerozoic Michigan Basin. U-Pb zircon ages of similar rocks adjacent to the Grenville Province in Ontario (Killarney granite, 1742 Ma; Killarney porphyry, 1732 Ma; Bell Lake granite, 1470 Ma) suggest that the mid-continental terranes extend northeast beneath and beyond the Michigan Basin. Prevalence of similar U-Pb zircon ages obtained from meta-granitoid plutonic rocks southeast of the Grenville Front, affected by the 1.15 to 1.0 Ga Grenvillian orogeny, prompts the interpretation that deformed equivalents of the mid-continental Proterozoic rocks form the bulk of the Grenvillian crust immediately east of Lake Huron. Farther east, pre-1.35 Ga terranes are tectonically occluded by 1.28 to 1.25 Ga Grenville Supergroup volcanic and sedimentary rocks and 1.26 to 1.22 Ga Elzevirian plutonic rocks, themselves deformed and intruded by even younger Grenvillian plutons. Recognition of ca. 1.65 Ga and 1.5 to 1.35 Ga granitic, volcanic and anorthositic rocks on both sides of the Grenville Front in Labrador and in the Sveconorwegian Province, Sweden, attests to the widespread nature of igneous activity comparable in age and type to that which characterizes the mid-continental terranes.

Geochemistry and Petrography of Selected Early
Proterozoic Metadiabase Dikes from
Marquette County, Michigan.

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Early Proterozoic dikes and sills of metadiabase intrude the sediments of the Marquette Range Supergroup and the Archean Granite-Greenstones throughout Marquette County, Michigan. Between Champion and Marquette, thirteen selected metadiabase dikes (.5-75 m wide and 4 km long) were studied. One thick dike was studied in detail for intra-intrusive variations.

The metadiabase is medium to coarsely crystalline, dark green to greenish black in color, commonly porphyritic, with ophitic to sub-ophitic textures. There is 15-40% groundmass, which is comprised of chlorite, calcite, biotite, amphiboles and quartz. Some sections have up to 15% large (.3-15mm) phenocrystic relict plagioclase and pyroxene crystals. They are altered with reaction rims of chlorite, hornblende (uralite), and biotite. The phaneritic mineral assemblage, other than the phenocrysts, accounts for 35-75% of the rock, and is composed of the following minerals (vol. %): plagioclase, 18; amphiboles, 15; chlorite, 15; calcite, 12; quartz, 12; pyroxene, 10; biotite, 8; opaques, 8; apatite, 1; and sphene, 1.

The metamorphic grade is low to middle greenschist facies, but there are no foliations visible in hand specimens. There is extensive secondary mineral growth of fibrous amphibole, felty chlorites with quartz, and calcite which is in micro-veinlets. There are multiple stages of oxy-exsolution in titaniferous magnetites. The primary ilmenites have reaction rims of rutile and secondary conversion of the rutile to sphene.

Geochemical data suggest that the metadiabases are tholeiitic in character. The average chemical composition is (wt%): SiO₂, 47.7; Al₂O₃, 13.6; total Fe as Fe₂O₃, 17.3; MgO, 8.3; CaO, 7.5; Na₂O, 1.9; K₂O, 1.3; TiO₂, 1.8; P₂O₅, .4; and MnO, .2. In PPM: V, 371; Cr, 264; Ni, 124; Cu, 58; Zn, 94; Rb, 27; Sr, 337; Y, 24; and Zr, 134. This compositional average reflects the data from seven different intrusive bodies. It should also be noted that there is as much intra-intrusive geochemical variation as there is inter-intrusive variation. Further data analysis is currently being performed.

The Great Abitibi Dyke - petrological overview

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The Abitibi dyke swarm, southeastern Superior Province, Canadian Shield, consists of at least 10 major dykes. The largest of these, the Great Abitibi Dyke (GAD), is more than 600 km long, up to ~0.25 km wide and subvertical in attitude. Previous workers have shown that the age of the GAD and probably the rest of the swarm, is 1.14 Ga (U-Pb data from baddeleyite and K-Ar data from biotite).

The GAD consists of transitional to weakly alkaline olivine gabbro to monzodiorite which can be subdivided into two compositional groups (Unit 1 and 2). Rocks of Unit 1 occur along the entire length of the dyke, while Unit 2 rocks are restricted to the dyke interior over about half of the dyke length.

A linear relationship between the Fo content of olivines, the Mg/(Mg + Fe) ratio of clinopyroxenes and the whole-rock Ba concentrations suggests compositional control by fractional crystallization. The range in chemistry (particularly for olivines) is comparable to that found in large, layered, mafic bodies such as Kiglapait and Skaergaard.

The chemical variation in Unit 1 and Unit 2 rocks can be modelled by fractionation of olivine and plagioclase from a magma corresponding in composition to the most primitive, chilled-margin sample. Some of these rocks could only have been derived, in situ, if olivine and plagioclase settled out to deeper levels in the dyke.

Feldspar alignment at one traverse across the dyke defines a synformal foliation (restricted to Unit 2) which suggests that the dyke dips southwards at about 75°. Asymmetrical variation in foliation and chemistry across the dyke suggests that the dyke was south-dipping during intrusion.

Incompatible-element spidergrams from the GAD are compared with data from igneous rocks of various tectonic settings. The GAD patterns and abundances are similar to those of Ocean Island Basalts and some uncontaminated Continental Flood Basalts. Relative to these, the GAD is enriched in Ba, Eu, K, P, and Ti, and depleted in Hf and Zr.

The GAD may be part of Lake Superior Keweenaw volcanism. The age and paleomagnetic signature of the GAD, suggest emplacement during the lower 'normal' polarity interval of Lake Superior Keweenaw stratigraphy. A positive Eu anomaly, high Al₂O₃ and other aspects of the chemistry of the GAD are similar to those of some Lake Superior Keweenaw volcanics.

The Utility of Werner Deconvolution as a Geomagnetic Mapping
Tool in East-Central Minnesota

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Werner deconvolution is an inverse magnetic modeling technique used to estimate position, depth, susceptibility contrast, and dip parameters for anomaly sources that can be approximated by thin sheets or planar interfaces. Related software was designed specifically for microcomputers and the end product consists of magnetic source parameter maps plotted at various scales. The technique was applied to high-resolution aeromagnetic data from east-central Minnesota (305 flight lines at 150 m mean terrain clearance, spaced 400 m apart with a 50 m sampling interval).

The utility of Werner deconvolution as a structural and lithologic mapping tool has been proven by its application in areas where direct geological and drill hole information exist. The major syncline in the North range of the Cuyuna iron district is successfully represented by thin sheet solutions. Results obtained north of the major syncline imply a second, more elongate, syncline. Along the northeastern two-thirds of the South range, the iron-formation is represented by thin sheets dipping steeply southeast, consistent with observed data. Along the southwestern third, calculated dips systematically change to steeply north. Northeast of Mille Lacs Lake in the Glen Township area, a known syncline-anticline pair is successfully represented by thin sheet solutions. The causative magnetic bodies are pyrrhotite layers, that at one time were considered for mining as a source of sulfur, and/or metamorphosed diabase sills.

Werner deconvolution results are presently being interpreted in areas of poorly understood geology. East of Mille Lacs Lake, where several two-dimensional aeromagnetic anomalies occur, associated sheets and interfaces have been characterized and are consistent with modern concepts of the geology in the region. Geologic features represented by these results may include magnetite- and pyrrhotite-rich lenses, sills and dikes, limbs of folds, and thrust faults.

In the past, Werner deconvolution has been used primarily to obtain depth estimates for basins associated with oil exploration. This study shows that the technique also has great potential as a mapping tool for Precambrian terranes of complex structural geology.

Geology of the Batchawana area, Ontario

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The Batchawana area has been subdivided into two supracrustal and three plutonic-gneissic, litho-tectonic domains. The two supracrustal domains are predominantly volcanic and are divided into a western and an eastern domain. The plutonic terranes that enclose the supracrustal rocks has been previously subdivided by Card (1979) into the Chapleau Gneiss, Ramsey Gneiss, and Algoma Plutonic domains. Each of these five litho-tectonic domains are geologically and geochronologically distinct. The two supracrustal domains are distinct volcanic cycles that are spatially separated by a major tectonic event of ~2715 Ma.

The oldest domain is the western supracrustal group of rocks in the Batchawana "greenstone" belt. The succession is principally a homoclinal sequence of submarine tholeiitic mafic volcanics with minor intercalated sediments and felsic tuffs (first cycle). The entire sequence defines a single volcanic cycle and is interpreted as a mafic plain extrusive environment that grades from thick flows in the west with minor intercalated tuffs and sediments eastward into a distal facies equivalent containing more abundant sediments. U/Pb zircon data from a felsic tuff in the western part of the succession yields an age of ~2729 Ma (Corfu and Grunsky, in press). This sequence is bounded to the north by post kinematic intrusions of ~2668 Ma and by gneisses of the Chapleau gneiss domain. The southern part of the sequence is bounded by a large (~2715 Ma) granodioritic intrusion which predates the the younger eastern supracrustal group. The western boundary is covered by Keweenaw volcanics and it is not known how far west the sequence extends. The eastern margin of the western domain is bounded by a fault that possibly developed around the time of the early intrusions in the Algoma Plutonic Domain (~2715 Ma).

The eastern supracrustal domain (second cycle) can be subdivided into an early mixed tholeiite-calc-alkalic volcanic succession that evolved upward into a calc-alkalic environment. The upper part of the succession is predominantly tuffs and sediments. U/Pb zircon age determinations in the eastern supracrustal group yield a range of ~2711 to ~2698 Ma (Corfu and Grunsky, in press). These ages have been determined from sites in the south east part of the eastern group. The volcanics in the northeast part of the area have been inferred to be of approximately the same age based upon stratigraphic correlations from north to south. The lowest part of this succession is interpreted as a mafic plain environment that evolved upward into a shield volcano environment as evidenced by the increasing component of calc-alkalic pyroclastics interbedded with mafic flows.

The sedimentary basin in the north-central part of the belt began as a distal environment to the mafic plain volcanics at the base of the eastern volcanic succession (second cycle). The lower part of the basin is comprised of turbiditic sediments of mafic provenance with minor amounts of interbedded felsic tuffaceous units. Abundant turbiditic sediments interbedded with conglomerates derived from the pyroclastic events to the southeast dominate the middle to upper part of the basin. The basin was probably active from early in the development of the eastern succession until the onset of plutonism (~2675 Ma). The southern boundary of the sedimentary basin is fault bounded with the older western volcanic cycle. This fault is a major disconformity within the supracrustal succession.

The structural fabrics of the two volcanic domains are distinctly different. The western volcanic cycle (first cycle) is only slightly deformed with northeasterly trending, steeply dipping foliations and subsequently intruded by the Griffin Lake and Pancake Lake post-kinematic stocks (~2675 Ma). Large scale plutonism occurred at ~2715 Ma

and terminated the western volcanic cycle. A major fault/shear system bounds the western volcanic domain and the sedimentary basin. This disconformity was probably active during the development of the sedimentary basin. The only known gold occurrences within the "greenstone" belt occur in proximity to this fault.

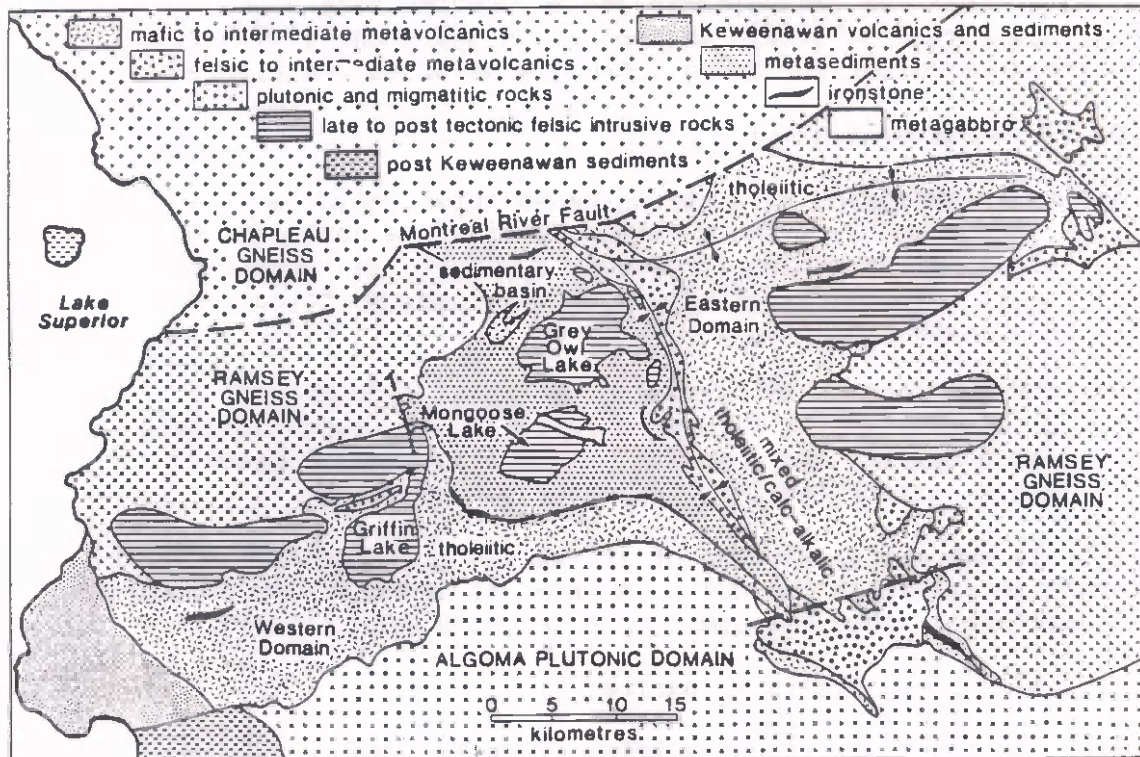
The eastern volcanic cycle (second cycle) is dominated by a distinct northwest trending schistosity in the southern and central parts of the domain. Top determinations in the southeast part of the belt indicate overturning of the sequence. A northwest trending zone that extends from the northern to the southern part of belt demarcates a zone over which the sequence is thrust. This zone is part of a tightly folded syncline that extends into the north central part of the area where it merges with a northeast-east trending syncline from the northeast group of volcanics. This zone developed in part due to active subsidence associated with a major shield volcano environment accompanied by later contemporaneous tectonism-plutonism.

The Algoma Plutonic Domain appears to be the oldest plutonic terrane (~2715 Ma). This domain is characterized by massive granodiorite, quartz monzonite, and granite plutons with small enclaves of supracrustal material situated between the major intrusive phases. The domain is distinctly lacking in any significant amounts of gneiss/migmatitic supracrustal material.

The Ramsey Gneiss Domain (~2675 Ga) is dominated with metasomatized and tectonized equivalents (paragneiss) of the eastern supracrustal domain. The domain is characterized by linear zones of gneiss intruded by massive to foliated felsic plutonic rocks. The gneiss zones are commonly gneiss at the borders and migmatitic at the cores. These linear zones strike northeasterly and are of amphibolite rank metamorphism.

The Chapleau Gneiss Domain is dominated with a mixture of paragneiss, migmatite, orthogneiss, pegmatite, and intrusive stocks. The domain is distinctly more heterogeneous relative to the Ramsey Gneiss Domain and the Algoma Plutonic Domain.

General Geology of the Batchawana Area



Gold Mineralization of The Mishibishu Lake Greenstone Belt

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The Mishibishu Lake belt is located 35 km west of Wawa, Ontario and approximately 80 km south of Hemlo, Ontario. Deformation zones host all the known gold occurrences found to date within the Mishibishu Lake belt. The Scuzzy Little Lake (1), Granges-MacMillan (2), Magnacon (3), Northwest (4), Amichi (5), Hollinger (6) and Discovery (7) gold occurrences all occur within a lithologically and structurally complex zone known as the Mishibishu Deformation Zone (MDZ) (Figure 1). The No Name Lake (8) gold occurrence is hosted within the Eagle River Deformation Zone (ERDZ), while no gold mineralization has been found to date within the Rook Lake Deformation Zone (RLDZ) (Figure 1).

