



**Institute on Lake Superior Geology
Thirty-First Annual Meeting**

KENORA, Ontario

May 6-11, 1985



ABSTRACTS

TECHNICAL SESSIONS
AND
ABSTRACTS
FOR THE
31ST ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

HELD AT
INN OF THE WOODS
KENORA, ONTARIO

MAY 8, 9, 1985

IN CO-OPERATION WITH THE
RESIDENT GEOLOGIST OFFICE, KENORA

AND THE
ONTARIO GEOLOGICAL SURVEY,
ONTARIO MINISTRY OF NATURAL RESOURCES

PROGRAM CHAIRMAN AND EDITOR

C. E. BLACKBURN

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COVER PHOTO; Sultana Mine (circa 1898);
 Courtesy of Lake of the Woods
 Museum, Kenora

INSTITUTES ON LAKE SUPERIOR GEOLOGY

<u>INSTITUTE 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, Ont. (Thunder Bay)
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	Hosted by Wisconsin GS

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

April 4, 1981

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

RECIPIENTS

1979 Sam Goldich
1981 Carl Dutton
1982 Ralph Marsden

1983 Burton Boyum
1984 Richard Ojakangas
1985 Paul Sims

REPORT OF THE CHAIRMAN
30th INSTITUTE ON LAKE SUPERIOR GEOLOGY
1984

The 30th Annual Institute on Lake Superior Geology was held April 24-28, 1984 at the Holiday Inn of Wausau, Wisconsin. Conference registration was 220, including professional geologists and students. The program consisted of one pre-meeting and two post-meeting field trips and two days of technical papers. The two-day or pre-meeting trip I to show features of the Dunbar gneiss-granitoid dome and associated Early Proterozoic volcanic rocks in northeastern Wisconsin, led by P.K. Sims, K.J. Schulz, and Z.E. Peterman, had approximately 60 participants. The post-meeting trip II "Early Proterozoic Tectonostratigraphic Terranes of the Southern Lake Superior Region", led by D.K. Larue, had approximately 25 participants, and field trip III "Geology of the Wausau Syenite Complex", led by P.E. Myers, had approximately 12 participants. The technical sessions consisted of 51 papers, of which 13 were poster presentations. One full day of the technical sessions was devoted to papers on the Early Proterozoic of the Lake Superior region. Proceedings of the conference were published in four separate volumes; abstracts and each of the field trip guidebooks.

The annual banquet was held on April 26th, 1984, and was attended by approximately 100 people. William F. Cannon presented the qualifications of the Goldich Medal recipient, and the Medal was presented to Richard Ojakangas by Sam Goldich. The banquet address "The Ore Metals in Earth History" was presented by Dr. Charles Meyer of Sedona, Arizona. The address contained a wealth of information on the nature and evolution of ore deposit types.

Two student paper awards of \$150.00 each were presented this year, one each for poster and oral presentation. Christopher A. Scholz, from the University of Minnesota-Duluth received the award for the best poster presentation for his paper "Late and Post-glacial Lacustrine Sediment Distribution in Western Lake Superior from Seismic Reflection Profiles", and Warren Beck, from the University of Minnesota-Twin Cities, received the best student oral presentation for his paper "Nd and Sm Isotopic Studies of the Quinnesec and Hemlock Formations in Northeastern Wisconsin and Adjacent Michigan". The awards were presented by Val W. Chandler, Chairman of the Student Paper Awards Committee.

The Board of Directors of the Institute met on April 26, 1984. Present at the meeting were: G.L. LaBerge (Chairman), T.J. Bornhorst, D.L. Southwick, F.W. Cambray, P.E. Myers, J. Kalliokoski (Secretary-Treasurer) and C.E. Blackburn (incoming Chairman for 1985). The Board took the following action:

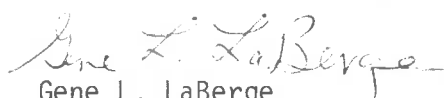
1. Accepted the invitation by Charles Blackburn of the Ontario Geological Survey to hold the 1985 meeting in Kenora, Ontario.
2. Tentatively accepted the invitation of the Wisconsin Geological Survey to hold the 1986 meeting in Wisconsin.

3. A motion by Kalliokoski, second by Bornhorst, that for financial reasons the Institute discontinue paying the expenses of the recipient of the Goldich Medal.
Passed unanimously.
4. Conference registration should include a \$1.00 per person charge to maintain the Goldich Medal account. The funds will be used to strike the medals as the need arises.
5. Replace Richard Buchheit on the Goldich Award Committee with another Member from Industry. Willard Bodwell agreed to serve a three-year term. The Committee for 1985 will be William F. Cannon (U.S.G.S.), Chairman; M.F. Kehlenbeck, and Bodwell.
6. Send a list of recipients of the Goldich Medal to the incoming Chairman to be included in the Proceedings volume.

I would like to extend a bit of hard-earned advice to future Institute Chairmen. The high cost of printing and binding abstract volumes and guidebooks necessitates that we do not print many extra copies (I did). In doing so we tie up the Institute's resources in printing costs that probably will not be recouped. So my advice is to print only a few dozen extra copies of the guidebooks and abstracts.

Serving as Institute Chairman has been a major learning experience. It has been both a lot of work and very rewarding. The willingness of colleagues in the Lake Superior region to serve on the various committees, chair sessions, lead field trips, etc., made my job much easier, and I am grateful for the cooperation of so many individuals.