The 40 km long MDZ extends eastward from the East Pukaskwa River, north of Mishibishu, Mishi, and Katzenbach Lakes, at which point it swings to the southeast and continues to Lake Superior (Figure 1). The MDZ varies in width from 200 to 500 m and is composed of several anastomosing shear zones localized along a major volcanic-sedimentary contact. The metavolcanics to the north of the MDZ consist of massive to foliated mafic to intermediate tuffs, lapilli tuffs, crystal tuffs and volcanic breccias. The metasedimentary rocks to the south of the MDZ consist of interbedded polymictic and oligomictic conglomerates, wackes, quartz grits, and argillites. Both the metavolcanic and metasedimentary rocks exhibit an increasing state of strain as the MDZ is approached, with rocks within the core of the MDZ being intensely deformed and altered.

The MDZ is characterized by:

- (a) the development of a strong penetrative foliation (including S, C, and C' shear fabrics), a north-northeast plunging stretching lineation, symmetric and asymmetric small scale folds of the foliation, chevron folds and conjugate kink bands.
- (b) the development of variable degrees of hydrothermal alteration in the form of chloritization, carbonatization (both calcite and ankerite), sericitization ($\pm$ green mica), silicification, and minor albization.

A relatively systematic pattern of alteration minerals flanks the auriferous zones within the MDZ. In order of increasing proximity to the auriferous zones the dominant alteration minerals are:

- (1) chlorite $\pm$ calcite $\pm$ pyrite
- (2) chlorite + ankerite $\pm$ calcite $\pm$ pyrite
- (3) chlorite + sericite $\pm$ calcite $\pm$ pyrite

(4) sericite + chlorite + ankerite + green mica + pyrite

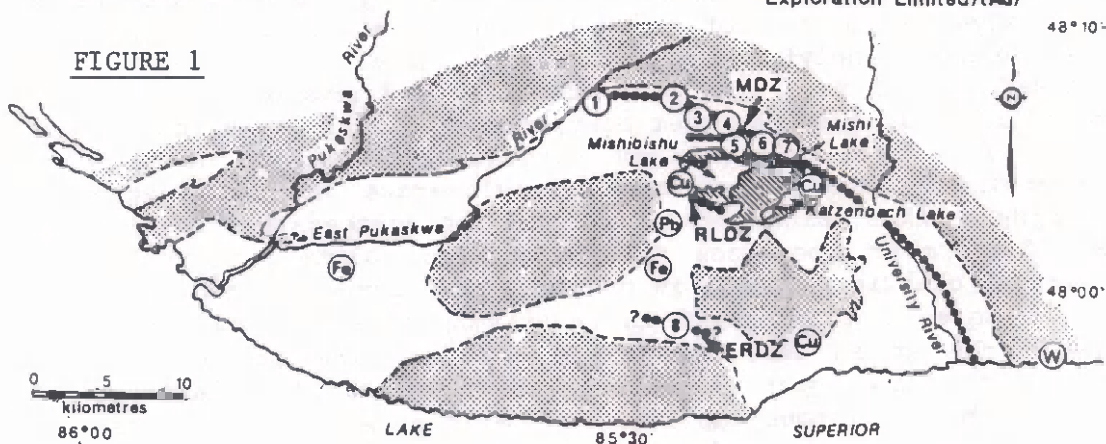
Gradational contacts exist between each of these alteration groups, with the overall progression manifest best within the mafic metavolcanic rocks and more cryptically within the metasediments.

All known gold occurrences in the MDZ occur within the most intensely deformed and altered portion that is located north of the Mishibishu Lake stock, a late tectonic intrusion of monzonitic to quartz monzonitic composition. Both quartz-feldspar porphyry (QFP) and feldspar porphyry (FP) dikes, texturally similar to those crosscutting the Mishibishu Lake stock, occur in close proximity to several of the gold occurrences. A protracted history of porphyry dike emplacement is evident, as there are dikes with varying degrees of alteration and deformation, ranging from weakly foliated with porphyritic texture preserved to intensely foliated quartz + sericite + hematite + pyrite schists.

Native gold occurs in quartz veins (+ ankerite + arsenopyrite + pyrite + galena + chalcopryite + sphalerite + tourmaline + albite + sericite + green mica + chlorite) which vary from several centimetres to several metres in width and are several tens of metres in length, within zones up to several metres in thickness. Three types of mineralized quartz veins have been recognized: strongly boundinaged foliation-parallel pods of quartz, laterally continuous zones of quartz veins which crosscut the foliation at a low angle and likely occupying large shear fractures, late quartz-filled fractures within both of above vein types.

There is a spatial relationship between the majority of the known gold occurrences within the MDZ and major structures, commonly filled by diabase dikes, that intersect the MDZ.

- | | |
|--|---|
| <ul style="list-style-type: none">  Mishibishu Lake Greenstone Belt  Batholithic Granitoid Rocks  Mishibishu Lake Stock  Iron  Lead  Copper  Tungsten  Deformation Zones | <ul style="list-style-type: none"> ① Scuzzy Little Lake (Dominion Explorers Limited)(Au) ② Granges-MacMillan (Granges Exploration Limited) ③ Magnacon (Muscocho Explorations Limited)(Au) ④ Northwest (Westfield Minerals Limited)(Au) ⑤ Amichi (Westfield Minerals Limited)(Au) ⑥ Hollinger (Westfield Minerals Limited)(Au) ⑦ Discovery (Westfield Minerals Limited)(Au) ⑧ No Name Lake (Central Crude-Noranda Exploration Limited)(Au) |
|--|---|



Stratigraphic Evolution of part of the Archean Itasca County
Metavolcanic Belt, Northern Minnesota

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The Itasca County metavolcanic belt is the southwestern-most exposed Archean metavolcanic terrane in the Superior Province. It lies 40 km west of the western Vermilion district, separated from it by Giants Range Granite and several major faults. Rocks exposed in the southern part of the belt, in the Sherry Lake 7-1/2-minute quadrangle are the subject of this presentation. Volcanic and clastic rocks in the Sherry Lake area are generally upright and steeply dipping, with predominantly east and southeast younging directions. Locally complex fold patterns are the result of at least two deformations, the dominant one (D_2) being a transpressional event.

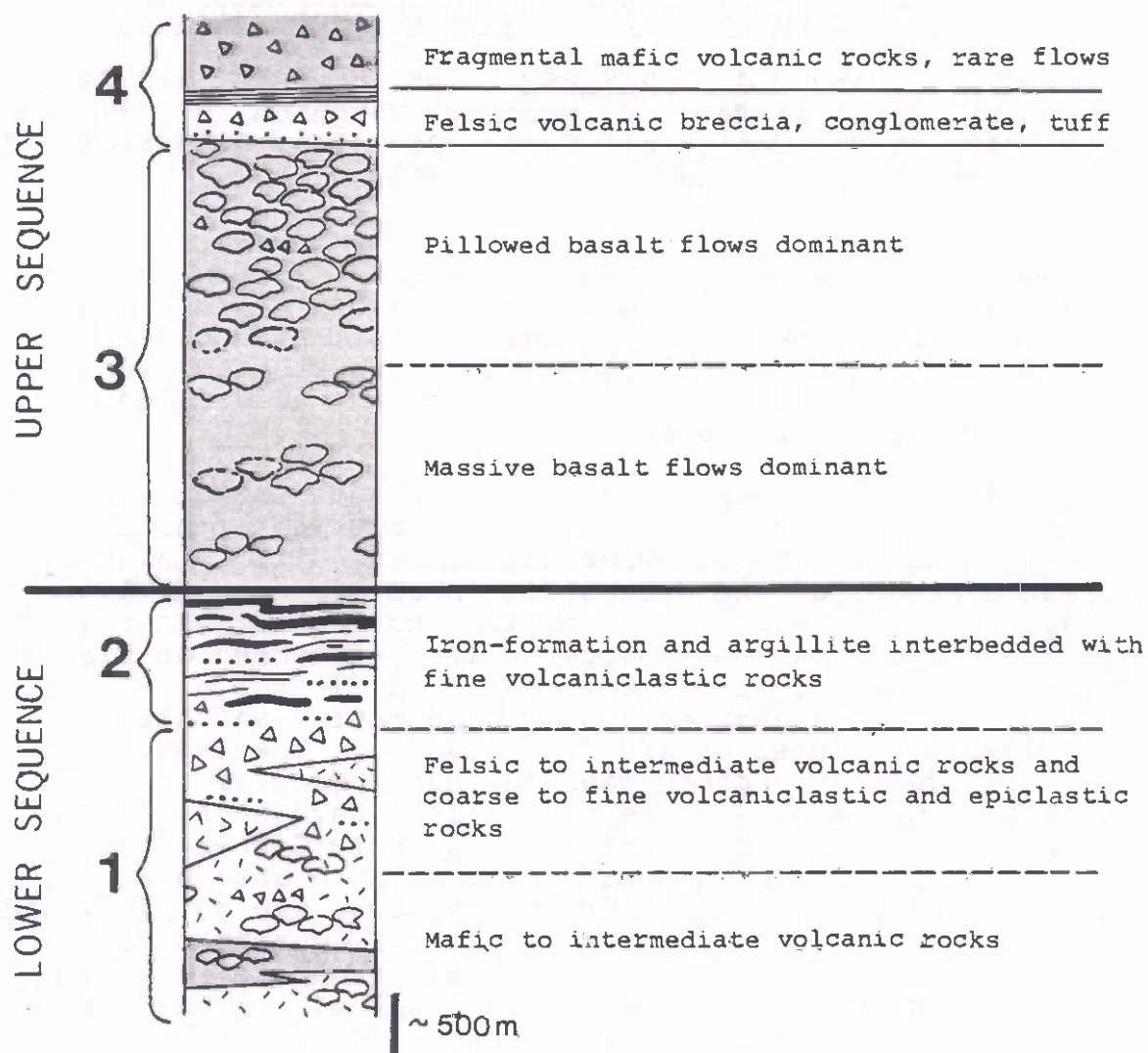
Two contrasting cycles of volcanism and sedimentation exist in the Sherry Lake area (see figure). A lower sequence of mafic to felsic volcanic and clastic rocks capped by iron-formation is conformably overlain by a second sequence composed predominantly of basaltic flows. Both are metamorphosed to greenschist and, locally, amphibolite facies.

The lower sequence is at least 2500 m thick and contains plagioclase-phyric, pillowed, mafic to intermediate flows, blocky felsic flows, and lenticular units of volcanoclastic and clastic rocks. The succession becomes increasingly more felsic and fragmental stratigraphically upward (eastward), and finally passes into laminated, sulfide-, magnetite- and chert-rich iron-formation and tuff inferred to have been deposited in relatively deep, quiet water.

The upper sequence is 4000 m thick and consists mainly of dark green, massive, pillowed basalt and rare lenses of fragmental basalt. In a broad sense, the upper sequence contains evidence of stratigraphically-upward shoaling processes. The basal and central parts of the sequence contain a high proportion of massive flows, and lack vesicles and hyaloclastite units implying deposition in relatively deep water. These grade irregularly to more pillowed, vesicular and fragmental flows upward (eastward). In the uppermost part, mafic volcanism was interrupted by a pulse of dacitic volcanism and subsequent deposition of a 400 m-thick heterolithic (dacite-dominated) conglomerate and tuff sequence. Dacite porphyry dikes which irregularly cut the northeastern basalts may represent feeders or apophyses of this felsic volcanic source. The dacite-bearing clastic sequence is overlain by fragmental basaltic rocks inferred to have been deposited in relatively shallow water, possibly onto the flanks of an emerging felsic center. The source of mafic volcanic rocks in the upper sequence may be represented by large, semi-concordant gabbroic plutons emplaced in the lower sequence, and smaller mafic sills and dikes within the upper sequence.

A four-stage depositional model is outlined on the figure.

SCHEMATIC STRATIGRAPHIC SEQUENCE



DEPOSITIONAL SUMMARY

1. Mafic-intermediate volcanism passing upward to explosive felsic to intermediate volcanism and sedimentation.
2. Cessation of felsic volcanism (collapse?), deepening of basin, relative tectonic and volcanic quiescence.
3. Basin filling with mafic flows.
4. Initial resurgence of nearby felsic source, shedding debris flows and water-laid tuffs into shallowing basin.

Geology and Precious Metal Mineralization of
the Hill's Lakes Area, Marquette County Michigan

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The bedrock geology of a 5 mi.² (13 km²) area including sections 3, 11, 12, 13 and 14 of T. 49 N., R. 28 W, in northern Marquette County, Michigan was mapped during the summer of 1986. Several abandoned prospects and trenches as well as significant quartz veining and alteration are contained within the area.

The oldest rocks in the area are Archean tholeiitic pillow basalts of the Upper Pillowed Basalt Member of the Metavolcanics of Silver Mine Lakes. The Hill's Lakes Pyroclastic Member of the Metavolcanics of Silver Mine Lake crops out in section 11 and strikes to the northeast where further exposures are expected. It is composed of highly deformed, white to tan, pumiceous lapilli in a black, hornblende-plagioclase-garnet, schistose matrix and has a thickness in excess of 150 feet (46 m). The basalts have been intruded by Archean gabbros and diabase of the Metagabbro of Clark Creek. The mafic rocks have been intruded by the Archean Rhyolite Intrusive of Fire Center Mine the Granodiorite of Rocking Chair Lakes. The Granodiorite of Rocking Chair Lakes is generally massive, tan to pink, and is composed of granodiorites, tonalites, quartz monzodiorites and quartz diorites. Their massive nature, association with schistose amphibolite facies basalts, and the intrusion along the hinge of the major fold in the area suggest that the granodiorites are syntectonic. These rocks are cut by Archean quartz veins. The Archean units are intruded by Lower Proterozoic Metadiabase and Keweenaw Diabase and are unconformably overlain by Lower Proterozoic metasediments.

The major structure in the area is a large steeply plunging fold. The fold symmetry is outlined by a gabbro sill and the pyroclastic unit. The typical Archean foliation in the area strikes N 68° W and dips 4° N. The typical Lower Proterozoic cleavage strikes N 74° W and dips 51° S. This suggests that the Archean rocks were relatively unaffected by the Lower Proterozoic deformation. The rhyolite dikes typically strike N 70° W to N 60° W, a strike subparallel to the Archean foliation in the area. This suggests that they intruded the axial planar foliation and, if contemporaneous with the granodiorites, are also syntectonic.

The pillowed basalts are metamorphosed from lower greenschist to upper amphibolite facies. The increase in metamorphic grade is associated with contact metamorphism related to emplacement of the granodiorite plutons. Lower greenschist facies metabasalts are characterized by chlorite-actinolite-albite-clinzoisite/epidote with minor carbonate and sericite and have relict magmatic textures. The upper amphibolite facies metabasalts are characterized by hornblende-calcic plagioclase-hypersthene and are schistose.

Altered basalts are found closely associated with faults and shear zones. The alteration forms varied retrograde assemblages of chlorite-albite-carbonate-epidote-sericite-quartz. The retrograde assemblages indicate that the mineralization in the area postdates the Archean metamorphism. The alteration is commonly associated with pyrrhotite and pyrite and locally is associated with quartz veins. Chalcopyrite and pyrite and occasionally sphalerite-galena-arsenopyrite-pyrrhotite are commonly associated with the quartz veins. Several quartz veins in the area exceed 1000 ft. (300 m) in length and 20 ft. (6 m) in width. The Central Section 14 Prospect consists of one shallow test shaft, two pits and several trenches. This prospect is located on a quartz vein hosted in altered basalts adjacent to a rhyolite dike. The dominant sulfide found at this prospect is pyrite. Within this area a limited number of gold assays were completed and several were anomalous. In addition, significant areas of alteration, numerous faults and shear zones, and several large quartz veins are favorable indicators of precious metal mineralization.

Rhyolite and basaltic volcanism from the Huronian of the Thessalon area, central Ontario

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The bimodal Huronian volcanics of the Thessalon region, central Ontario, are composed of interfingering calc-alkaline rhyolite, tholeiitic basalt and andesite flows, and minor pyroclastic sediments erupted in a developing continental rift zone environment. The rhyolites are subdivided into 1) a high-LILE, low-LREE group (75%) with Ba/La ratios greater than 50, low-LREE contents ($\text{LaN} = 100 - 50$), and moderate HREE ($\text{ERN} = 15$), and 2) a low-LILE, high-LREE group (25%) with Ba/La less than 20, and high-LREE ($\text{LaN} = 150 - 200$). Batch melting calculations suggest the latter were generated by up to 20% melting in granulitic siliceous tonalite gneiss at deep levels, while the former were derived at shallower depths by about 30% fusion of low-melting sources, such as pegmatites and K-rich migmatitic leucogranites.