Respectfully submitted,


Gene L. LaBerge
Chairman 30th Annual I.L.S.G.
Oshkosh, WI
May 21, 1984

INSTITUTE BOARD OF DIRECTORS

- C. E. Blackburn, Resident Geologist, Ministry of Natural Resources,
808 Robertson St., Kenora, Ontario, P9N 3X9 (1985)
- G. L. LaBerge, Department of Geology, University of Wisconsin-Oshkosh,
Oshkosh, Wisconsin, 54901 (1984)
- T. J. Bornhorst, Department of Geology and Geological Engineering,
Michigan Technological University, Houghton, Michigan, 49931 (1983)
- D. L. Southwick, Minnesota Geological Survey, 2642 University Avenue,
St. Paul, Minnesota, 55114 (1982)
- F. W. Cambray, Department of Geology, Michigan State University,
East Lansing, Michigan, 48824 (1981)
- J. Kalliokoski, Department of Geology and Geological Engineering,
Michigan Technological University, Houghton, Michigan, 49931
(Secretary-Treasurer)

Copies of the abstract and field guidebook
volumes may be purchased from:

M.M. Kehlenbeck
Department of Geology
Lakehead University
Thunder Bay, Ontario
P7V 5E1

Costs:

Abstracts \$5.00
Field Guidebook \$10.00
(plus \$2.00 postage and handling charges)

Make cheques payable to:
Institute on Lake Superior Geology

LOCAL COMMITTEE

C. E. Blackburn: Conference Chairman, and Technical Sessions

R. C. Beard: Treasurer

J. Parker: Registration

C. C. Storey: Poster Session

M. R. Hailstone: Field Trip Logistics

All at Ministry of Natural Resources, 808 Robertson Street,
Kenora, Ontario

BEST STUDENT PAPER COMMITTEE

Gene LaBerge, Chairman, Department of Geology, University of Wisconsin,
Oshkosh, Wisconsin

Graham Borradaile, Department of Geology, Lakehead University,
Thunder Bay, Ontario

Klaus Schulz, United States Geological Survey,
Reston, Virginia

GOLDICH MEDAL COMMITTEE

W. F. Cannon, Chairman, United States Geological Survey,
Reston, Virginia

M. M. Kehlenbeck, Department of Geology, Lakehead University,
Thunder Bay, Ontario

Willard Bodwell, Resource Exploration,
Marquette, Michigan

FIELD TRIP LEADERS

David R. Melling, Ottawa-Carleton Centre for Geoscience Studies,
Carleton University, Ottawa, Ontario

David H. Watkinson, Ottawa-Carleton Centre for Geoscience Studies,
Carleton University, Ottawa, Ontario

John C. Davies, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

P. Mark Smith, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

Charles E. Blackburn, Ministry of Natural Resources
808 Robertson St., Kenora, Ontario

Gary P. Beakhouse, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

Glen W. Johns, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

Fred W. Breaks, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

Howard K. Poulsen, Geological Survey of Canada, 601 Booth St.,
Ottawa, Ontario

Don A. Janes, Ministry of Natural Resources, Court House Building,
Sioux Lookout, Ontario

Richard C. Beard, Ministry of Natural Resources, 808 Robertson St.,
Kenora, Ontario

SESSION CHAIRMEN

Richard W. Ojakangas, Geology Department, University of Minnesota,
Duluth, Minnesota

John Wood, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

LeRoy Warren, Department of Natural Resources,
Hibbing, Minnesota

Joop Langelaar, Norontex Exploration Ltd., Bedworth Road,
Dryden, Ontario

Henry Lepp, Geology Department, Macalaster College
St. Paul, Minnesota

William H. McIlwaine, Ministry of Northern Affairs, 435 James St. South,
Thunder Bay, Ontario

Jack Everett, Consulting Geologist, 1015 North Shore Drive,
Duluth, Minnesota

Michael E. Cherry, Ontario Geological Survey, 77 Grenville St.,
Toronto, Ontario

GOLDICH MEDAL RECIPIENT

Paul K. Sims United States Geological Survey, Denver Federal Centre,
 Denver Colorado

ANNUAL BANQUET SPEAKER

Grant M. Young, Department of Geology, University of Western Ontario,
 London, Ontario

TECHNICAL SESSIONS

Asterisk denotes student papers
Speakers are underlined

SESSION 1

Morning

Wednesday, May 8, 1985

Co-chairmen: Jack Everett and Henry Lepp

8:15		Opening Remarks
8:20	* T. Chartier	The texture and mineralogy of the Lake Ellen kimberlite, Crystal Falls, Michigan, U. S. A.
8:40	<u>J. J. Mancuso & C. W. Schick</u>	Unconformity-type uranium mineralization at the Groveland Iron Mine, central Dickinson County, Michigan.
9:00	* C. L. Reichhoff	Geology of a Lower Proterozoic volcanoclastic sequence, Marathon County, Wisconsin.
9:20	<u>J. S. Klasner & G. L. LaBerge</u>	Structural geology and kinematics of Early Proterozoic shear zones in central Wisconsin.
9:40	P. A. Nielsen	Metamorphism of the Dunbar Gneiss and associated supra-crustal rocks: northeastern Wisconsin, U. S. A.
10:00		Coffee.
10:40	<u>G. M. Young & H. W. Nesbitt</u>	Major element geochemistry of the Gowganda Formation, Ontario.
11:00	* R. C. Johnson	Documentation of a subaqueously emplaced volcanic horizon in the upper Portage Lake Volcanics, Keweenaw Peninsula, Michigan.
11:20	<u>J. Kalliokoski & E. J. Welch</u>	Caliche paleosol in the lower part of the Calumet and Hecla Conglomerate, Centennial Mine, Calumet, Michigan.
11:40	<u>W. C. Hood & P. J. Vanstone</u>	Economic geology of the rare element pegmatites at Lilypad Lake, northern Ontario.
12:00		Lunch.