Tholeiitic flows are subdivided into 1) an upper basaltic unit, characterized by lithophile element ratios approaching chondritic levels ($\text{Ti/Zr} = 80$ compared to 110 in chondrites), low REE and nearly flat HREE chondrite-normalized patterns generated by about 20% fusion of a peridotitic source, and 2) an early and central unit of fractionated andesites and subordinate basalts, with variable Ti/LILE ratios (Ti/Zr ranges from 35 in early types to 55 in central basalts), negative K, Zr, and Ti anomalies on distribution diagrams, and high REE with moderately fractionated HREE segments, generated by lesser degrees (from 10 to 20%) of peridotite melting. Garnet, amphibole, zircon, apatite and Ti-oxide phases remained residual in the source after generation of early flows, but only olivine, orthopyroxene, and clinopyroxene persisted after removal of late basalts.

Many of the early basalts, especially fractionated end-members, were contaminated by or hybridized with the rhyolitic liquids during a residence period at crustal levels. Ba/La vs. Rb/La ratio diagrams, used to constrain the degree of contamination, reveal that basalt magma was commonly mixed with up to 40% of either rhyolite type. Compositions of the basalt hybrids can be reproduced by mixing calculations.

The mantle source of the Huronian volcanics displays evidence of a long and complex history. All of the basalts, including least contaminated and uncontaminated representatives, carry low Ti and Nb and high Rb, Ba, K, La, and Ce, indicating their source was hydrated and metasomatically enriched in LILE. Pronounced negative anomalies characterize Ba, Nb, P, Ti, and HREE abundances due to withdrawal of basaltic liquids prior to the metasomatic episode, probably during Archean time.

Applicability of a sediment-hosted copper deposit model to
the Keweenaw Solor Church Formation, Minnesota

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Large tonnage sediment-hosted stratiform copper deposits occur within many middle to late Proterozoic basins throughout the world. Prominent North American examples include White Pine, Michigan, Spar Lake, Montana, and Redstone, NWT. Although specific processes of formation are unique at each locality, these deposits share many of the same basic characteristics: (1) restricted to Proterozoic age rocks, (2) thick basinal sequences indicative of rapid subsidence and sedimentation, (3) basic to bimodal volcanic association, (4) thick "redbed" host rocks, and (5) "green beds" of marine or lacustrine origin. Source rocks for copper are probably underlying basalts, but in some cases may be the redbeds, themselves. Deposition of the copper generally seems to be controlled by local reducing conditions in thick redbed sequences.

The Solor Church Formation is a fluvial/alluvial redbed sequence within the Keweenaw Midcontinent rift system. The formation consists of 580 to 980+ meters of interbedded arkosic sandstone and limestone. Numerous grayish-green siltstones and shales occur within the primarily redbed sequence, and the presence of oncolites suggests organic activity during deposition. Copper staining has been recognized in core samples from the Solor Church Formation as well as in underlying basalts. Structural complexities within the Keweenaw rift-parallel faults associated with the Solor Church basin may represent basin-growth faults. These faults would provide important conduits and focal points for copper-bearing fluids.

Clearly the above description of the Solor Church Formation shows similarities to environments which host known stratiform copper deposits elsewhere. Furthermore, the Precambrian rocks of the Lake Superior region are major sources of copper (the native copper deposits of the Keweenaw Peninsula in amygdaloidal basalts and conglomerates, and shale-siltstone-sandstone-hosted copper at White Pine, Michigan). These examples demonstrate the presence of copper and its mobility in a variety of host rocks. Therefore, if a reasonable concentrating mechanism can be identified, the potential for large-scale copper concentrations exists in the Solor Church Formation.

Major lithological units in the Wisconsin magmatic terrane:
New Data from Drill Core

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More than 250 exploration drill cores from central and northern Wisconsin have been examined and their locations plotted on 1:250,000 base maps. Because northern Wisconsin is characterized by extremely meagre outcrop, the data from these drill cores, in conjunction with the recontoured aeromagnetic map of northern Wisconsin (Karl, 1987), provide a significant improvement in the data base for inferring the regional extent of major lithologic units in the Wisconsin magmatic terrane.

The drill core demonstrates that northern Wisconsin consists of large areas underlain by either greenschist facies volcanic, sedimentary and plutonic rocks or by amphibolite facies quartzofeldspathic gneisses, amphibolites and sillimanite-bearing schists. In Rusk and Price counties, the highly foliated amphibolite facies rocks are intruded by isotropic potassic granites that appear to be postorogenic. The aeromagnetic map of northern Wisconsin contains several rhomboid-shaped areas in Rusk and Price counties with subdued magnetic expression that are separated by areas of similar size with high amplitude, short wavelength anomalies. Drill cores show that the rhomboid-shaped areas are underlain mainly by graphitic argillite and graywacke whereas the magnetically high area are underlain by greenschist or amphibolite facies volcanic rocks. The rhomboid-shaped areas are also characterized by gravity lows relative to the intervening areas, suggesting a horst and graben basement structure (LaBerge and others, 1986; Suszek and Meyer, this conference). Linear magnetic trends and the presence of highly foliated and flattened rocks along the margins of the rhomboid-shaped grabens suggest that the boundaries are faults. Diabase dikes and ultramafic rocks are present along some boundaries.

The drill cores show that the Wisconsin magmatic terrane consists of numerous "blocks" of disparate metamorphic grade. However, the stratigraphic and structural relationships between these blocks remain to be resolved.

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U-Pb dating of pitchblende from Dickinson County, upper Michigan,
suggests reactivation of Precambrian structures during formation of
the Michigan Basin

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Exploratory drilling has delineated an east-west striking, north dipping (~60 degrees) brittle fault within the Gene Lake Gneiss, an Archean gneiss complex on the north edge of the Middle Precambrian Felch Trough. The brittle fault closely coincides with, and locally cuts, a mylonitic fault which in turn is parallel to the dominant Felch Trough trend. Thus the mylonitic fault is at least Middle Precambrian in age and the brittle fault is younger.

Pitchblende-carbonate mineralization occurs as space fillings which have healed brittle structures within the hanging wall and, less extensively, the footwall of the east-west fault. Four pitchblende samples were analyzed for U and Pb isotopic composition by Teledyne Isotopic Laboratory and the ratios of $^{206}\text{Pb}^*/^{238}\text{U}$ and $^{207}\text{Pb}^*/^{235}\text{U}$ were calculated (* denotes radiogenic lead). Ratios are as follows:

<u>sample #</u>	<u>206/238</u>	<u>207/235</u>
FR3	.047040	.354300
C18/4	.050370	.366770
C2/14	.064910	.508890
C3/10	.093450	.701320

Core sample C18/4 is concordant, indicating a possible mineralization event at 317 m.y. Core sample C2/14 and surface sample FR3 are normally discordant and (assuming a single remobilization) represent modification of mineralizations with minimum ages of ~400 and ~500 m.y. respectively. Core sample C3/10 is reversely discordant and results from modification of mineralization, with a maximum age of 400 m.y., again assuming a single remobilization event. Cross-cutting veinlets in core indicate two, and possibly three, mineralization/remobilization episodes.

Concordia-discordia intercepts have been calculated employing all four analyses and assuming a single remobilization. An upper intercept of 403 m.y. and a lower intercept of 41 m.y. were obtained using a program written by Haxel and Wright (1982, USGS Open File Report 82-898). While no attempt has been made to determine the uncertainty in the data, the correlation coefficient of the discordia best fit is 0.996 which is sufficiently good to support the conclusions to follow.

The calculated intercepts suggest that 400 m.y. old uranium was partly remobilized between about 50 m.y. and the present, perhaps during the erosion of Paleozoic strata, outliers of which occur throughout the area. Other interpretations include episodic mineralization ending at about 300 m.y. or a single episode at 500 to 300 m.y. which has been mobilized more than once.

The Felch area is on the margin of the Michigan Basin, indeed it can be viewed as on, or near, a north-south hinge line between a stable shelf

to the west and the periodically subsiding basin to the east. The most active period of deposition was during the Upper Silurian, averaging 65 m of sediment per m.y., over twice the rate of the next active period, the Mississippian (~30 m/m.y. deposited). Note that the close of the Silurian corresponds nicely with the upper concordia-discordia intercept, 405 vs. 403 m.y., and the close of the Mississippian corresponds closely with the age of the one concordant sample, 310 vs. 317 m.y.

Therefore it is strongly indicated that the space fillings, and fault, are Paleozoic in age and represent reactivation of a Precambrian structure in response to the formation of the Michigan Basin.

This work was supported by Minatome Corporation, a subsidiary of CFP (Total Oil), and Central Electricity Great Britain as part of a uranium exploration program.

PERIOD/EPOCH	SEDIMENTATION RATE (meters/m.y.)	U/Pb AGE (m.y.)
Jurassic	1.5	
Pennsylvanian	2.6	
Mississippian	30.5	317
Devonian - Upper	16.9	
- Middle & Lower	28.8	
Silurian - Upper	65.3	403
- Middle	6.6	
- Lower	8.7	
Ordovician - Upper	28.9	
- Middle	17.6	
- Lower	5.9	
Cambrian	2.3	

Sequence of Faulting and Folding, Southwest
Michipicoten Greenstone Belt, Ontario.

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The rocks of the Michipicoten Greenstone Belt record a complicated sequence of faulting, folding and intrusion. Our primary objective is to determine the tectonic setting(s) for the deposition of the sedimentary and volcanic rocks and for their early deformation. This requires determination of the structural sequence so that the effects of younger deformation can be removed. This abstract reviews the evidence pertaining to this sequence in the southwest part of the belt. Localities are located on Figure 1 by letters that are referenced in the text (in parentheses). All localities are in Chabanel Township, and all are in or along the margins of the fume kill.

At present, we do not have the evidence needed to determine if the tectonic evolution of the Michipicoten Greenstone Belt occurred as an essentially continuous single event or as a series of discrete events separated by intervals of little or no deformation. Very likely, the truth lies between these extremes. The structural style did change, from one characterized by penetrative deformation with cleavage development and marked flattening and stretching, to one characterized by faulting that appears to have occurred in the brittle/ductile transition regime. We suspect that at least some of the early penetrative structures developed in a single evolving event. The young faults probably represent discrete later events.

The youngest major structure in the area we have mapped is the Mildred Lake fault (M-M'), one of a belt-wide system of NNW-trending late faults. All rock units and major faults that intersect the Mildred Lake fault are offset. Correlation of three contacts and units with differing attitudes across the fault indicates a sinistral net slip of 3.2 km. An unnamed fault (A-A') west of the Magpie River with 700 m of sinistral separation is very likely a young NNW-trending strike-slip fault also.

Next oldest is a fault (B-B'') that strikes parallel to the strike of bedding. This fault has caused a dextral separation of diabase dikes of 100-200 m; the true net slip cannot be determined because the fault does not offset anything other than steeply dipping diabase dikes. Diabase dikes offset by this fault are commonly distorted as well, suggesting that, at the level of modern exposure, deformation was in the brittle/ductile transition regime for the diabase,

NE-trending faults of moderate apparent displacement (separations of 10's to 100's of meters) occur throughout the area, but are most abundant near the east and south margins of the Pleistocene gravel plain. These faults probably occur beneath the gravel as well, and they could be responsible for the relative ease of erosion of the rocks beneath the gravel and along the Magpie River below Siderite Junction (SJ). Some of these faults offset diabase dikes, generally dextrally. Furthermore, faults that offset diabase dikes dextrally commonly offset contacts in older rocks sinistrally. It is not entirely clear if this is due to a

single post-dyabase oblique-slip event or to fault reactivation, but we suspect the latter. Because distinctive contacts in the older rocks can be traced across the zone of NE faults at the SW end of Mildred Lake (C), there can be no major fault passing through that location (cf. "Magpie River fault" of Sage et al., OGS Prelim. Map P.2439); instead, a set of three or four small faults is responsible for a sinistral separation of about 300 m (where the "Magpie River fault" follows the river below Siderite Junction there is significant faulting due to coincidence of NE-trending faults with older bedding-related faults).

Dyabase dikes truncate all penetrative structures, and thus are younger than the deformation event(s) responsible for the steep dips, metamorphism, cleavages, and strain that characterize the Archean meta-sediments and metavolcanics. Major overturning occurred with or before the earliest cleavages, resulting in areally extensive terranes with opposed stratigraphic tops that are juxtaposed by bedding-related faults. These pre-dyabase structures are described in more detail in a companion abstract in this volume.

As a somewhat speculative working hypothesis, we propose that the earliest structures formed during imbrication of volcanics and poorly consolidated sediments. The bewildering complexity of the cleavages and the stratigraphy would thus be due in part to the tendency for each imbricate slice to have its own stratigraphy and to some extent its own structure as well. The generally steep bedding dips most likely are associated with a later but still pre-dyabase NE-trending cleavage. In most places, the effects of younger faulting and dyabase intrusion are relatively minor and can be "removed" by detailed mapping. Unscrambling the earliest events is the key to our effort to determine the tectonic significance of the Michipicoten Greenstone Belt.

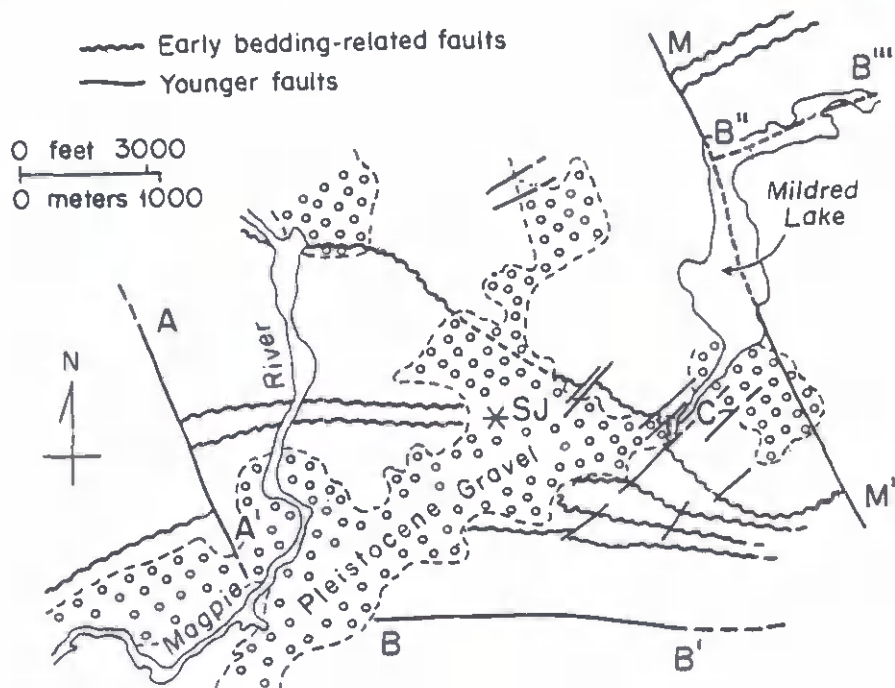


Fig.1. Central Chabanel Township

Magnacon Project - Mishibishu Lake Greenstone Belt

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The Magnacon Project is located in the Mishibishu Greenstone Belt of the Superior Province, approximately 60 kilometers west of Wawa, Ontario. Flanagan McAdam Resources Inc. owns 50%, Muscocho Explorations Limited owns 25% and Windarra Minerals Ltd. owns 25% of the property. A royalty of 3% to 5% is payable to Westfield Minerals out of production. Presently, the project is at an advanced exploration stage with a decline, underground exploration and bulk sampling, plus surface drilling underway.

Auriferous hydrothermal quartz veins occur within an extremely dilatant shear zone. The host rock within the gold-bearing horizon is a quartz-sericite-ankerite +/- fuchsite +/- chlorite +/- albite schist. Mineralization is characterized by the presence of visible gold, pyrite, galena, arsenopyrite, chalcopyrite and sphalerite. Structurally, all primary textures have been obliterated within the shear zone.

At October 1986, drill-indicated reserves were 1,032,435 tons grading 0.156 oz. gold per ton or 647,769 tons grading 0.219 oz. per ton. These reserves occur between lines 79+00W and 116+00W and to a depth of 450 feet.

Displayed will be polished specimens, drill core, property geology map, sections and photomicrographs of ore.

Magino Project - Michipicoten Greenstone Belt

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The Magino Project is a joint venture between Muscocho Explorations Limited and McNellen Resources Inc. The property consists of 55 claims located in the Goudreau-Lochalsh area, approximately 95 kilometers by road, northeast of Wawa, Ontario.

The gold on the Magino property occurs mainly in a series of parallel quartz veins and alteration zones within a large mass of trondhjemite which intrudes a series of mafic flows.