S E S S I O N 2

Afternoon

Wednesday, May 8, 1985

Co-Chairmen: R. W. Ojakangas and John Wood

- | | | |
|------|---|--|
| 2:00 | <u>R. L. Morton,</u>
D. A. Groves, &
J. M. Franklin | Volcanic stratigraphy and nature of the semi-conformable alteration zone beneath the Mattabi massive sulphide deposit, Sturgeon Lake, Ontario. |
| 2:20 | M. M. Kehlenbeck | Structure of the Beardmore-Geraldton fold belt. |
| 2:40 | M. J. Lavigne | Geological setting of gold mineralization in Beardmore-Geraldton. |
| 3:00 | <u>P. W. Fralick &</u>
<u>B. M. Scott</u> | Controls on the genesis of epigenetic auriferous vein systems in Archean chemical-siliciclastic submarine fan deposits, Geraldton area, Ontario. |
| 3:20 | | Coffee. |
| 3:50 | H. G. Clark | Preliminary metallogenic subdivision of the Lake of the Woods metavolcanic-metasedimentary belt, northwestern Ontario. |
| 4:10 | <u>M. G. Parr &</u>
<u>C. Boben</u> | The geological setting of gold mineralization observed at the Scramble Mine, District of Kenora, N. W. Ontario. |
| 4:30 | *J. Stix | Volcanic facies of the Andrew Bay area, Lake of the Woods, Ontario. |
| 4:50 | B. A. Brown | The deformational history of Archean greenstones in the Central Lake of the Woods area, northwestern Ontario. |

S E S S I O N 3

Morning

Thursday, May 9, 1985

Co-chairmen: Joop Langelaar and LeRoy Warren

8:15		Opening Remarks
8:20	<u>J. C. Green & V. W. Chandler</u>	Keweenawan dikes of Minnesota.
8:40	<u>M. G. Mudrey & P. E. Myers</u>	Proterozoic diabase dike swarms in Wisconsin.
9:00	<u>T. B. Holst, E. E. Mullenmeister & J. C. Green</u>	Keweenawan structural features at the base of the Duluth Complex in the Dunka Pit near Babbitt, Minnesota.
9:20	*J. D. Miller	Petrogenesis of anorthositic rocks of the Duluth Complex.
9:40	J. T. Wilband	Magmatic processes during the Midcontinent Rift interval in northern Michigan: chemical and isotopic constraints.
10:00		Coffee.
10:40	<u>D. W. Davis & G. R. Edwards</u>	Evolution of an Archean igneous complex from high precision U-Pb geochronology: the Kakagi Lake area, N. W. Ontario.
11:00	J. A. Percival	Metamorphism and plutonism in the Quetico belt, N. W. Ontario.
11:20	R. H. Sutcliffe	Mulcahy Lake gabbro: a well-preserved Archean layered intrusion.
11:40	<u>D. A. Morrison W. C. Phinney, & D. E. Maczuga</u>	The Mulcahy Lake gabbro and related intrusions.
12:00		Lunch.

S E S S I O N 4

Afternoon

Thursday, May 9, 1985

Co-chairmen: W.H. McIlwaine and M.E. Cherry

- | | | |
|------|---|---|
| 1:30 | <u>E. O. Owens</u> &
<u>T. J. Bornhorst</u> | Geology of Precambrian-hosted precious metal prospects in the Fire Center and Holyoke mines area, Marquette County, Michigan. |
| 1:50 | *J. D. Vervoort | Geology of the Jap Lake area of the eastern Vermilion district, northeastern Minnesota. |
| 2:10 | R. L. Bauer | Multiphase fold geometry along the southeastern margin of the Vermilion Granitic Complex, northeastern Minnesota. |
| 2:30 | <u>T. L. Lawler</u> &
<u>J. M. Sellner</u> | Ranier, Minnesota, Mineral potential evaluation: outcrop sampling, geophysics and soil geochemistry. |
| 2:50 | <u>D. Ela</u> &
<u>P. Hudleston</u> | The significance of strain patterns in deciphering the deformational history of Archean rocks in the Vermilion district, Minnesota. |
| 3:10 | | Coffee |
| 3:35 | | Announcement of best student papers. |
| 3:40 | M. T. Corkery | Stratigraphic and structural evolution of the Cross Lake supracrustal belt in northwestern Superior Province, Manitoba. |
| 4:00 | <u>E. P. Moreton</u> &
<u>R. Gerber</u> | Stratigraphy and hydrothermal alteration in an Archean structural zone, the Katisha Lake area, Wabigoon Subprovince, N.W. Ontario. |
| 4:20 | <u>B. J. Christie</u> &
<u>C. J. Hodgson</u> | Alteration and gold mineralization associated with a sheeted veinlet zone at the Campbell Red Lake Mine, Balmertown, Ontario. |
| 4:40 | <u>P. M. Berger</u> ,
<u>J. M. Dixon</u> &
<u>H. Helmstaedt</u> | Structural geology of northern Dome and southern McDonough Townships, Red Lake, Ontario. |

POSTER PRESENTATIONS

Tuesday, May 7	4:00 - 10:00 p.m.
Wednesday, May 8	8:15 - 5:00 p.m.
Thursday, May 9	8:15 - 5:00 p.m.

- | | |
|--|---|
| C. Anderson | Correlation of nearly continuous magnetic profiles to lithology: case histories. |
| D. T. Anderson | Remote sensing application in the Cameron Lake Area, N.W. Ontario. |
| T. D. Browning,
S. Beske-Diehl,
J. Diehl, &
T. J. Bornhorst | Age of copper mineralization in the flow tops of the Portage Lake Lava Series determined by paleomagnetic methods. |
| *G. T. Burgess | Chemical characterization and petrogenesis of Keweenawan diabase dykes of Northern Michigan. |
| K. D. Card | Decade of North American Geology (D-NAG) geological and tectonic maps of the south-eastern Canadian Shield. |
| F. Corfu &
G. M. Stott | U-Pb geochronology and tectonic history of the Shebandowan belt, northwestern Ontario. |
| F. Corfu,
G. P. Beakhouse,
G. M. Stott &
R. H. Sutcliffe | U-Pb geochronology and tectonic history of the Winnipeg River granitoid terrain, northwestern Ontario. |
| *S. E. Crissman | Geochemical constraints on the REE distribution in the Neganee Iron Formation of the Empire Mine, Palmer, Michigan. |
| R. M. Easton | Anomalous radiometric ages from the Superior Province, Ontario: sense? or non-sense? |
| T. Fitz &
J. C. Green | Large ignimbrites in the Keweenawan North Shore Volcanic Group in Cook County, Minnesota. |
| *J. W. Gell | Geochemistry of the Powder Mill Group: the earliest lavas of the Midcontinent Rift in Michigan. |
| H. P. Gilbert | Stratigraphic evolution of the Island Lake greenstone belt, Manitoba. |
| J. K. Greenberg &
B. A. Brown | The central Wisconsin Archean block: new evidence suggests a partially reworked granite/greenstone terrane. |
| G. W. Johns | Facies interpretation of the Berry River formation, Lake of the Woods. |