Calculations of drill-indicated tonnage at the end of the 1986 drill programme gave a total of 1,962,645 tons averaging 0.251 oz. gold per ton. These preliminary reserves occur to a depth of 500 feet.

The 1986 drill programme has now encountered good gold values over a strike length of 5200 feet with the zones open at both ends. Although the 1986 drilling has been concentrated on the zones within the intrusive, recent drilling has intersected additional zones at or near the contact but within the volcanics. These will be tested in the current drilling.

A decline ramp of 1600 feet has been driven to the 200-foot level with drifting occurring on several gold zones.

The display will consist of drill core, hand specimens, maps and drill sections.

Bedrock Geology of Keweenawan Rocks in the Vicinity of Silver
Bay and Beaver Bay, Northeastern Minnesota

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Geologic mapping in the Silver Bay and Split Rock Point NE 7.5' quadrangles along the north shore of Lake Superior has established the presence of a variety of Middle Proterozoic (Keweenawan) mafic plutonic and hypabyssal rocks emplaced in a thick sequence of dominantly basaltic volcanic rocks of similar age. The intrusive rocks, collectively assigned to the Beaver Bay complex, include at least three temporally distinct intrusive suites; the Lax Lake gabbro, the Beaver River diabase, and the Beaver Bay gabbro. The complex also includes two relatively minor diabase sills. Faulting, coeval with magmatic intrusion, disrupted the sequence of volcanic flows and minor interflow sedimentary rocks of the normally polarized (upper) North Shore Volcanic Group (NSVG), host rocks for the BBC.

Most volcanic rocks of the NSVG range in composition from tholeiitic basalt to basaltic andesite, but some quartz-feldspar-porphyritic rhyolite flows also occur. Three textural types of basaltic flows are distinguished: ophitic basalt, plagioclase-porphyritic ophitic basalt, and intergranular to intersertal basalt and basaltic andesite. Drill core (Green, 1982) and exposures to the east of the field area indicate that interflow arkosic siltstones and sandstones and volcanoclastic conglomerates are fairly common in this interval of the NSVG, although they are rarely exposed in the Silver Bay-Beaver Bay area. Hornfels of volcanic and sedimentary rocks result locally from thermal metamorphism by Beaver Bay complex intrusions.

Subophitic olivine gabbro, granophyric gabbro and gabbro-norite, mafic granodiorite, and granophyre comprise the Lax Lake gabbro, the oldest intrusive rocks in the area. Collectively, these rocks define a continuous range of evolved (Fe-Ti-rich) to highly evolved (Si-K-rich) compositions, implying a coeval evolution by differentiation. However, the spatial relationships between various rock types and the overall shape of the Lax Lake body are obscured by a lack of internal structures and post-crystallization faulting.

Both the Lax Lake gabbros and the lava flows are intruded by dikes and sills of Beaver River diabase, typically a fine- to medium-grained, ophitic olivine gabbro which locally grades into a coarse-grained, oxide-rich ophitic gabbro. The Beaver River diabases are unique in that they contain numerous inclusions of anorthosite, some as much as 100 meters in diameter. The inclusions tend to be concentrated in the lower parts of the sills. Typically, they are coarse-grained, consist almost entirely of calcic plagioclase (An 54-80, Morrison et al., 1983), and are commonly tectonized. Though less common, inclusions of medium-grained granite and aphanitic felsite also occur locally in the margins of both dikes and sills where they commonly are partially assimilated by the diabase. The basal portions of the diabase sills and the underlying volcanics are commonly intruded by thin (1 cm-1 m) granophyre dikes which may have been generated by partial melting of the volcanics.

The iron-rich Beaver Bay gabbro is the youngest intrusive unit in the area. Near the lakeshore, it consists of three zoned, elliptical-shaped bodies which were emplaced in the upper part of a thick Beaver River sill. Each intrusion typically grades abruptly from a margin of coarse-grained to pegmatitic, vari-textured, commonly granophyric gabbro to an interior of medium-grained, moderately to well-laminated, locally layered, gabbronorite or olivine ferrogabbro (Shank, 1987). Inclusions of Beaver river diabase are especially common in one of the intrusions centered south of Silver Bay. Inland, Beaver Bay gabbro is represented by an irregular-shaped intrusion of medium-grained ferrogabbro which grades into mafic granodiorite and which was emplaced in the axial portion of a Beaver River diabase dike. Intrusions of this type are fairly common in the area to the northeast.

Two relatively minor Beaver Bay Complex intrusions are a 15-20-meter-thick, aphanitic to fine-grained, intergranular diabase sill (compositionally ferrodiorite, Green, 1982) and a 55-65-meter-thick, fine to medium-grained, hematitic-stained, slightly Pl-porphyritic ophitic diabase sill. Petrogenetic relationships with other intrusive rocks are uncertain, but the ferrodiorite sill is mineralogically and texturally similar to some Lax Lake gabbros and therefore may be an offshoot of that suite. Similarly, sills of ophitic diabase are texturally similar to Beaver River diabase and may be comagmatic with it.

This mapping was conducted in conjunction with the U.S. Geological Survey's COGEOMAP program.

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Stratigraphic and Structural Considerations on the Hemlo Gold Deposit Setting

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Initial investigation of the Hemlo Gold Deposit and its setting, in the early 1980s, resulted in the interpretation of a relatively undeformed, homoclinal sequence of Archean metavolcanic and metasedimentary units that contained a conformable, syngenetic (exhalative), gold-bearing sinter horizon. Recently, more detailed surface mapping, drill core logging, and work in three mines, has led to recognition of major lithological, structural, and alteration features which have introduced significant complications for the syngenetic model. These complications have forced a re-evaluation of the setting and timing of mineralization, and now mounting evidence, some of which is covered below, strongly supports an epigenetic origin for the gold deposit.

No siliceous sinter has been found at Hemlo. Potassic feldspathization is the dominant form of alteration of the mineralized metavolcanic and metasedimentary rocks. Some features point to a hydrothermal origin for the barite that is associated with the deposit. In any case, evidence for bedding in the barite-bearing rocks is equivocal.

Gold and molybdenum are present in the western part of the deposit within an intermediate to felsic quartz-feldspar porphyritic complex (extrusive and/or hypabyssal?), and in the eastern part of the deposit within laminated metasediments which show evidence of some tectono-metamorphic banding due to shearing. As such, the mineralization appears to crosscut stratigraphy over a strike length of a few kilometres.

Major isoclinal folding of the supracrustal rocks has taken place. This is clearly evident in rocks structurally overlying the deposit where reclined, antiformal synclines have been delineated; rocks structurally underlying the deposit have also been folded. Hence the rocks hosting the mineralization have almost certainly been folded and may themselves be overturned. Structurally overlying the eastern part of the orebody are pelitic metasediments containing several key alteration/metamorphic minerals (eg. anthophyllite, cordierite, staurolite). This spatial association is a result of tight folding which limits the apparent strike extent of this unit here; it is not a result of localized syngenetic alteration of sediments.

The isoclinal folding predates, and is not a result of, dextral shearing which is manifest as several zones of strong to intense deformation, one of which hosts the main orebody. This shearing is incipiently developed locally between these highly deformed zones, and significantly, the shearing has affected at least the earlier stages of mineralization.

Dislocation along bedding and isoclinal fold limbs, by dextral and sinistral faults resulting from folding and/or the dextral shearing event, is evident in small- and medium-scale structures. This suggests that bedding dislocation may have occurred on a mega-scale, which may be one of the reasons why stratigraphy cannot be matched consistently across major fold axes. Considerable vertical component displacement is suspected with some faults.

Transposition due to folding and/or shearing is present particularly within noses of small- to medium-scale, tight isoclinal folds. However, the development of this feature on a large scale likely has not affected notable proportions of the supracrustal rocks. This is because distinguishable lithologic units can generally be traced for some distance along strike.

Tectonic pull-apart features due to ductility contrast have developed in some tight isoclinal fold noses. The degree to which these tectonic features sufficiently mimic primary fragmental rocks, such that their misidentification is inevitable, is considered minimal. Only one notable unit, which is within the ore deposit, is considered by the author to be a possible tectonic breccia due to ductility contrast. Numerous units of deformed pyroclastic rocks, volcanoclastic rocks, and conglomerates are recognizable. However, the degree of tectonic folding, dislocation, and transposition of the rocks in this area precludes any delineation of primary growth faults so far.

Possible conjugate shears in the relatively isotropic quartz-feldspar porphyritic complex appear, locally at least, to control some of the mineralization and alteration. These shears are likely related to the zones of strong dextral shearing, and must have been created during a compressional event which involved pressures and stresses well in excess of those attainable with lithostatic loading. This strongly suggests that the host rocks must have been deformed and tilted subvertically before this major compressive force was exerted. The timing of mineralization is thereby constrained to post deposition and post folding of the host rocks. Zircon dating of several rocks from within and around the deposit indicates a 70 to 90 Ma difference between the age of the intermediate to felsic quartz-feldspar porphyritic complex which locally hosts the mineralization, and the age of major granitic plutonism (eg. Cedar Lake Pluton) and numerous feldspar and quartz-feldspar porphyritic dikes. However, as yet, no clear age relationship between dike intrusion and mineralization/alteration has been established.

Petrologic evolution of early Proterozoic supracrustal rocks
from Florence County, WI and their bearing on the development of
the Dunbar Gneiss

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90 samples obtained from drill cores provided by the Kerr McGee Corporation have been examined petreographically. The cores are from restricted basins with shallow water sediments. All holes were oriented towards the contact between the sediments and the Bush Lakes Granite. Samples represent up to 300 feet of the sedimentary sequence and show no coherent pattern of metamorphic grade as a function of proximity to the contact (the distance ranges from 1.7 km to less than 100 m).

The metasediments range from micaceous quartzites through marbles, graphite and sulfide rich schists and mafic volcanoclastics. Mineral assemblages imply metamorphic conditions ranging from uppermost greenschist facies to amphibolite facies. Assemblages include garnet amphibolites, diopside marbles and biotite-garnet-cordierite-plagioclase-quartz schists. Nearly all samples have been affected by retrograde alteration due to fluids from the Bush Lake Granite.

Late stage quartz-tourmaline veins locally cut the metasediments, as occurs in the Dunbar Dome (Sims et al., 1985). Polyphase deformation is evident in most samples. An early S_1 foliation defined by biotite is parallel to original layering (S_0). Retrograde biotite produces a weak S_2 foliation which is inclined to S_1 by up to 90° . These fabrics are probably correlative with D_2 and D_4 in the Dunbar Dome (Sims et al.).

Prograde mineral assemblages restrict peak metamorphic conditions to 500-550° at low to intermediate pressure (4-5 kbar). Fluid pressure probably was equal to lithostatic pressure; the fluid was heterogeneous and ranged from nearly pure water in the micaceous quartzites to fluid with high concentrations of CO_2 and H_2S in carbonate, graphite, and sulfide bearing layers.

The evolution of the Dunbar Gneiss dome described by Sims et al., (1985), is similar in style to the supracrustals described above. Both areas display prograde metamorphism followed by later retrograde metamorphism accompanied by deformation. Sims et al. (1985) show clear evidence that the Dunbar Dome is a large scale fold-interference structure resulting from polyphase deformation and diapirism. I suggest that the two areas were co-eval and that the differences in metamorphic grade between the Dunbar Gneiss and the Florence County supracrustal rocks may represent an original difference in depth of burial - the Dunbar having formed at a deeper crustal level and then been displaced to a shallower level by diapirism while the supracrustals were not displaced vertically to as great an extent during the D_2 and D_4 deformations.

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On the failure of the Midcontinent Rift System to proceed to
sea-floor spreading

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The system of gravity and magnetic anomalies that extends from Kansas to Lake Superior and then southwards into central Michigan is one of the most prominent in North America. It reflects a major geologic feature which has been identified as an abortive rifting of the North American craton - the midcontinent rift system (MCRS), summarized in Wold & Hinze, 1982. Numerous authors have proposed that this feature is a result of 'active' rifting processes in response to one or more hot spots intersecting the North American plate approximately 1100 Ma B.P. (Burke & Dewey, 1973; van Schmus & Hinze, 1985). Others (Tapponnier et al., 1982; Gordon & Hempton, 1986) have presented arguments that the tensional environment represented by the MCRS may have been produced by the Grenville Orogenic event.

The MCRS is unique in that there is no third arm associated with this failed RRR triple junction (Burke & Dewey, 1973). Although true rifting and associated mafic rocks are absent, a number of alkaline intrusive centers along the Coldwell Trend may mark the position of this arm (Currie, 1976; Wieblen, 1982). The trace of the potential third arm may also be represented by the suite of north-trending mafic dikes which are prominent north of Lake Superior. The presence of a passive margin on the west (receiving Belt Group and equivalent sediments) coupled with a continent-continent collisional margin on the east (the Grenville Orogeny) not only prevented a sea-floor spreading center from developing, but also inhibited the development of the third arm of the conventional 'RRR' triple junction from forming.

Stress conditions imposed on the North American plate 1100 Ma B.P. were such that generation of a rift in the direction of the third arm of the ideal RRR triple junction was prohibited (Fig. 1) and that extension of more than 65-70km was not permitted along the two successful arms (the MGA and the mid-Michigan geophysical anomaly). Global plate distribution, plate boundary orientation, plate boundary type and intraplate stress distribution control whether continental lithosphere can respond to hot spot induced stress by forming an RRR triple junction. Under unconfined extensional stress situations, continental lithosphere can form an RRR triple junction in response to emplacement of a hot spot (Burke & Dewey, 1973). A new divergent boundary can form a new mid ocean ridge system (MOR) where plate boundary conditions allow continued extension. This can occur when one or more of the pre-existing plate boundaries is a continent-ocean (C-O) or ocean-ocean (O-O) convergent boundary (cf. the break up of Pangea). The absence of an oceanic free face (Tapponnier et al.) for the North American continent between 1200 and 1000Ma B.P. caused the failure of the MCRS to proceed to sea-floor spreading.

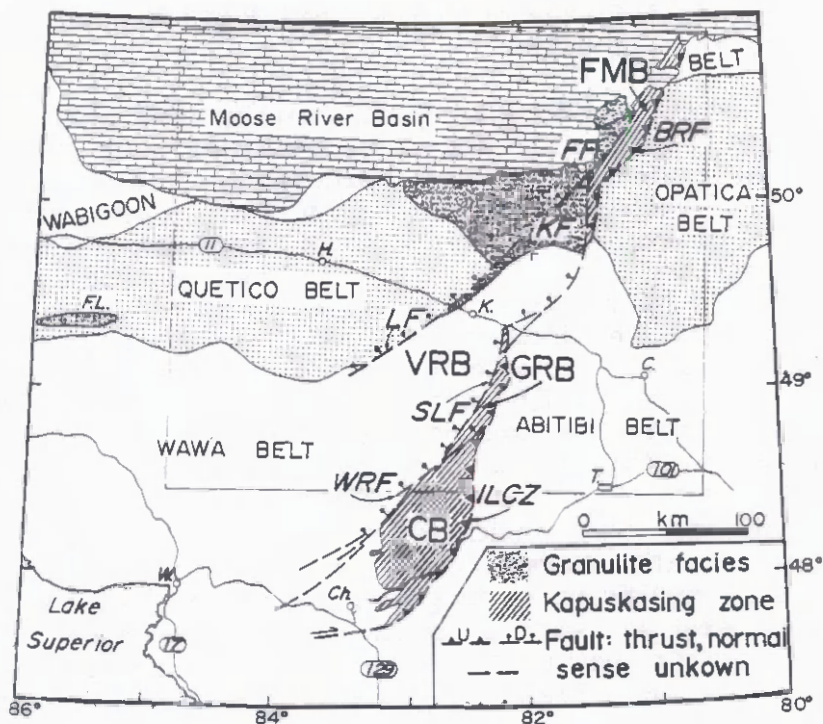
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"Basement-uplift" tectonics in the Kapuskasing Structural Zone,
central Superior Province

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The 500 km long, NNE-trending Kapuskasing uplift exposes deep crustal sections of the east-west striking Wawa-Abitibi and Quetico-Opatika belts of the central Superior Province. Granulite to upper amphibolite facies rocks of the uplift form three distinct geological-geophysical entities: from south to north the Chapleau, Groundhog River and Fraserdale-Moosonee blocks. Chapleau block (CB) consists of dense gneissic and anorthositic rocks, with high seismic velocities, in the upper amphibolite and granulite facies, metamorphosed at 7-9 kbar. It is in gradational contact, across a Conrad-like discontinuity, with amphibolite-facies (5-6 kbar) tonalitic rocks with lower seismic velocity, of the Wawa belt to the west. In contrast, the eastern contact of CB with the Abitibi belt is the well-defined Ivanhoe Lake thrust, imaged by seismic reflection as a 35-38° NW-dipping structure. The positive gravity anomaly over the block is caused by the presence of dense granulites at surface, as shown by gravity modelling and supported by seismic refraction evidence which indicates anomalously thick (ca. 48 km) crust beneath the structure, relative to regional values under 40 km. Groundhog River block (GRB) consists of tonalitic and mafic gneiss in the granulite facies (7-8 kbar), bounded on the east, west and south by brittle faults. It is characterized by a strong positive aeromagnetic anomaly, but a sub-parallel, arcuate gravity anomaly occurs up to 40 km to the west. Fraserdale - Moosonee block (FMB), exposing deep levels of the Quetico belt, consists of paragneiss, diatexite and minor tonalitic gneiss in the granulite facies (7-9 kbar). The wedge-shaped block is fault-bounded to the east and west, has a strong positive magnetic anomaly and lies within a broad positive gravity anomaly. A 65-km "gap" without granulites occurs between the GRB and FMB.

Integrated geological-geophysical models involving a major SE-directed thrust and later, W-side-down normal movement on brittle faults, explain the diverse characteristics of each block: CB is a northwest-dipping tilted slab, exposing an oblique crustal cross-section; GRB and southern FMB are thrust tips truncated by normal faults; an arcuate normal fault cuts out granulites in the GRB-FMB gap; the northern FMB has pop-up geometry. The overall geometry, scale, timing and chronology of the diverse structures in the Kapuskasing uplift closely resemble those in Phanerozoic basement uplifts such as the Laramide province of the western U.S.A. Early Proterozoic cooling dates in the Kapuskasing zone are consistent with remote basement uplift effects of "Hudsonian" orogeny in the Churchill Province.



Regional geology of the central Superior Province showing major tectonic features associated with the Kapuskasing zone, a composite structure made up of the Chapleau (CB), Groundhog River (GRB) and Fraserdale-Moosonee (FMB) blocks. The Val Rita block (VRB) is bounded by the Lepage (LF), Foxville (FF), Kinasau (KF) and Saganash Lake (SLF) faults. Additional structures indicated include the Bad River (BRF) and Wakusimi River (WRF) faults and Ivanhoe Lake cataclastic zone (ILCZ). Geographical locations include Cochrane (C), Chapleau (Ch), Hearst (H), Kapuskasing (K), Timmins (T), and Wawa (W).

Geological and Geophysical Investigation of Graphite Resources
in Upper Michigan

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Graphite was produced from several small quarries in Baraga County, Michigan around the turn of the century for use in coating foundry molds and as a battleship paint. The graphite occurs in the Lower Slate Unit of the Lower Proterozoic (Proterozoic X) Michigamme Formation. The strata crop out sporadically along the northern margin of the Marquette Trough from Alberta on the west to the Humboldt area on the east, a distance of approximately 50 km (Klasner, 1972), (Bodwell, 1972), (Cannon and Klasner 1977). Recent work by Michigan Technological University and the Michigan Geological Survey established that the strata range from 17% to 30% carbon. Three billion tons of graphitic material are estimated to be contained in a 1.6 km wide zone along the 50 km strike length (Hwang, et al., 1986).

It is known that the area is structurally complex and has undergone regional metamorphism (LaRue and Sloss, 1980; James, 1955). A 1986 literature search revealed scant information pertaining to details of the graphitic slate unit of the Lower Michigamme Formation. Much of the early prospecting work was done prior to the 1900's and during World War II; none of this work was published. Subsequent work in Baraga County has shown mappable graphitic units (Klasner, 1972). However, detailed regional mapping has not been possible because of extensive glacial overburden. Core from regional diamond drilling done in the mid 1970's for uranium exploration shows some graphitic zones. This core was available for study and was used to delineate the extent of graphitic zones.

During the summer of 1986, a geophysical survey was conducted using a VLF-EM (very low frequency electromagnetic) meter and a proton precession magnetometer. The EM readings have been correlated with known graphite occurrences, and compared with areas of unknown potential. Unfortunately the interpretations are complicated by characteristics of the overburden and individual conductor response. However, filtering techniques combined with magnetic data are being used to enhance the graphitic anomalies.

Ongoing research involves study of the mineralogy, geology, geophysical response, beneficiation characteristics and economics of the graphite resource. Aside from uses as an industrial mineral a principle application considered for the graphite is as a reductant in steelmaking.

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The Hardwood gneiss, a basic two-pyroxene granulite

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The Hardwood gneiss is a unit of Early Precambrian age outcropping in eastern-central Dickinson County, Michigan. The unit is exposed along State Route M-60 between Foster City and Hardwood, Michigan. The general lithology of the unit is described by James et al., 1961*, and consists of garnet-hornblende-pyroxene gneiss, plagioclase-quartz gneiss, hornblende-pyroxene gneiss, amphibolite, garnet-quartz-mica schist, and micaceous quartzite. This assortment of rocks is suggestive of a supracrustal sequence. Samples containing garnet-hornblende-clinopyroxene-orthopyroxene-plagioclase-quartz have been examined petrographically, and analyzed with electron microprobe techniques. The pyroxenes have been previously interpreted as primary igneous crystals (James et al., 1961). High average calcium content of the clinopyroxene (> 42 mole % Wo) as well as low average calcium content of the orthopyroxene (< 3 mole % Wo) indicate a lower temperature (i.e. metamorphic) origin. The close textural proximity of the pyroxenes with porphyroblasts of garnet also supports a metamorphic interpretation. Equilibrium assemblages of garnet-clinopyroxene, and orthopyroxene-clinopyroxene yield geothermometric paleotemperatures ranging from 730° – 890° C. Geobarometers that utilize assemblages of garnet-plagioclase-orthopyroxene-quartz yield paleopressures greater than 6.4 kbar. Garnet cores equilibrated at temperatures of ~ 850 – 890° C, and pressures between 7.4 and 11.0 kbar. Garnet rims are 16 mole % richer in iron, and 17 mole % more depleted in Ca^{++} than garnet cores. These differences represent a re-equilibration in temperature down to 730 – 770° C, and a reduced equilibrium pressure of 6.4 to 7.5 kbar. The presence of apparently metamorphic clinopyroxene and orthopyroxene, in conjunction with calculated temperatures and pressures of assemblages bearing the phases opx-cpx-garnet-plagioclase-quartz, is evidence that the Hardwood gneiss experienced granulite facies metamorphism -- requiring burial to at least 25 km depth.

* James, H.L., Clark, L.D., Lamey, C.A. and Pettijohn, F.J.; 1961, Geology of central Dickinson County Michigan: U.S. Geol. Survey Paper 310, 176 pp.

Natural Brine Contamination of Groundwater in the Keweenaw
Rocks of Northern Michigan

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Former Michigan State geologist, A.C. Lane (1908) first reported the presence of high concentrations of brines in the Keweenaw rocks of Michigan. Lane coined the term "connate" to describe the brines which were sometimes at concentrations greater than 15% dissolved solids (150,000 mg/l) in the deep native copper mines of the Portage Lake Lava Series. Less concentrated brines of similar composition have been encountered in relatively shallow water wells drilled along the Lake Superior shore, especially above Upper Keweenaw sedimentary strata; i.e., the Nonesuch and Freda Formations.

Working in cooperation with water well drillers in the western Upper Peninsula of Michigan, more than 100 brine contaminated water wells were identified. Of these, 37 wells were sampled and analyzed for a number of cations and anions including Cl, SO₄, Sr, Mn, Ba, Al, I, Zn, Cu, NO₃, Br, Fe, K, Na, Mg, and Ca. The total dissolved solids ranged as high as 24,000 mg/l with an average value of 2800 mg/l. Elemental concentrations of the nine samples with chloride levels above 1000 mg/l, in order of relative abundance, were: Cl, Ca, Na, SO₄, Br, Sr, Mg, Ba, and I. Statistical analyses established strong positive linear correlation coefficients between many of the analyzed elements.

A number of the brine contaminated wells were situated some distance inland from the Lake Superior shoreline. It was hypothesized that these wells may have been contaminated by brine migration along vertical fissures which transect the Keweenaw rocks. To test this hypothesis lineaments were mapped from aerial photographs and satellite imagery and compared to the brine occurrences. Preliminary data are not adequate to confirm this hypothesis. Geophysical field measurements using resistivity methods are proposed to resolve this problem.

We favor a model of origin for the brines which derives them from the Keweenaw sediments in the Lake Superior Basin. Compaction of the sediments and resulting fluid expulsion provides a plausible mechanism for updip movement of the brines. This model is similar to White's hypothesis for the origin of the native copper deposits of the Keweenaw Peninsula (White, 1966).

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Video Field Trip to The Keweenaw Rift

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A 40 minute video field trip to the Keweenaw Peninsula and Isle Royale is presented as a example of the unique ability of this medium to communicate the field setting and geologic context of classical areas. The video incorporates aerial views with numerous ground locations and maps. It is meant for audiences ranging from high school earth science classes through geology graduate students who are interested in an introduction to the large scale flood basalt phenomena of the area and the Michigan Copper District.

It is hoped that such video field trips will allow better and more frequent interchange of field observations among geoscientists and educators working in areas all over the world. The expansion of video systems and the availability of editing systems and technical communications students eager for projects which demonstrate the various advantages of video communication for certain natural science purposes makes it possible for scientists with little video background to produce high quality results. The video will be run continuously during the poster session, with the author available for questions and comments.

Structural and Economic Geology of Citadel Gold Mines Inc.
Wawa, Ontario

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The Surluga and Jubilee Mines of Citadel Gold Mines Inc. were reopened in 1987. These former gold producers are both located in or adjacent to the Surluga Fault Zone.

The Surluga Fault Zone is defined by a series of anastomosing mud slips and breccia zones up to 5 feet wide, within a wider fault zone from 50 to 200 feet wide. It dips east-south-east at 30° to 40°. Slickensides consistently indicate movement in a normal right lateral sense along a plunge direction of 15° to 20° south.

The fault zone is clearly defined where it crosses a complex multiple intrusive dioritic unit, but cannot be readily traced into tuffaceous rocks to the north and south. Outside the fault zone, the diorities are relatively fresh rocks.

Within the fault zone, anastomosing splay faults, schist zones and quartz veins trend at a higher azimuth and have a lower dip angle than the fault zone as a whole. Failure to recognize this relationship, and the assumption that the "shearing" was parallel to the fault was a major contributing factor in the economic failure of the Surluga Mine in 1970.

Siliceous alteration zones and quartz veins parallel the schistosity and the faults. Where siliceous alteration is most intense ore is developed. These ore zones are offset en echelon to the left and progressively beneath one another from south to north. The Surluga Mine is a classic example of en echelon dilatant zones related to movement on a fault.

Imprint of Archean Abitibi tectonics on the Proterozoic
Lake Superior Basin

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Archean supracrustals form six lithotectonic, volcanic-sedimentary facies associations: 1) Least differentiated PRIMATIVE CRUST consists of voluminous, thick submarine Mg-tholeiitic basalts with minor komatiitic lavas and ultramafic intrusions. Flat paleotopography collects thin but extensive pyritic-graphitic mudrocks. 2) The tholeiitic BASALT PLATFORM contains both Mg and Fe-tholeiites, with minor felsics and local mafic sedimentation near normal faults. The upper lavas are varicolitic, forming a transition to 3) the CENTRAL VOLCANIC COMPLEX which contains two thirds volume of tholeiitic and calc-alkalic basalts or andesites and one third submergent to emergent dacite-rhyolite cone complexes. As lavas become more felsic and emergent, pyroclastic flank facies develop and fine downslope into 4) lateral TURBIDITE BASIN deposits consisting of quartzo-feldspathic debris and minor but more laterally extensive iron formations. 5) RIFT BASIN-RIDGE deposits form along lineaments as predominantly calc-alkalic and locally alkalic lavas, alluvial-fluvial sediments and fault-bounded turbidites. 6) CRATONIC NUCLEI as basements are telescoped versions of other lithotectonic associations capped by stable shelf carbonates, stromatolites and iron formations.

Areal distribution of lithotectonic associations in the Abitibi terrane suggests that earlier deposition was favoured along regional structures which now trend WNW and record shearing as their latest movements. This is the direction of the boundary between the Abitibi northern "internal zone" and southern "external zone". Possibly contemporaneous ENE trending structures were reactivated and dilatant during later deposition and orogeny, and now host economic epigenetic ore deposits. Intersections of these two trends produce a regional tectonic grain of shear and fault-bounded lozenges with apparent east-west elongation.

Changes in regional stress during the Kenoran Orogeny produced a NNW-NNE fracture set represented by the Matachewan dike swarm and Kapuskasing Structural Zone respectively. The inherited ENE Abitibi trend controlled deposition of early Proterozoic greenstone in Wisconsin and Huronian stable shelf sedimentation in Ontario. Subsequent deposition of the Cobalt platform and Nipissing flood basalts was initiated at the intersection of the ENE Huronian trend and the southern termination of the NNW Matachewan dike swarm.

Younger analogous trends exist in the Lake Superior basin. The Animikie strand line, defined by the Mesabi-Gunflint iron range, trends ENE and is intersected by aborted NNW dilatant fractures. The NNW fractures allowed subsidence and deposition of the lacustrine-shallow marine Sibley Group and subsequent deposition of the Nipigon-Logan sills. Long-lived NNE faults subparallel to the Kapuskasing Structural Zone provided periodic access for alkalic intrusions such as the Coldwell complex at the close of Keweenaw volcanism. The Keweenaw, as the last major extrusive event in the basin, produced a thick sequence of emergent

tholeiitic basalts and felsic extrusives. The trace of the axial surface of the Lake Superior syncline defined by Keweenawan strata is ENE in the western and WNW in the eastern portions of the basin as, respectively, later and earlier inherited Abitibi structural trends. The ENE Abitibi trend was once again predominantly dilatant during Keweenawan volcanism, as evidenced by the trans-Abitibi Keweenawan dike swarm which originated from the Aphebian greenstone belt axis in Wisconsin. A final argument for Abitibi tectonic imprint in the Lake Superior basin is the presence of either ENE or WNW fault contacts between Archean granite-greenstone and gneiss-amphibolite crustal remnants within the Lake Superior basin.

Nature of Cleavage, Folding and Strain in the Michipicoten
Greenstone Belt, Near Wawa, Ontario

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The rocks within the Michipicoten Greenstone Belt near Wawa, Ontario are exceptionally well exposed. This and the generally low metamorphic grade and excellent preservation of primary sedimentological features permit detailed structural analysis.

Development of multiple phases of folding with associated cleavages and shear zones characterizes the predominantly ductile earlier Archean deformation. These were subsequently dissected and displaced along faults and shear zones (McGill and Shradly, this volume). Strain during the earlier deformation of the area is generally heterogeneous although conglomerate pebbles deformed very early in the history of this part of the Belt record moderate, relatively homogenous strain.

Rootless tight to isoclinal mesoscopic folds of probable soft sediment slump origin and generally larger, meter-scale tight folds without associated axial planar cleavage but of probable tectonic origin are among the oldest recognized structures. Conglomerate pebbles lie within an approximately bedding parallel cleavage, the earliest penetrative cleavage observed. This cleavage is only rarely observed to be axial planar to folds. The existence of clastic dikes parallel to this early axial planar cleavage suggests that, at least locally, this cleavage developed in incompletely consolidated sediments. Mineral lineations and the long axes of deformed pebbles define a NE-E principal extension within this cleavage plane. Estimates of the axial ratios of oblate strain ellipsoids suggest strain of moderate intensity with little variation across the area. Bedding-related faults are also of comparable relative age. Although the precise relation among the early folds, faults and this cleavage is not at present known, a continuum of deformation resulting in these structures is suspected. Regional overturning and stratigraphic inversion suggestive of thrusting and large recumbent folds also is associated with this phase of deformation. In comparison, younger deformation and strain are inhomogeneous and have had little effect, except locally (e.g. in shear zones) on the deformed conglomerate pebbles.

A younger, generally NW-trending, moderately NE-dipping crenulation cleavage is most strongly developed in the western and northwestern sections of the area. Related mesoscopic folds are rare.