- * W. J. Johnson The petrology and sedimentation of the Lower Proterozoic Barron Quartzite, northwestern Wisconsin.
- T. L. Lawler &
J. M. Sellner Ranier, Minnesota, mineral potential evaluation: outcrop sampling, geophysics and soil geochemistry.
- * E. K. Linscheid The petrology of the Longnose Peridotite deposit and its relationship to the Duluth Complex.
- * J. R. Lundy Minor folds in the Soudan Iron Formation, northeastern Minnesota.
- A. D. MacTavish &
R. J. Dutka The Atikokan cobalt-base metals-platinum group elements project.
- * M. P. McDermott Chemical characterization of the Unnamed Formation, a central volcanic complex of Keweenaw age.
- D. R. Melling,
D. H. Watkinson,
L. B. Chorlton, &
K. H. Poulsen The influence of shear zone geometry and vein paragenesis on gold-pyrite mineralization at Cameron Lake, northwestern Ontario.
- E. Mullenmeister,
T. B. Holst, &
J. C. Green Structural analysis of the northeastern Mesabi Range and adjacent basal Duluth Complex.
- J. B. Paces &
T. J. Bornhorst Geology and geochemistry of lava flows within the Copper Harbor Conglomerate, Keweenaw Peninsula, Michigan.
- H. C. Palmer &
H. C. Halls The paleomagnetism of the Powder Mill Group: its relevance to correlation with other Keweenaw sequences and to tectonic development of the South Range.
- * E. E. Peterson The tectonic significance of the Porphyritic Red Granite, Dickinson County, Michigan.
- * B. A. Ross Petrogenesis of the Bardon Peak peridotite, Duluth Complex.
- T. Sabelin Platinum group element minerals in the Duluth Complex.
- W. A. Schleiss,
T. J. Bornhorst, &
A. P. Ruotsala A study of vein mineralization and wall rock alteration at the Delaware Mine, Keweenaw County, Michigan.
- P. M. Smith The geological setting at the Duport Mine, Cameron Island, Shoal Lake.

- M. M. Swan,
S. B. Keith, &
M. G. Parr
- Magma series and their relationship to
greenstone gold metallogeny in the
Lake Superior Region.
- K. Thomson &
D. Gliddon
- The Hemlo baritic horizon; a possibly
syngenetic Archean barite occurrence.
- J. L. Welsh
- Preliminary investigations into the geology
of the Giants Range Complex, Virginia-
Biwabik area, N. E. Minnesota.
- * S. F. Wright
- Strain patterns in the Kiruna district,
northern Sweden; implications for
Proterozoic deformation.

ABSTRACTS

CORRELATION OF NEARLY CONTINUOUS MAGNETIC PROFILES TO LITHOLOGY - CASE HISTORIES

DR. CHRIS ANDERSON, DEPT. OF EARTH SCIENCES
UNIVERSITY OF MANITOBA, WINNIPEG

A RESEARCH PROJECT RELATING LITHOLOGY TO MAGNETIC MEASUREMENTS ALONG PROFILES WITH A STATION SPACING OF THE ORDER OF ONE METRE HAS BEEN CONDUCTED BY THE AUTHOR OVER THE LAST DECADE. PROJECTS HAVE BEEN COMPLETED AT A NUMBER OF LOCATIONS ACROSS CANADA AND PATENTS OBTAINED ON INSTRUMENTATION FOR RAPID DATA ACQUISITION.

IN THIS PRESENTATION RESULTS WILL BE SHOWN FROM (1) THE FALCON LAKE STOCK, BETWEEN THE INTERMEDIATE INTRUSIVE AND THE METAVOLCANIC HOST ROCKS, (2) THE EUCLID LAKE CHROMITE DEPOSIT WITH THE PROFILE DATA COVERING METAVOLCANICS, MAFIC, ~~AND~~ ULTRAMAFIC INTRUSIONS, AND (3) THE BIRD RIVER SILL WHICH IS A LAYERED BASIC TO ULTRAMAFIC INTRUSIVE. THESE SITES ARE ALL LOCATED IN SOUTH-EASTERN MANITOBA.

THESE DATA SHOW VARIATIONS OF BOTH POSITIVE AND NEGATIVE VALUES UP TO SEVERAL THOUSAND GAMMAS (NANO TESLAS) WITH SOME ANOMALY WIDTHS OF ONLY A FEW METRES. THESE VARIATIONS CAN BE RELATED DIRECTLY TO THE OBSERVED LITHOLOGY.

REMOTE SENSING APPLICATION IN THE CAMERON LAKE AREA, N.W. ONTARIO

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THE CAMERON LAKE AREA IS OF CONSIDERABLE INTEREST BECAUSE OF THE ACTIVE REGIONAL GOLD EXPLORATION BEING CARRIED OUT. A VARIETY OF TECHNIQUES HAS BEEN APPLIED IN PARTS OF NORTHERN MANITOBA WHEREBY SPECTRAL AND GEOPHYSICAL REMOTE SENSING DATA HAVE BEEN INTEGRATED WITH MAPPED GEOLOGY TO ASSIST IN THE INTERPRETATION OF THE STRUCTURE AND LITHOLOGY OF AN AREA.