Post-dating this and crenulating all previous surfaces is a NE-trending cleavage that dips steeply SE and NW and is axial planar to folds of open to tight geometry. Shear zones parallel the axial surfaces of these folds. Regional steepening of dips probably is associated with this deformation phase which appears more intensely developed in the southern part of the area mapped. This older cleavage is crenulated by a younger northeasterly trending axial planar cleavage with shallow to moderate southeasterly dips. In addition to those described above, are cleavages of only local development; some parallel faults followed by diabase dikes, others are of variable attitude and uncertain association.

The deformational history recorded by these structural features is more complex than previously recognized, with significant shortening and strain achieved through early folding and shearing. Subsequent folding, cleavage development and associated strain are more local and heterogeneous in character. Our observations are inconsistent with a simple Archean deformational history dominated by either vertical motion or horizontal compression resulting in an uncomplicated synclinal geometry. We suggest that the complex nature of deformation in this part of the Michipicoten Greenstone Belt is more consistent with that recently documented in some other Archean terranes (e.g. the Barbeton Greenstone Belt, de Wit, 1982; the Norseman-Wiluna Greenstone Belt, Martyn, 1986) and with that observed within many Phanerozoic orogenic belts.

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Structural Geology of the Southwestern Portion of the
Michipicoten Greenstone Belt, Ontario

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The Michipicoten Greenstone Belt extends for about 150 km ENE from the northeastern angle of Lake Superior. The eastern limit of the belt is the high-grade Kapuskasing zone that separates the Michipicoten from the Abitibi Greenstone Belt. We are mapping key areas in the southwestern portion of the Belt at a scale of 400' = 1", tying these areas together with 1 mile = 4" mapping and recent Ontario Geological Survey preliminary maps by Sage and others. All of our mapping to date has been within Chabanel Township, and most of it is in or adjacent to the large fume kill downwind from the sintering plant in Wawa where outcrops are very abundant and easily located. This abstract accompanies a poster displaying some of our detailed maps.

The rocks of our area may be divided into the traditional lithologic types: mafic-intermediate volcanics, intermediate-felsic volcanics, clastic sediments, and chemical sediments (including iron formation). In the southwestern portion of the Michipicoten Greenstone Belt there is a northern (interior) terrane consisting mostly of intermediate to mafic volcanics. These rocks dip north to northeast at intermediate angles, and are overturned (all indicators suggest southward or southwestward younging). Along the southern margin of the belt is a thick sequence of volcanic rocks with minor iron formation that youngs northward and has steep north or south dips. Between these dominantly volcanic terranes is an extensive belt of clastic sedimentary and pyroclastic rocks. Much of our detailed mapping has been concentrated in this belt because of the abundance of good indicators of younging direction, and because cleavages generally are better developed in the metasedimentary rocks than they are in the metavolcanic rocks.

In the eastern part of Chabanel Township, there is a single, abrupt reversal in younging direction within the sedimentary belt that is interpreted to be a fault (or a faulted isoclinal fold). One late fault that generally follows bedding is present south of this reversal, but the displacement does not appear to be significant. Other bedding-related faults may be present but obscure due to lack of such features as truncation, obvious shearing and local stratigraphic inversion. Overall, however, the impression is that the sedimentary sequences north and south of the one obvious younging direction reversal are not severely disrupted.

To the west, the width of the sedimentary belt widens rather rapidly, in part due to increasing thicknesses of individual lithologic units, but also we suspect due to fault imbrication (imbrication is very difficult to prove in the absence of fossils!). Within the widest part of the sedimentary belt we have been able to define and map lithologic "packages", most of which are bounded by contacts that we believe are early faults, based on the presence of one or more suggestive characteristics (deformed conglomerate pebbles, local spaced cleavages, gossans, mafic sills, networks of quartz veins, narrow linear topographic depressions, truncation of layering, or abrupt tops reversals). In addition, the sedimentary belt appears to be separated from the northern volcanic terrane by a fault that we have been able to trace across almost the entire width of Chabanel Township.

Tentatively, we interpret the mapped relationships as representing a thrust-imbricated sequence of volcanic and sedimentary rocks, with imbrication increasing westward within the area we have mapped. Because of the faulting, the age of the rocks in the northern (interior) volcanic terrane relative to the volcanic rocks along the southern margin of the belt near Wawa is not known (no published radiometric ages come from the northern volcanic terrane), nor do we know the sense of relative movement across the imbricate faults. Efforts to eliminate these uncertainties are underway.

A Structural Analysis of Proterozoic Metasediments,
Northern Falls River, Baraga County, Michigan

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The geologic feature historically referred to as the "Baraga Basin" is a roughly crescentic depression trending east-west across north-central and northeastern Baraga County in the Upper Peninsula of Michigan. It contains deformed and metamorphosed sediments that have been correlated with the lower Proterozoic Michigamme Formation, and is bounded by Archean rocks of the Northern Complex to the south and northeast.

The best exposures of the structure within the Baraga Basin occur in the beds of the northward-flowing streams draining into Lake Superior. The westernmost of these streams, the Falls River, was intensively mapped from its mouth in the village of L'Anse to a terminal point located approximately one mile upstream to the south. Other aspects of the investigation included description of microstructural features and geometric analyses of various elements of the rock fabric.

The slates and metagreywackes of the Falls River area are characterized by three roughly coaxial systems of folds, two of which are mesoscopically distinct. Style group B₁ consists of a series of tight to isoclinal overturned folds with axes that plunge shallowly to the west-northwest and east-southeast. Small-scale parasitic folds are commonly associated with these larger folds. The overall vergence of the system suggests that the field area is located on the long limb of a B₁ regional fold. The axial-planar foliation associated with this style group (S₁) dips gently to the southwest in those areas unaffected by later deformation. Microscopically, S₁ varies in appearance from a well-developed continuous slaty fabric in the pelitic units to an irregular domainal rough cleavage in the matrix-rich greywackes. In nearly all cases, the mineral chlorite defines the cleavage fabric. Matrix-poor varieties of greywacke display an S₁-parallel flattening of clasts. Recrystallization textures are common in these rocks. A system of S₁-parallel thrusts is also associated with this style group. The fault zones are commonly cataclastized and mineralized with quartz and carbonate.

Style group B₂ exhibits considerable lateral variation within the field area from north to south. To the north, B₂ is best visualized as a series of gentle folds and asymmetric flexures in the previously existing S₁ fabric. Fault zones have also been visibly folded in some locales. Fold axes appear to be horizontal and trend roughly east-west. A sinuous crenulation cleavage (S₂) is developed

in the proximity of the B_2 hinges. Cleavage domains vary from zonal to discrete. B_2 folds become tight at the southern end of the survey line, and S_2 is generally pervasive. Microscopically, S_2 is more strongly developed here than to the north, with well-defined cleavage domains, anastomosing morphologies and commonly symmetrical profiles.

B_3 deformation is characterized by macroscopic folds which overprint B_2 style group elements. Field evidence is most easily seen at the southernmost extent of the field line and consists mainly of the reorientation of S_2 cleavage attitudes. Originally east-west striking, nearly vertical crenulation cleavage planes have been rotated more than 70 degrees along a roughly east-west trending horizontal axis. Mesoscopic fold axes for this system have not been precisely located in the field. Additional field evidence in the form of a localized steeply dipping spaced cleavage (S_3) is recognized in outcrops at the terminus of the survey line. These cleavage surfaces appear in thin section as rough fractures and irregular seams of dark residual material that overprints earlier foliations, and has a strike coincidental with the rotational axis of the earlier S_2 fabric.

The operation of nappe-style tectonism during the Penokean Orogeny has been proposed by several authors in recent years. Although it may not be the only mechanism capable of producing the structural features observed at this and other locations in the Baraga Basin, it is a tectonic model that is consistent with known field evidence:

- 1) The B_1 fold systems in the region display a vergence indicative of a position on the long limb of a large-scale overturned regional B_1 fold system. Fold systems reflective of a position on the short limb of a regional fold are not seen.
- 2) Systems of S_1 -parallel thrust faults are observable throughout the region, perhaps reflective of large-scale overthrusting.
- 3) The systematic disappearance of later-stage fold systems towards the north, and the overall reduction in the intensity of deformation towards the north, is something observable on a regional scale, and reflective of a lateral progression from a deformational foreland to a hinterland.
- 4) Previous work regarding multiply-deformed terranes (overthrust belts in particular) has shown that a single progressive tectonic event can produce poly-phase deformational features such as refolded folds. This eliminates the need for models involving discrete "pulses" of deformation.

Mesozoic Paleogeography: implications for economic
deposits north of Lake Superior

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During the Mesozoic major shifts took place in the position and attitude of the North American crustal plate and by early Cretaceous time Africa had split away from North America to form the Atlantic ocean. Great movements also took place in the position of magnetic north, influencing global weather patterns.

For long periods the Precambrian Shield stood as a continental massif subject to intense tropical weathering, which advanced most quickly along existing fracture zones or in rocks of susceptible composition. By late Jurassic time this process had developed a subdued surface of advanced karst across parts of Minnesota on which quartz-feldspar debris, supplied by the granite terranes of Manitoba and Saskatchewan, was slowly transported southwards across a gentle topographic gradient.

By early Cretaceous time a rapid pulse of seafloor spreading and renewed sources of volcanism in the mantle caused rotation of the North American plate. Mountain building and local explosive volcanism marked the western margin of the continent, whereas a shallow north-south seaway developed across the continental midline. Once again the Ontario Shield was a landmass upon which terrestrial materials were patchily deposited. The 50° parallel now ran from about Kenora to Cape Henrietta Maria and the climate on the eastern shore of the inland sea was warm but semi-arid.

The long episodes of continental weathering, the subaerial volcanism and the climate conditions influenced the formation and concentration of a suite of economic mineral deposits which are characteristic of this time. Kaolin, valuable for the refractory properties of iron-free aluminous materials, and secondary kaolins, which in addition have special plastic properties, were formed worldwide in the Mesozoic. Volcanic dusts, produced by explosive subaerial volcanism, have been subsequently weathered to special-use bentonitic clays. The hot, often humid climate produced karst depressions filled with concentrates such as hematitic iron-ores or carbonate-free clays. Leaching of carbonate from carbonatite bodies has left gravelly phosphate residues enriched in rare earths and fluorine. Silica leaching has upgraded siderite iron ores to a soft hematite-limonite concentrate which was the earliest Great Lakes iron ore.

The common theme of these deposits is their relationship to the Mesozoic evolution of the North American Shield. Ontario examples suggest that beneath a glacial cover more of these valuable concentrations may be found and that the importance of this time interval has been undervalued.

Solid Pyrobitumen in Veins, Panel Mine, Elliot Lake Uranium District, Ontario

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Globular blebs of solid pyrobitumen (thucholite of older reports) are found in veins exposed in open stopes and drifts in the Panel Mine in the Elliot Lake Uranium District, Ontario. The veins fill fractures in the 2.2 billion year old Matinenda Formation. The blebs are small (1-10 mm) and free-form, varying in shape from round to disc, twisted or elongate. The surfaces are shiny and permeated with vesicles. Analyses show the blebs to be predominantly carbon with a H/C ratio of 0.51, a reflectivity (max Ro) of 0.91%, and a $\delta^{13}\text{C}$ value of -33‰ (PDB).

Kaiman and Horwood (1976) concluded that blebs of thucholite in the Milliken Mine were formed by the agglomeration and polymerization of carbon particles from the exhaust of diesel mining equipment. We propose that the pyrobitumen blebs in the Panel Mine are the result of the natural migration and maturation of petroleum. The Precambrian petroleum migrated into the fractures and with time and increased temperatures polymerization progressed and the tarry masses matured into the blebs of pyrobitumen.

Blebs of similar morphology and occurrence have been reported from fracture fillings in the Cambrian Bonnetterre Formation from the Magmont West Mine on the Viburnum Trend, Missouri (Marikos, et al. 1986) and in the Ordovician Trenton Formation in Wyandot County, Ohio (Haefner, et al., 1986). Both are considered to have been formed from locally derived oil that was polymerized in the fractures.

Based on observations with the petrographic and scanning electron microscopes, a paragenetic sequence of mineralization in the fractures and the occurrence of the pyrobitumen have been determined. Quartz was the first mineral to crystallize in the fractures followed by a first generation pyrite. The pyrite was subsequently altered morphologically by partial dissolution. Petroleum migrated into the fractures and was partially polymerized into blebs which were encased by fibres of sepiolite. Near the end of sepiolite formation a second generation pyrite was deposited. This pyrite is in the form of larger (5-15 mm) cubes. The fact that this pyrite contains inclusions of sepiolite and pyrobitumen indicates that the pyrobitumen formed prior to the pyrite. At the same time or just after the second generation pyrite was formed, minor pyrrhotite and galena deposition began. Large (5-20 mm) calcite crystals cover and overgrow the blebs of pyrobitumen and all other minerals in the fractures.

The source of the organic material which produced the petroleum is still in question. Willingham et al. (1984) cited the occurrence of stratiform kerogens in the Matinenda Formation in the Elliot Lake Region as evidence for ancient mats of cyanobacteria. The other possible sources of organic material for petroleum formation are the argillites and siltstones of the Mckim Formation.

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The "Hager Suite" and Problems Concerning the Nature and Location
of the Northern Boundary of the Wolf River Batholith

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It is the contention of this abstract that the "Hager Granite / Porphyry", which has previously been considered to be the northernmost unit in the Wolf River Batholith of northeastern Wisconsin (Anderson and Cullers, 1978; Greenberg and Brown, 1984), is neither a member of the batholith, nor a granite. The northernmost member of the Wolf River Batholith is the "Belongia Granite" which has intruded into the Hager--a volcanic suite of felsic to intermediate rocks--and into older greenstones and gneisses.

The extent of the Hager Suite is larger than currently recognized because exposures of this suite can be found along the entire southern boundary of the McCaslin Quartzite in regions currently mapped as Belongia Granite (Greenberg and Brown, 1984). The distinction between rocks of the Hager Suite and the Belongia Granite can be made on the basis of petrographic and/or chemical criteria. The felsic member of the Hager Suite is a metarhyolite with abundant (20%) relic quartz phenocrysts that commonly display resorption embayments. The intermediate members of the suite show an increase in mafic minerals and plagioclase and rarely contain the resorbed quartz phenocrysts. The eastern boundary of the Hager appears to have been intruded by the High Falls Granite; the High Falls is currently thought to be older than the Hager (Greenberg and Brown, 1984). An increase in metamorphic grade can be seen in the pelitic components of the McCaslin Quartzite from east to west as the High Falls Granite is approached. A similar gradient may be evident in the more mafic units of the Hager Suite.

The boundaries, extent of differentiation, degree of metamorphism, and timing of formation of the Hager Suite is being reevaluated. Preliminary results of field and chemical works show that the Hager Suite can be distinguished as a separate volcanic sequence from the other rocks of the region. A knowledge of the character of this suite will be essential in determining the nature of the northern boundary of the Wolf River Batholith.

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Geology of the Atikokan Area, northwestern Ontario: an overview

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Beginning late in the nineteenth century, geologists have more or less continuously studied Archean rocks in the Atikokan area, with particular emphasis on the metavolcanic belt at Steep Rock Lake. The first recorded survey of the area identified an unconformity overlain by conglomerate, dolomite and tuff formations along the northeastern margins of the Steep Rock belt (1). These formations, which comprise the Steep Rock Group, were studied extensively during open-pit mining of the iron ore zone at the top of the dolomite unit (2). Early workers thought that the Steep Rock Group was one of the youngest supracrustal sequences in the area (e.g. 3), but recent lead isotope studies yield an age of 2.929 Ga for the Marmion Lake tonalite basement (4). Accordingly, the overlying Steep Rock Group may be older than most metavolcanic rocks in the Wabigoon Subprovince since these tend to be in the range of 2.71-2.76 Ga (5).

Three distinct assemblages of metavolcanic rocks are identified in the Steep Rock belt on the basis of Atomic Energy of Canada Limited's (AECL) mapping survey and studies of major and trace element geochemistry. These consist of the lower lapilli tuff (ash rock) overlain by voluminous mafic pillow lavas, followed by intermediate to felsic flows, tuffs and breccias. Erosion of these metavolcanic extrusives and exposed tonalite appears to be the source for clastic sediments in both the Quetico Subprovince and in narrow units throughout the greenstone belts (Figure 1). Several phases of felsic plutonic and gneissic rocks occur outside of the supracrustal belts. Tonalitic gneisses containing thin amphibolite units are extensive in the map area and can be correlated with the Marmion Lake tonalite basement complex and early supracrustal sequences. During or immediately after the late stages of volcanism, the gneisses were intruded by several "young" tonalite plutons. Emplacement of granitic magma, such as the Eye-Dashwa pluton at 2.672 Ga, marked the latest stage of crustal genesis in this area.