A SIMILAR PROCEDURE HAS BEEN APPLIED TO THE CAMERON LAKE AREA. TO THIS END, THE AVAILABLE AERIAL PHOTOGRAPHS HAVE BEEN EXAMINED AND A PHOTOLINEAMENT TREND MAP PRODUCED. THE AVAILABLE GEOPHYSICAL SURVEY DATA HAVE BEEN EXAMINED AND AN ANALOGOUS LINEAMENT TREND MAP PRODUCED. MULTISPECTRAL AND MULTITEMPORAL LANDSAT DATA HAVE BEEN EXAMINED USING BOTH THE PHOTOGRAPHIC IMAGERY AND THE DIGITAL INFORMATION, AND YET ANOTHER ANALOGOUS TREND-LINE MAP PRODUCED. THESE THREE LINEAMENT MAPS HAVE BEEN SUPERIMPOSED ON ONE ANOTHER, AND UPON THE AVAILABLE GEOLOGICAL MAPS OF THE AREA. IT CAN BE SEEN THAT A HIGH DEGREE OF USEFUL CORRELATION EXISTS BETWEEN THESE DATA. THIS STUDY CONSISTED OF "MANUAL" CORRELATION OF THE DATA, BUT AUTOMATIC CORRELATION SHOULD ALSO BE POSSIBLE. TIME AND EQUIPMENT CONSTRAINTS PRECLUDED DIGITAL CORRELATION AT THIS TIME.

THE VALUE OF SUCH INTEGRATION LIES IN THE RAPID OVERVIEW THAT IS POSSIBLE. THE CLOSE CORRELATION SUGGESTS THAT SPECTRAL AND GEOPHYSICAL REMOTE SENSING INTERPRETATION MAY GIVE VALUABLE INSIGHTS INTO EXPLORATION METHODOLOGY, EVEN IN THOSE AREAS WHERE DETAILED GEOLOGICAL MAPPING IS NOT AVAILABLE. FURTHERMORE, IT MAY DIRECT THE GEOLOGICAL MAPPING TO CRITICAL AREAS WHERE THE ELUCIDATION OF THE STRUCTURAL STYLE MIGHT MOST READILY BE DERIVED.

Multiphase Fold Geometry Along the Southeastern
Margin of the Vermilion Granitic Complex,
Northeastern Minnesota

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The Archean schist and migmatites along the southern margin of the Vermilion Granitic Complex (VGC), south of the Lac La Croix Granite, have undergone three periods of regional folding which are differentially developed and decipherable in various portions of the terrane. A pervasive S_1 foliation in the schist is generally parallel to bedding (S_0) except in the hinges of rare minor F_1 folds. Local graded bedding indicates a downward-eastward structural facing in the S_2 foliation. We have interpreted this facing and reversals in facing in the Vermilion district to be a result of regional F_1 folding (Bauer and Hudleston, 1982).

D_2 produced the most prominent fold structures (F_2), including a major westerly plunging antiform along the boundary of the Vermilion Granitic Complex and the Vermilion district to the south. This east-west trending boundary, marked by strike-slip and dip-slip faulting on the Vermilion and Haley faults, follows the axial surface trace of the antiform. Large-scale parasitic folds on this structure are invariably of S symmetry in the southern VGC and occur on the northern limb of the antiform. These folds are correlated with F_2 folds of Z symmetry that occur in the Vermilion district on the southern limb of the antiform.

The orientation of F_2 fold hinges and coaxial L_2 lineations are relatively constant in the VGC along the boundary with the Vermilion district, but in the Burntside Lake area, large-scale F_2 parasitic folds are strongly noncylindrical, and F_2 and L_2 vary from SW to NE plunging within the local S_2 axial surface. This local noncylindricity is attributed to a combination of: (1) pre- F_2 reorientation of S_0 and S_1 by intrusion of the Burntside tonalite, and (2) to late-stage F_2 synformal folding induced in part by gravitational subsidence around a dense amphibolite body.

In the Norwegian Bay block, bounded by the Haley and Vermilion faults, regional F_2 folds have been refolded by a doubly plunging, east-west-trending F_3 fold cored by the Wakemup Bay tonalite. Northwesterly plunging, F_3 , conical folds just north of the Vermilion fault also fold large-scale F_2 antiforms and synforms but are not associated with emplacement of granitic plutons such as the Wakemup Bay stock.

Relationships between folding and the various granitic rocks of the region indicate that the Burntside tonalite was emplaced prior to the initiation of D_2 ; the Lac La Croix Granite was syn- D_2 ; and the Wakemup Bay tonalite was emplaced post- D_2 , but pre- D_3 .

REFERENCES

- Bauer, R.L. and Hudleston, P.J., 1982, F_1 recumbant folding in the western Vermilion greenstone-granite terrane, NE Minnesota: Ann. Inst. Lake Superior Geol., 28th, Proc., p. 4.

STRUCTURAL GEOLOGY OF NORTHERN DOME AND
SOUTHERN MCDONOUGH TOWNSHIPS, RED LAKE, ONTARIO

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Northern Dome and southern McDonough Townships, within the Red Lake "greenstone" belt of northwestern Ontario, were mapped on a 1:1000 scale with emphasis on geological structures. Mafic to ultramafic metavolcanic rocks, felsic metavolcanic to metavolcaniclastic rocks, and clastic to chemical metasedimentary rocks, metamorphosed to greenschist grade, occur within the area. These supracrustal rocks are crosscut by felsic to intermediate intrusives, the largest being the McKenzie Island Stock.

Planar, penetrative fabric elements occur in nearly all exposures. This cleavage is parallel or at a low angle to contacts of the granitoid batholiths surrounding the belt. In the study area the fabric dips steeply and changes gradually and continuously in strike from southeast near Cochenour to northeast near Slate Bay. The cleavage resulted from bulk, inhomogeneous shortening in a horizontal direction, accompanied by near-vertical extension.

Competency contrasts between rock types resulted in the development of different structures. The cleavage is axial planar to folds within the metasedimentary layers. In contrast, the cleavage within the metavolcanic and massive metasedimentary units is crosscut by conjugate sets of shear fractures. The shear fracture planes maintain a constant orientation of 30° from the penetrative, flattening fabric and exhibit right-lateral slip along the clockwise striking fracture planes and left-lateral slip along the counterclockwise striking fracture planes. The shear zones and fractures formed in a ductile to brittle-ductile environment subsequent to the formation of the cleavage but during the same deformational event. Near Post Narrows, the left-lateral, northeast-striking fracture set is expressed as several meters-wide shear zones in the metavolcanic rocks.

Pressure shadows around contact-metamorphic garnets near the McKenzie Island Stock, and shear zones through the stock indicate that it intruded prior to or early in the deformational history.

Bedding is subparallel to the cleavage except on and southeast of McKenzie Island where bedding strikes northeast and the cleavage southeast. This geometry, along with a younging reversal without a change in strike, suggests the presence of early, pre-"main-stage" deformational folds.

All earlier structures are crosscut by a second brittle-ductile to brittle conjugate fracture set. The bisectrix of the acute angle between the conjugate pair strikes north to north-northeast. These fractures occur throughout the entire belt without a significant change in strike.

The Deformational History of Archean Greenstones
in the Central Lake of the Woods Area
Northwestern Ontario

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Four distinct deformational events have been identified in the Archean greenstones of the Central Lake of the Woods area of northwestern Ontario. These events represent distinct stages in the tectonic evolution of the region during Archean time.

The first stage (D_1) produced upright, isoclinal folds (F_1) which have shallowly plunging to nearly horizontal axes, and a penetrative axial planar foliation (S_1). F_1 folds are expressed as large scale anticlines and synclines traceable across much of the adjacent region. D_1 was accompanied by regional greenschist facies metamorphism (M_1).

The second stage, (D_2) produced steeply plunging folds and a complex pattern of ductile shear zones. The D_2 deformation was a complex event. Style, orientation, and intensity of development of D_2 structures vary widely throughout the area. At a given locality, it is common to find more than one generation of D_2 structures developed, such as F_2 folds overprinting a D_2 cataclastic zone and vice versa, suggesting that stress orientation and conditions of deformation varied through time during the D_2 event. Whereas D_1 structures were uniformly developed across the region, D_2 structures are most intensely developed in the eastern part of the area, adjacent to large and small granitic plutons.

The D_3 deformation produced kink bands which are distributed throughout the area, and clearly overprint D_1 and D_2 structures and fabrics. D_4 produced faults marked by cataclastic zones which cross both the greenstones and the adjacent granitoid rocks.

D_1 and M_1 apparently represent early regional tectonism and cannot be equated with granitoid emplacement. D_2 and localized contact metamorphism are interpreted to be the result of diapiric emplacement of the granitoid batholiths flanking the area and smaller plutons within the area. The complex geometry and sequence of D_2 structures is attributed to continually changing deformational conditions during the rise and expansion of these intrusive bodies. The origin of D_3 is obscure, but these structures may be the result of regional stress imposed during the late stages of, or following pluton emplacement. D_4 is attributed to adjustment faulting which restored isostatic equilibrium following the widespread granite emplacement during the D_2 event.

Age of Copper Mineralization in the Flow Tops of the Portage Lake Lava Series Determined by Paleomagnetic Methods

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Native copper mineralization in the Portage Lake Lava Series occurs within amygdaloidal and brecciated tops of lava flows. Rb-Sr dating indicates the age of mineralization to be around $1,051 \pm 15$ Ma (Paces, L.S.I. abstract, 1984) as compared to the 1,110 Ma age of extrusion. The relatively unaltered flow interiors contain magnetite whereas hematite is common in the mineralized flow tops (Scofield, Ph.D. thesis, M.T.U. 1976). The remanent direction associated with the magnetite is acquired during the cooling and solidification of the lavas and should be parallel to the earth's magnetic field present at that time. During mineralization of the flow tops, the original magnetite was altered to secondary hematite. Therefore, the primary remanence acquired during the solidification of the lavas would be destroyed and replaced by another representing the mineralization event. The purpose of this study is to determine the relative time of the copper mineralization by comparing the remanent directions of mineralized flow tops with the unaltered flow interiors.

Preliminary thermal demagnetization results reveal two distinct remanent directions, one associated with the initial cooling of the lava (magnetite component), and another which may represent the copper mineralization event (hematite component). Both show similar declinations of around 295 degrees. However, the hematite component consistently exhibits steeper inclinations on the order of 5 to 10 degrees (approximately +33 degrees and +40 degrees inclination respectively). These directions are consistent with the directions predicted using the North American polar wander path for Keweenaw age rocks. The steeper inclinations in the hematite cannot easily be explained by tectonic tilting towards the present tilt direction prior to mineralization. There are two possible alternative explanations of these results. (1) The relatively steep inclinations seen within the mineralized flow top may be the result of polar wander which suggests some paleomagnetically significant period of time between the extrusion of the lavas and mineralization. (2) The hematite crystallization, hence the mineralization, may have occurred over a long period of time starting soon after the extrusion of the lavas. The hematite remanence would then be an average of the short-term changes in the earth's magnetic field (secular variation) over that period of time. On the other hand, the magnetite remanent direction would represent a point in time on the secular variation curve because the lava cooled in a relatively short period of time. At this point in our study, we do not have adequate information to choose between these alternative explanations.

CHEMICAL CHARACTERIZATION AND PETROGENESIS OF KEWEENAWAN
DIABASE DYKES OF NORTHERN MICHIGAN

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Keweenawan age diabase dykes of Northern Michigan, which intrude Archean basement and early Proterozoic metasediments, can be subdivided into eastern (Baraga and Marquette Co's.) and western (Gogebic Co.) swarms. Thirty-four samples from fourteen dykes in the east and twenty-two samples from thirteen dykes in the west were analyzed.

The widest dykes were sampled several times from the chill margin inwards. There are some subtle changes in the major oxides, from the chill margin to the interior, but these changes are small and have no consistent trends. Quartz and olivine tholeiites, which plot as separate clusters on TiO_2 vs P_2O_5 diagrams similar to those noted by Wilband and Wasuwanich (1980), are recognized in the east. In addition to these, dykes of basaltic andesite are found in the western swarm. Although the TiO_2 - P_2O_5 plot of this swarm is linear, it lacks the bimodal clustering noted in the east. Characteristic major oxide abundance ranges in the bimodal olivine tholeiites are Al_2O_3 : 13-18%, MgO : 7-8.5%, Na_2O : 1.6-2.3%, TiO_2 : 0.5-1.5%, P_2O_5 : 0.05-0.16%, and for the quartz tholeiites are Al_2O_3 : 12-16%, MgO : 3.7-7%, Na_2O : 2-2.8%, TiO_2 : 1.2-3.9%, P_2O_5 : 0.15-0.5%.