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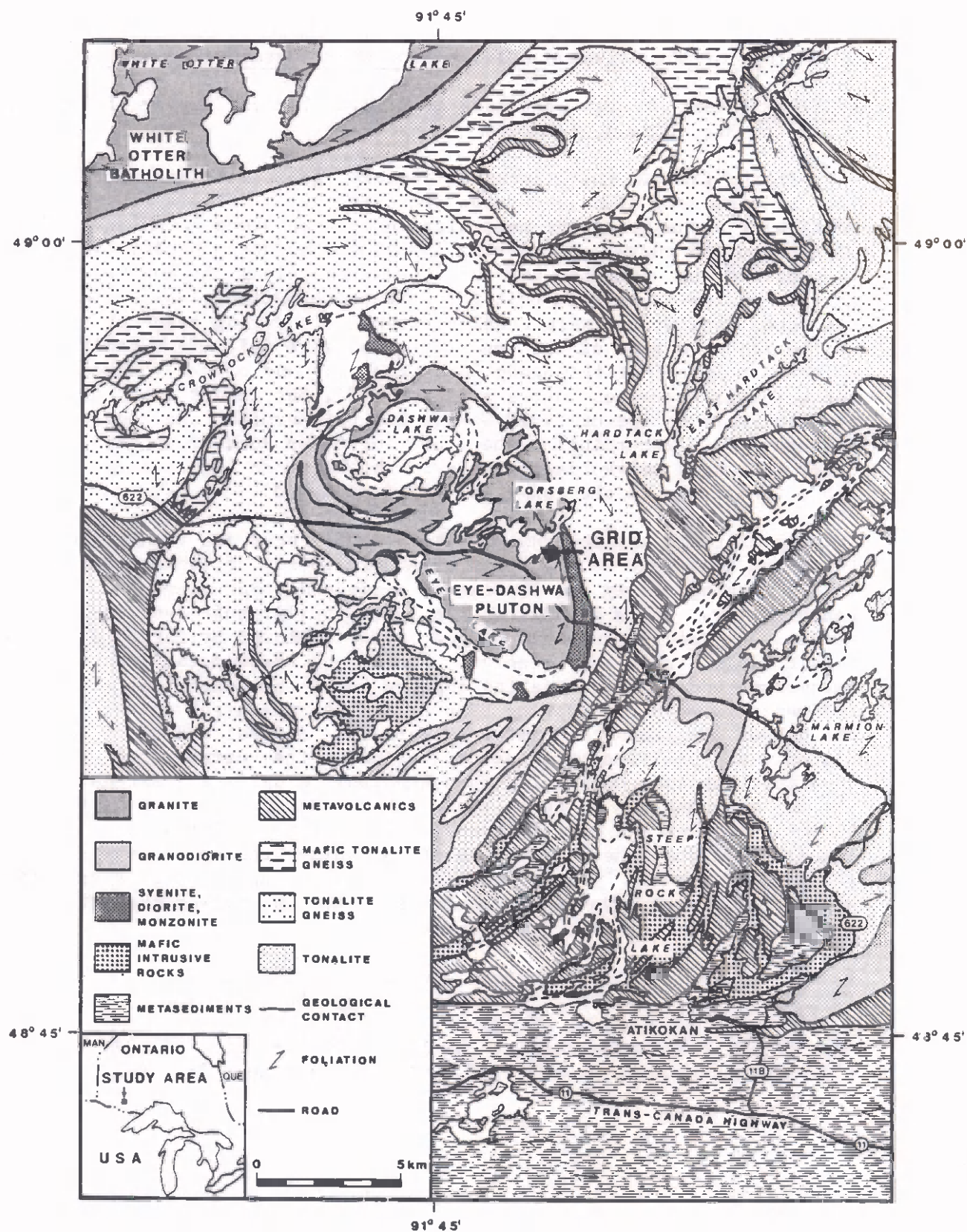


Figure 1: Geology of the Atikokan area, northwestern Ontario.

Gravity and Magnetic Evidence for Rhomboid Sedimentary Basins in the Wisconsin Magmatic Terrane

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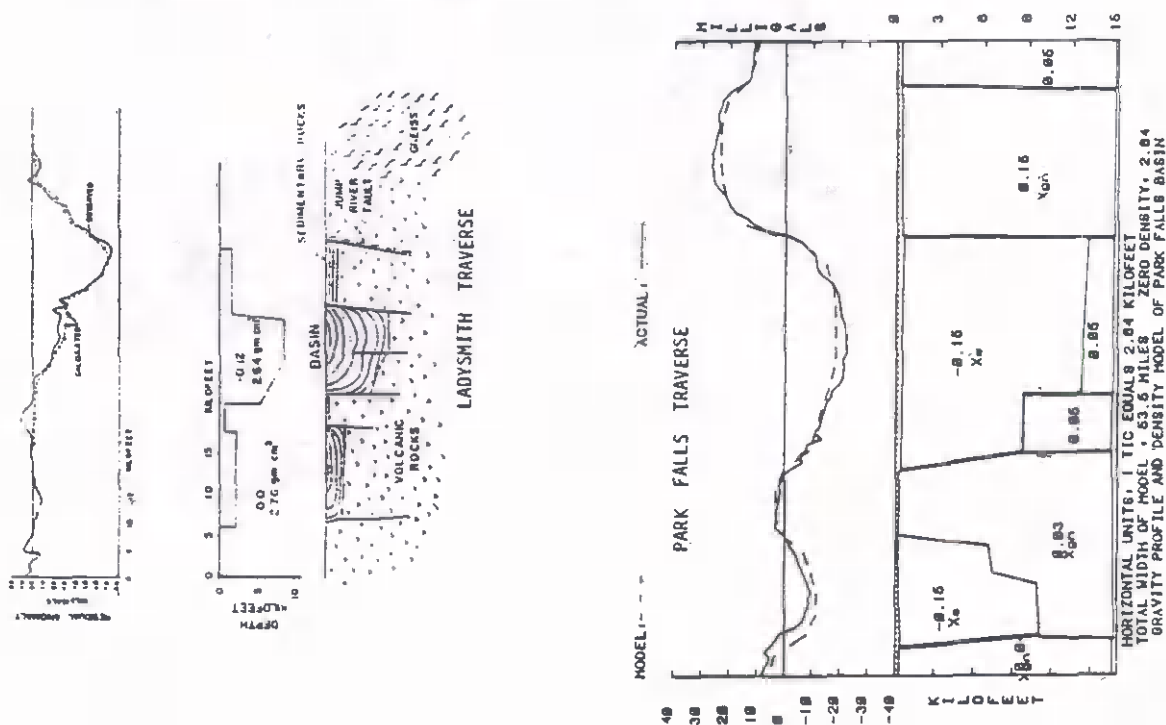
Gravity and magnetic data from Rusk, Chippewa, Sawyer and Price counties in northern Wisconsin indicate the presence of Early Proterozoic rhomboid shaped sedimentary basins. (Fig. 1)

Gravity readings taken across three basins, the boundaries of which have been defined by the aeromagnetic pattern, have provided data for the construction of two, two dimensional gravity models. (Fig. 2)

The Ladysmith gravity model, which spans one basin in Rusk and Chippewa counties, was developed from data taken along a fifteen mile traverse with readings taken at one thousand foot intervals. This model suggests an asymmetrical basin deepening to the south with a thickness of sediments of approximately thirteen thousand feet.

The Park Falls gravity model, which spans two basins in Sawyer and Price counties, was developed from data gathered along a fifty-four mile traverse with readings taken at one half mile intervals. The model of these basins suggests a sediment thickness of twelve thousand to sixteen thousand feet. Both profiles and models indicate that the gravity highs correspond to the magnetic highs and gravity lows to magnetic lows.

Drill core from these areas show that greenschist to amphibolite grade metavolcanic and granitoid rocks underlie the gravity highs, and graphitic argillites and graywackes underlie the gravity lows.



AEROMAGNETIC MAP OF A PORTION
OF NORTHWESTERN WISCONSIN
Showing the Sedimentary Basins (Xs)
and location of Gravity Traverses



Contemporaneous late Archean mafic and granitoid magmatism in the
Lac des Iles area, Wabigoon Subprovince, Ontario

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The Lac des Iles area, located approximately 100 km north of Thunder Bay in the Wabigoon Subprovince, contains a suite of mafic to ultramafic intrusions which show evidence of being contemporaneous with late Archean tonalite and granodiorite. The mafic to ultramafic and granitoid intrusions are emplaced into older gneissic biotite tonalite and form part of the Wabigoon Diapiric Axis.

The tholeiitic mafic to ultramafic intrusions in the area have similar lithologic, tectonic, and metallogenic characteristics and define a circular structure approximately 30 km in diameter. The Lac des Iles Complex, the largest of these intrusions, is host to significant Pd, Pt mineralization and formed as a result of the emplacement of multiple batches of magma with minor in-situ fractionation. The more fractionated gabbroic rocks were emplaced first and consist of plag-cpx-opx and plag-cpx cumulates. The younger ultramafic suite consists of ol, ol-cpx, cpx, cpx-opx, and cpx-opx-plag cumulates. The Tib Gabbro, the second largest mafic intrusion, represents a more fractionated sequence and consists of opx-cpx-plag cumulates grading to zones with cumulus apatite, Fe-olivine and magnetite. All of the intrusions have marginal zones characterized by the presence of hornblende gabbro to hornblendite.

Late granitoid rocks ranging in composition from hornblende tonalite to biotite granodiorite occupy the center of the circular structure defined by the mafic intrusions. The hornblende tonalite has textures that indicate mixing between leucocratic tonalite and mafic magmas. These textures include net veined mafic dikes, mafic "pillows" in tonalite, and hybrid zones characterized by coarse, skeletal hornblende. The mixing textures occur within the tonalite pluton and at the contacts of the tonalite pluton with the mafic intrusions. Mixing and hybridization appears to have been a widespread process as indicated by the development of coarse skeletal to blocky hornblende throughout the tonalite pluton. Breccia zones developed in the tonalite may have resulted from degassing of a zoned magma chamber with mafic magma underlying the granitoid magma.

The relationships in the Lac des Iles area suggest that mafic intrusions played a significant role in late Archean granitoid magma genesis. The emplacement of mafic magma into older crust resulted in the generation of crustal melts and the development of zoned mafic-felsic magma chambers. The resultant magma compositions reflect mixing between these end-members.

Lead Isotope Evidence for an Old Crustal Source for Many Ore Leads in the Wawa Region

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Lead isotope analyses for galena from deposits and occurrences in the Wawa region (Table 1) are significant because of the old model lead ages for a few deposits and the high $^{207}\text{Pb}/^{204}\text{Pb}$ values for many of the specimens. In these respects they are comparable in composition to leads from selected localities in western Superior Province (Wabigoon Subprovince) and are dissimilar to leads from Abitibi Subprovince.

Application of Archean lead evolution models derived by Thorpe (in preparation) yields model lead ages greater than 2830 Ma for the BCH and J veins by the Abitibi model, and greater than about 2870 Ma by the Western Superior model. The latter model may apply because a comparable zircon U-Pb age of about 2888 Ma has been reported for the biotite granite phase of the Hawk Lake complex (Turek *et al.*, 1984), an external pluton that has intruded the supracrustal rocks of Subcycle 1 hosting these mineralized zones. The leads with old model ages are thus restricted to metavolcanic rocks at the base of the section that are recognized as the oldest in the region. Other leads from localities in Wabigoon Subprovince, and from the Musselwhite property, Sachigo Subprovince, also yield model ages greater than 2800 Ma, and in two cases as great as about 3000 Ma.

The Kozak mineralization, probably synchronous with volcanism, yields model lead ages of 2770 Ma (W. Superior) and 2724 Ma (Abitibi). We consider that the Abitibi model most likely applies, but this can only be confirmed by zircon dating. Model ages (W. Superior model) of 2657 Ma and 2658 Ma for two of the MacLeod East galenas and of 2670 Ma for Leclair Township galena are within analytical uncertainties of ages for some plutons in the area, possibly indicative of a genetic relationship. The Northern Granite (granitic gneiss) that is located along the northern boundary of the greenstone belt has a zircon U-Pb age of 2662 ± 2 Ma, and the Troupe Lake trondhjemite is apparently of the same age (Turek *et al.*, 1984).

Many leads from the Wawa region plot well above the fields for Superior Province massive sulphide deposits with ages in the 2695 to 2770 Ma range, and for most Superior Province gold deposits. They mostly lie within the field for Zimbabwe gold deposits (Robertson, 1973; and unpublished data). Such $^{207}\text{Pb}/^{204}\text{Pb}$ -enriched leads are generally interpreted to have evolved in sources that had high U/Pb ratios (μ values) for extended periods of geological time prior to ore formation, specifically in upper crustal terranes that have not been subjected to high-grade metamorphism (e.g. Robertson, 1973). These leads, and some of those from the Wabigoon Subprovince, thus suggest the presence in these regions of an ancient lead source of "Minnesota River

Valley-type". In the Wawa area these leads are from within or near Subcycle 1 rocks.

The calculated Th/U ratios for the lead sources of the Wawa region galenas are, with two exceptions (the BCH vein at a value of 4.12 and the epigenetic vein in the Woman River iron formation), in the range 4.00 to 4.07. The uniformity in these ratios suggests that these leads must have been derived from large volumes of source rocks, because local sources would be expected to contribute leads with much more variable ratios.

Galena that, with calcite, pyrrhotite and graphite, occupies a late fracture cutting ore in the Kremzar gold deposit, Goudreau area, has a very radiogenic composition. Assuming it formed at a geologically recent time, the calculated source age is 2680 to 2735 Ma if the initial Pb composition of the source was in the range of the Ranson and Renabie compositions.

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Table 1. Lead isotope data for deposits and occurrences in the Wawa region

Property	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	Model Ages	
				W. Superior Model	Abitibi Model
J Vein	13.584	14.921	33.391	2879 Ma	2838 Ma
BCH Vein	13.617	14.947	33.477	2873 Ma	2832 Ma
Lakemount	13.666	14.940	33.462	2829 Ma	2788 Ma
Lakemount	13.653	14.939	33.455	2838 Ma	2798 Ma
Lakemount	13.681	14.949	33.494	2824 Ma	2783 Ma
Kozak	13.208	14.402	33.083	2770 Ma	2724 Ma
Edwards pros.	13.957	15.077	33.699	2709 Ma	2670 Ma
MacLeod East	13.953	15.006	33.723	2657 Ma	2617 Ma
MacLeod East	13.979	15.033	33.789	2658 Ma	2618 Ma
MacLeod East	13.972	15.014	33.774	2649 Ma	2609 Ma
Soocana	14.241	15.194	33.991	2587 Ma	2548 Ma
Renabie	13.343	14.484	33.216	2723 Ma	2678 Ma
Michipicoten	13.546	14.657	33.394	2699 Ma	2655 Ma
Leclair Twp.	13.565	14.642	33.272	2670 Ma	2627 Ma
Rengold	13.472	14.532	33.336	2654 Ma	2609 Ma
Braminco pros.	13.48	14.52	33.35	2637 Ma	2591 Ma
Ranson	13.595	14.625	33.448	2631 Ma	2587 Ma
Kremzar	28.867	17.419	49.105	anomalous	
Vein in Woman R. iron formation	14.814	15.123	34.422	2107 Ma	2066 Ma

Reconnaissance Geology of the Granitic and Gneissic Terranes in the Wawa District

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On the basis of reconnaissance and detailed geological mapping completed in the Wawa District over the past two years, together with regional lake sediment/water data, aeromagnetic data, and studies by the Geological Survey of Canada, a preliminary geological evaluation of the granitic and gneissic terranes in the Wawa District is in progress.

The granitoid rocks in the Wawa area can be subdivided into three main classes from oldest to youngest: a) tonalite to granodiorite gneiss "domes" or oval structures ranging from massive to well-layered gneiss containing metavolcanic-metasedimentary enclaves metamorphosed to amphibolite grade; b) medium-to coarse-grained granodiorite to quartz monzonite ranging from large plutons to batholiths in size; c) late quartz diorite to syenite plutons.

The granitoid complexes of the Wawa District have geological characteristics which are similar to those described by Schwerdtner et al. (1979). Some of these include:

- 1) Tonalite gneiss domes displaying a transition from a coarse-grained gneissic core to a marginal zone composed of layered tonalite gneiss containing arcuate-shaped metavolcanic-metasedimentary segments.