Based on geochemical grounds, the eastern swarm may have been derived from two mantle sources which varied in depth and trace element content. The western swarm may have formed by fractional crystallization of a less varied source. Further interpretations based on trace element data are pending acquisition of that data.

DECADE OF NORTH AMERICAN GEOLOGY (D-NAG) GEOLOGICAL
AND TECTONIC MAPS OF THE SOUTHEASTERN CANADIAN SHIELD;
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1:5 million scale geological and tectonic compilations of the Archean Superior Province and surrounding Proterozoic orogens reveal some lithological, structural, metamorphic, and geochronologic patterns that bear on the tectonic evolution of this part of the Canadian Shield.

Superior Province has northern (Pikwitonei, Minto) and southern (Minnesota River Valley) high-grade gneiss regions characterized by the presence of granulites; one of these (MRV) has rocks older than 3.5 Ga. Between the high-grade regions are alternating, east-west trending belts or subprovinces whose supracrustal components are dominated by metavolcanics or by metasediments. The metavolcanic-rich belts (Abitibi, Wabigoon, etc.) are characterized by sinuous, metamorphosed komatiitic-tholeiitic, calc-alkalic, and rare alkalic volcanic sequences with volcanogenic clastic and chemical sediments. Intervening metasedimentary subprovinces (Quetico, Pontiac, etc.) consist mainly of turbiditic wacke and pelite metamorphosed at grades ranging from low greenschist to upper amphibolite, and locally, granulite facies. Supracrustal sequences are cut by abundant plutonic rocks, including tonalitic gneiss, quartz diorite, and trondhjemite, younger granodiorite batholiths, and still younger granite and syenite plutons. Plutonic rocks that may represent basement to the supracrustals are known in only a few localities. Zircon dating demonstrates that volcanic, plutonic, deformational, and metamorphic episodes of relatively brief duration were essentially synchronous over large parts of Superior Province, but there are detectable differences in the ages of events from one area to another. In the north (Sachigo, Uchi) major volcanism and plutonism occurred between 3.0 and 2.8 Ga and again between 2.75 and 2.7 Ga. In the south (Abitibi, Wawa, Wabigoon) major volcanism and plutonism occurred from 2.75 to 2.66 Ga. The contemporaneity of short-lived magmatic episodes along the lengths of these belts seems consistent with a subduction-dominated tectonic regime for the Superior Orogen.

Late tectonic history of Superior Province was dominated by faulting. Dextral transcurrent faults trending EW and NW and sinistral faults trending NE form subprovince boundaries in part, as do NE and EW trending thrusts. The most notable product of faulting, the Kapuskasing structural zone, exposes granulites considered to represent lower crust brought to surface along major NE trending faults that transect the east-west subprovinces.

Superior Province, representing part of a previously more extensive Archean Craton, is bisected and surrounded by Proterozoic orogens. The Early Proterozoic fold belts (Ungava, Penokean) display lithological and tectonic zonation consistent with the operation of plate tectonic processes.



THE TEXTURE AND MINERALOGY OF THE LAKE ELLEN KIMBERLITE
CRYSTAL FALLS, MICHIGAN, USA

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March, 1985

The Lake Ellen kimberlite (figure 1) was discovered by William H. Spence and Klaus J. Schultz in 1966 and was described physically by Cannon and Mudrey (1981). Hearn and McGee (1983) studied the mineralogy and concluded that the mineral assemblages show equilibrium compositions of mantle derived inclusions were formed at temperatures of 700-1300°C and at depths of 55-160 km, within the stability field of diamond.

This isolated kimberlite occurrence has raised considerable interest in view of the widespread discoveries of diamonds in the glacial overburden in Wisconsin. This has prompted kimberlite exploration in this region. Specimens from six representative sites on the Lake Ellen kimberlite diatreme were studied in hand specimen and thin section for diagnostic texture and mineralogy. The characteristic features were then photographed. The purpose was to search for distinct kimberlite facies in the body.

The Lake Ellen kimberlite is a breccia consisting of crustal and mantle derived xenoliths. Crustal xenoliths are most abundant and consist of Ordovician limestone and metamorphic clasts of biotite and talc schist. A smaller fraction of the xenoliths are of highly altered possible eclogitic nodules and possible melilitic clasts now pseudomorphs of calcite.

Around the xenoliths, the kimberlite matrix consists of two distinct sizes of olivine grains: small (.5mm), rounded to subangular grains in the groundmass and larger (.5-2mm), subhedral to euhedral xenocrysts. The fine grained olivine is usually completely replaced by calcite, serpentine and minor chlorite, which occurs in a clastic groundmass of still finer-grained alteration minerals. Some olivine xenocrysts and lithic clasts are coated with a fine-grained magmatic kimberlite rind interpreted to be autolithic. The only magmatic texture recognized in this body occur in these rinds.

The most common unaltered primary minerals are ruby-red pyrope garnet, magnesium ilmenite, and occasionally olivine, phlogopite and microscopic apatite. None of the specimens showed pyroxene minerals. Secondary minerals which commonly mask the primary mineralogy include serpentine (optically identified as antigorite), calcite, phlogopite, chlorite, and microscopic millerite (NiS) in calcite.

The Lake Ellen kimberlite can be classified as a serpentine-carbonate kimberlite breccia according to the Skinner and Clement (1979) classification scheme. Because of the lack of distinguishing features, the body is interpreted to represent a single breccia phase.