- 2) Crescent-shaped plutons of hornblende diorite to granodiorite occupying quasi-concordant sites between gneissic "domes" and adjacent supracrustal belts.

- 3) A large batholith ranging in composition from quartz monzonite to granodiorite and occupying the central portion of the granitoid terrane in the study area representing a post-tectonic period of emplacement.

- 4) Evidence of high and low ductility contrast between the metavolcanic-metasedimentary segments and gneissic/layered tonalites.

- 5) The arcuate-shaped metavolcanic-metasedimentary enclaves can be traced around the outer perimeter of the gneissic "domes" and traced adjacent to larger synformal-shaped metavolcanic-metasedimentary belts.

The geological history of the granitic and gneissic terranes appears to involve an early magmatic period of tonalite intrusion into metavolcanic-metasedimentary rocks under conditions of high ductility contrast. This was followed by a period of auto-deformation with low ductility contrasts and the development of gneiss domes which resulted in the infolding and fragmentation of the metavolcanic-metasedimentary belts. A period of intense, post-tectonic felsic plutonic activity followed, forming the large plutons and "central" batholith. The arcuate and amoeboid shape of the metavolcanic-metasedimentary belts such as the Dayohessarah greenstone belt and the Michipicoten greenstone belt reflect the broad scale deformation which resulted from the early and late periods of felsic plutonic/gneissic diapiric activity.

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The meaning of U-Pb and Rb-Sr ages in the Wawa area

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U-Pb zircon ages for the Michipicoten greenstone belt appear chronostratigraphically correct. The greenstone belt and surrounding granitic terrane evolved around 2888 to 2615 Ma ago. Volcanism occurred at 2743, 2717, and 2696 Ma. Plutonic rocks dated fall into 5 events; 3 are coeval with the above volcanic periods while 2 are independent at 2668 and 2888 Ma. The 2668 Ma plutonism is probably part of the Kenoran orogeny, while the 2888 Ma granite may be a reafter of older basement or related to older volcanism as yet not identified in this belt.

The Rb-Sr ages obtained for rocks in the area have large age uncertainties and chronostratigraphically do not make sense; probably because they are hybrid ages, between primary and metamorphic. An attempt at unmixing these ages mathematically suggests 5 possible events around 2750, 2615, 2510, 2410, and 2330 Ma. The first age is essentially a primary age for the specific rocks dated, the subsequent ages are thought to be thermal events.

Paleomagnetism of Archean granites in the Wawa area: further
definition of the Apparent Polar Wander Path

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Paleomagnetic measurements have been completed on about 500 specimens from Archean granitic plutons in the Michipicoten and Gamitagama greenstone belts. The plutons had all been dated by the U-Pb zircon method and in most cases by other methods also. Extensive AF and thermal step demagnetization analysis was used to isolate stable remanence directions. The first paleopole (HSE) at 20°W , 37°S ($D_p = 5^{\circ}$, $D_m = 10^{\circ}$) defines the ~ 2694 Ma position of the APWP. The pole position was established by averaging single component remanences isolated within the Southern Granitic Terrane, Hawk Lake Granitic Complex and the Eastern External Granite rock units. This remanence apparently records the acquisition of the magnetization during the last intrusive event of these adjacent plutons. The second paleopole (NM) is derived from the Northern External Granite and the Baldhead River Quartz Monzonite which have U-Pb zircon ages of 2662 Ma and 2668 Ma respectively. They yield a single component remanence which defines a paleopole for the ~ 2665 Ma position of the APWP at 16°E , 20°S ($D_p = 12^{\circ}$, $D_m = 18^{\circ}$). The third paleopole (GD) comes from the NNW-trending diabase dikes. They give a position of 57°E , 41°N ($D_p = 7^{\circ}$, $D_m = 14^{\circ}$) which agrees with poles determined from the Matachewan and Hearst dike swarms elsewhere. This result shows that a tectonically stable craton existed since the time of intrusion at 2633 Ma and also improves the precision of the 2633 Ma Matachewan pole on the APWP. These results, when compared to paleomagnetic data from the eastern side of the Kapuskasing Structural Zone, also imply relatively little tectonic rotation or translation between the Wawa and Abitibi Subprovinces.

Rapakivi textures of central Minnesota

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Crystalline rock samples were collected from the mapped St. Cloud red granite. The K-spar megacrysts, about 0.5 to 3 cm across, have rims like the commonly described rapakivi texture. In a hand sample there are euhedral megacrysts showing little fracturing and subhedral or ovoidal megacrysts with extensive fracturing, but both types have an easily observable rim on about fifty percent of the megacrysts.

The rim of the fractured megacrysts is composed of K-spar crystals not in optical continuity with the rest of the megacryst. The rim, in some cases, has an outline made by biotite that is mostly outside the K-spar rim but is included in small parts. The rim is frequently made up of many crystals with groundmass between individual crystals.

The rim of the euhedral megacrysts is also composed of K-spar crystals. Its main differences from the anhedral rims are that the optical continuity is better and not as much groundmass occurs.

There are inclusions in both the fractured and euhedral megacrysts of quartz, biotite, plagioclase, K-spar relics, and chlorite. The most interesting inclusion is chlorite, without any apparent fracture along which it could grow. The groundmass about the megacrysts contains quartz, biotite, plagioclase, K-spar, chlorite, and other small crystals not yet identified.

At this time we are looking at rapakivi from the Wolf River Batholith for comparison purposes.

A review of the
LaSalle Falls massive sulphide prospect

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The LaSalle Falls massive sulphide prospect is located at the LaSalle Falls (Pine Rapids) on the Pine River, Florence County, northeastern Wisconsin. The prospect occurs within a graphitic slate in the Quinnesec Formation (Early Proterozoic), near the contact between felsic tuffs to the north, and mafic flows to the south. Topping directions based on pillow structures are equivocal (Dutton, 1971).

Petrographic and geochemical analysis for both major and trace element oxides, indicate that the Quinnesec Formation in the study area is comprised of tholeiitic basalts (some komatiitic) and calc-alkaline andesites and dacites, with minor gabbro sills and volcanogenic sediments locally present. Just to the south of the prospect, rocks of the Dunbar dome have intruded the Quinnesec Formation. All units in the region have been metamorphosed to amphibolite facies. A penetrative NW-SE foliation is present, along with local secondary folds and shear zones. Secondary fold axes and outcrop data indicate that the area has been isoclinally folded, possibly as a result of movement along the Niagara Fault Zone, which is less than two miles north.

Drill cores from near the prospect as well as outcrop data approximately three miles to the northwest indicate that the mafic and felsic rocks are often interbedded. Trace element data on units in an area approximately three miles to the northwest suggests the possibility that mineralization is greater there than at LaSalle Falls. Thus the possibility exists that if there is a massive sulphide deposit in the area, it is more likely to occur there.

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Fluid induced structures in Quetico metasediments,
northern Ontario

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Sediment dewatering and fluidisation phenomena, including pillars and hydraulic fracture and vein structures, have been identified within low grade metamorphosed sedimentary strata of the Quetico Subprovince. The structures are contained within size graded and ungraded lithic and feldspathic wackes that form a 60 Km thick, steeply dipping, probably thrust imbricated, northwards younging sequence. These strata occur within and south of the Beardmore-Geraldton Belt.

Early dewatering structures are common within the sediments, such as flames, convolute lamination, and pillars. The pillars are remarkable for their size and shape, occurring as parabolic or bell-shaped structures up to 2 m across. Fluidisation of slightly laminated strata within the structure and a contemporaneous doming over it, indicate a pre-lithification age for the structures. Concentration of phyllosilicates occurs both within the pillars as cirrus-shaped wisps, and around the margins of most pillars.

Intermittent, structurally controlled fluid flow through rocks may also be responsible for the initiation of bedding concordant breccia zones, listric structures, and quartz veins. These structures developed during or after the imposition of a weak regional cleavage. Mean bedding and cleavage orientations both trend easterly, dipping steeply. Quartz-filled extension fractures along both planar fabrics represent an early tectonic phase of fluid-enhanced brittle failure. These veins have been deformed by a subsequent episode of dextral ductile shearing that focussed on weak, pelitic units in the wacke sequence. Cutting this deformation fabric are bedding-parallel breccia zones consisting of centimetre, or smaller, unoriented fragments set in a pelitic or vein quartz matrix. The breccias maybe up to 20 cm thick and extend for up to 20 m along bedding strike, sometimes terminating as quartz veins or as subtle listric discontinuities.

The structures described indicate a protracted history of dewatering during compaction and subsequent deformation of this enormous pile of sediment. They are similar to structures found within recently drilled accretionary prisms.

Evidence for Widespread Basement Decollement Structures and Related
Crustal Asymmetry Associated with the Western Limb of the Midcontinent
Rift

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A magnetotelluric (MT) survey (180 km long, 18 stations) across the exposed Midcontinent Rift (MCR) and associated adjacent crust indicate that a major south to southeasterly dipping conductive unit is present on the western off-rift (WOR) margin in Minnesota [1]. The conductive unit seen dipping beneath the WOR has been followed in the MT data and in compatible controlled-source audiofrequency MT (CSAMT) data [2, 3]. The conductive unit has been traced to the surface along the northern edge of the McGrath Gneiss, at the southern edge of the Animikie basin. This suggests that the conductive unit correlates to Animikie basin rocks, and the upper contact of this unit represents a major decollement in which Archean McGrath Gneiss has been emplaced over Lower Proterozoic Animikie basin rocks. Near the western edge of the MCR the deepening conductive unit appears to thin or die out. Thus near the western edge of the MCR, the inferred decollement may either attenuate, be offset by Keweenaw faults, or it may continue into the MCR as a structure too thin or resistive to be resolved with this method.

Geologic evidence supports a decollement along the southern margin of the Animikie basin consistent with the MT and CSAMT data and the interpretation discussed above. Some structural interpretations in the Thomson Formation of the Animikie basin suggest an early Penokian south dipping nappe fold or thrust occurs there [4, 5, 6], just east of where the surface trace is observed in the CSAMT data. A decollement is also consistent with other observations: a) metamorphic grade and deformation increase toward the southwestern margin of the Animikie basin adjacent the proposed decollement [7], and b) inclusions in Late- to post-Penokian igneous stocks [7] located south and south-east of the surface trace of the decollement contain inclusions of rocks which are petrologically similar to rocks of the Thomson Formation of the Animikie basin [7], suggesting that these sediments are present at depth.

In contrast to the WOR where the decollement is the chief complexity, the eastern off-rift (EOR) MT data across the MCR in Wisconsin indicate the crust is lithologically and structurally complex to depths of tens of kilometers. The central MCR itself appears as an elongate plateau or horst and MT results are consistent with a body consisting of multiple mafic igneous intrusive sheet dikes overlain by a basaltic pile. Resolution of the deep roots of the MCR from the surrounding crust is difficult with available data.

Proprietary Iowa MT data [8] (specific location undisclosed), traverse the MCR with one site on each off-rift margin. The MT data east and west of the MCR in Iowa appear analogous to those obtained along the off-rift margins to the north on the EOR and WOR respectively. For example, the one available site west of the rift in Iowa shows a

nearby intrabasement conductive zone, Further studies are indicated but the conductive zone could be caused by decollement in a situation similar to the WOR in Minnesota. The Iowa MT site east of the rift again reflects extreme crustal complexity. COCORP data in Kansas [9, 10] (COK) show a prominent continuous east dipping feature in the basement to the west of the MCR which extends at least to the main rift axis. This structure has been interpreted as: 1) "... a low angle detachment similar to those seen in the Basin and Range..." or 2) "... a sill similar to the Duluth Gabbro in Lake Superior..." [9]. Again, east of the rift, extreme crustal complexity is seen in COK data [10] similar to the EOR MT data discussed above. The EOR complexity is consistent with Alpine nappes or the roots of island arcs [10] in both the COK and the MT data.

The decollement and observed crustal asymmetry in the MT and COK data are here interpreted to suggest that a Penokian continental margin preceded the emplacement of the MCR and that the younger rift structure is essentially a tectonic reactivation of this structure. If decollement and crustal asymmetry are indeed present and widespread this would be quite compatible to recent models of Phanerozoic rift genesis [11].

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Kremzar Gold Deposit, District of Algoma
CANAMAX Resources Inc. - Kremzar Gold Mines Ltd.

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Drill indicated geological reserves at the CANAMAX - Kremzar Gold Mines Ltd. gold deposit are calculated at 932,000 tonnes grading 8.6 grams gold per tonne in five subparallel mineralized zones, based on results of diamond drilling prior to September 1986. Additional recent drill results to the west confirming continuity of the 'B' Horizon have not been included.

In 1940, O'Brien Gold Mines, operators of the then producing Cline Lake Gold Mine, outlined 64,000 tonnes of gold mineralization grading 7.9 g Au per tonne in 17 drill holes on the 'New Zone'. Since the fall of 1984, CANAMAX's evaluation of the 'New Zone' gold bearing structure has expanded reserves substantially. In the fall of 1985 an underground exploration program was initiated, based on drill indicated geological reserves of 790,000 tonnes grading 7.9 grams gold per tonne. Results of the underground exploration program showed excellent correlation with the earlier drill results.

Auriferous quartz veins within mafic metavolcanics on the Kremzar project are localized within NW and NE striking biotitized shear zones. Mineralized veins are composed mainly of cherty blue-grey quartz, K-spar, and sericite. Accessory minerals include pyrite, pyrrhotite, biotite, chlorite, carbonate, and very fine free gold. Native gold occurs mainly as very fine free gold "dust clouds", as fine individual specks, and on the boundaries of fine anhedral to subhedral pyrite grains. The majority of the gold is restricted to 2nd order sigmoidal veins oblique to the shear zone, that dip vertically, and plunge to the NW within the shear zone structure. This deposit has formed in a ductile-brittle shear zone environment with strong but restricted wallrock alteration. All observations have been from hand samples, from drill core, and from detailed underground investigations.

On display will be a typical section of drill core and its corresponding drill section, a longitudinal section, and plan of the deposit, as well as hand samples.

Structurally hosted vein type gold mineralization, Goudreau - Lochalsh
gold camp, District of Algoma

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Since CANAMAX Resources Inc., commenced the search for gold mineralization in the Wawa greenstone terrane, gold has been noted to be hosted within major and minor structures transecting all lithologies, except the late Keweenawan diabase dike swarm. It also became apparent that the Goudreau-Lochalsh area hosted the major criteria for gold deposits. In 1983 CANAMAX entered into joint-venture agreements with Algoma Steel Corporation and with Kremzar Gold Mines Ltd., a subsidiary of Algoma Steel Corporation, to explore their large land holdings in the Goudreau-Lochalsh area. CANAMAX has since defined major auriferous structures, responsible for the many gold occurrences of the area, which eluded previous workers.

The historic Goudreau-Lochalsh gold camp is on the northern flank of the Wawa greenstone terrane. The lithology of the region is typically Archean metavolcanic rocks, ranging from felsic to mafic composition, with minor, but regionally extensive, carbonate-sulphide iron formations marking the major lithologic contact.

Gold mineralization within the camp is structurally controlled by the major east-northeast trending, low angle reverse fault system referred to as the Goudreau Shear Zone, and by subsidiary minor splays and shear fractures that transect all rock units except the late Keweenawan diabase dikes. Lithologies found to host these gold bearing structures include mafic and felsic volcanics, felsic intrusives, and sulphide-carbonate iron formation.

Hydrothermal alteration of these structurally prepared conduits is also essential for gold mineralization. Wallrock alteration includes potassic metasomatism (i.e. the biotization of the mafics and sericitization of the felsics), silicification, carbonatization, chloritization, and sulphidization (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, and sphalerite).

The Goudreau Shear Zone, a major zone of low angle reverse faulting, is host to the Magino-Muscocho gold deposit. Splays of the Goudreau Shear Zone, trending northwest at 35 - 45 degrees to the structure, host several other gold occurrences, namely the CANAMAX-Kremzar gold deposit, the Cline Lake past producer, and the Markes prospect. These northwest trending splays appear to have an extensional component, suggested by thrust movement on the Goudreau Shear Zone, allowing for a larger dilatancy of the splays, and thus widths, and therefore tonnage potential. Minor conjugate northeast trending splay structures such as Zones 2 and 3 on the Kremzar property are also auriferous. These minor structures are consistently narrow, and thus have lower tonnage potential. A compressional component of the major Goudreau Shear Zone may be responsible, making the minor splays a tighter structure.

This exhibit will illustrate the structurally controlled gold mineralization which transects all the various lithologies within the gold camp and the resulting hydrothermal alteration assemblages.

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