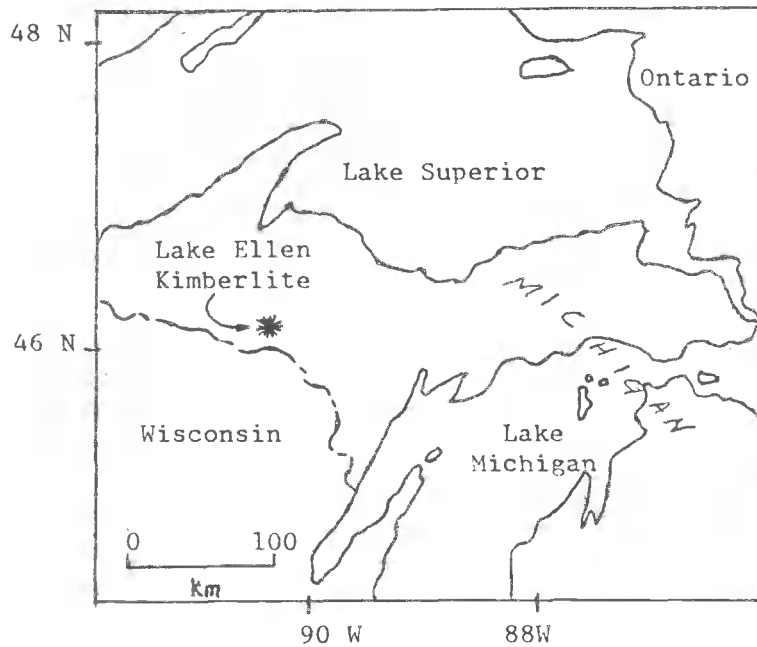


Figure 1. Location map for the Lake Ellen kimberlite.

REFERENCES

- Cannon, W.F., and Mudrey, M.G., 1981. The potential for diamond-bearing kimberlite in Northern Michigan and Wisconsin. Geol. Survey Circular 842.
- McGee, E.D., and Hearn, B.C., Jr., 1983. Lake Ellen kimberlite, Michigan, USA, USGS Open-File Report 83-156.
- Skinner, E.M.W. and Clement, C.R., 1979. Mineralogical classification of southern African kimberlites. Proceedings of the 2nd International Kimberlite Conference, Vol. 1:129-139.

ALTERATION AND GOLD MINERALIZATION ASSOCIATED WITH A SHEETED VEINLET
ZONE AT THE CAMPBELL RED LAKE MINE, BALMERTOWN ONTARIO

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The ore bodies at the Campbell Mine occur in a volcanic complex that is composed of massive to pillowed basalt, with lesser andesite and rhyolite. These units are intruded by concordant sills ranging from ultramafic to gabbroic in composition. The ultramafic lithologies and flanking zones of alteration are termed "altered rock" because of the uncertain origin of some of these petrologically distinctive rock bodies.

In several localities where there is a well developed cleavage, the "altered rock" unit is characterized by "sheeted veinlet zones". These zones are broadly lenticular in shape and consist of cleavage sub-parallel to stockwork, gold free, quartz-carbonate $\pm$ chlorite veinlets averaging about 1 cm wide. They are typically spaced at 2.5 to 10 cm intervals. Most "sheeted veinlet zones" extend from basalt-ultramafic contacts into the ultramafic rock. However some, such as the 1958W "sheeted veinlet zone", are entirely within the "altered rock" unit. These veinlet zones are thought to have formed by extension normal to the cleavage, and by a process of incremental opening and simultaneous outward growth of mineral fibres along the vein-wallrock contact.

Overprinting the veinlet zones are small pod or pipe-like, subvertically orientated and often spectacular high grade gold bearing siliceous replacement zones. These replacement zones are rich in quartz, fuchsite, pyrite and native gold, $\pm$ sphalerite $\pm$ arsenopyrite $\pm$ stibnite $\pm$ molybdenite.

A wide variety of alteration-mineralization types occur in association with the "sheeted veinlet zones". The objective of this study was to petrologically and chemically characterize these and investigate their relationship to the gold. The type of alteration developed here, as in most gold deposits, depends on the nature of the host rock. In general alteration in basalts is much less carbon dioxide rich than that in the "altered rock" due to the higher initial calcium, magnesium, and iron content of the "altered rock".

The earliest type of alteration occurring in the basalts involves alkali depletion and aluminium enrichment. It is characterized by the minerals garnet, biotite, andalusite, chloritoid, sericite and magnesium chlorite, and appears to be spatially related to the basalt-"altered rock" contacts. The alteration bears no known relationship to gold mineralization.

Synchronous with the early alteration of basalts is a chlorite-biotite-carbonate alteration in the "altered rock" unit which is characterized by the minerals chlorite, biotite, coarse grained carbonate, and locally, fine grained quartz-carbonate. It can occur anywhere in the "altered rock" unit and also bears no known relationship to gold mineralization.

Superimposed on these early alterations are three alteration types which are associated with gold mineralization.

The first is a buff-brown siliceous alteration of basalts that occurs near the basalt-"altered rock" contact. It is characterized by the

minerals quartz, carbonate, pyrite, chlorite and sericite, and has an average gold content of about 1000 p.p.b.

The other two alteration types occur in the "altered rock" unit.

One is a pistachio-green alteration characterized by the minerals quartz, carbonate, sericite, and pyrite. It occurs as 50 - 100 cm wide envelopes on 20 - 30 cm wide, banded auriferous quartz-carbonate veins. The average gold content of this alteration type about is 350 p.p.b. The other is a silicification that overprints the sheeted veinlets, and consists of quartz, minor carbonate, minor biotite, minor chlorite, pyrite and locally gold, arsenopyrite, sphalerite, stibnite and molybdenite. The alteration occurs in small pods or pipe-like bodies and is probably fault or fracture controlled. In some areas gold grades in silicified "altered rock" exceed 15 ounces per ton.

Most of the alteration and mineralization associated with "sheeted veinlet zones" occurs in strongly deformed rocks in close proximity to the basalt-"altered rock" contact. The contact, and fault or fracture zones appear to have provided channelways for the hydrothermal fluids responsible for the formation of the various auriferous and nonauriferous alteration-mineralization types found in the study area.

PRELIMINARY METALLOGENIC SUBDIVISION OF THE LAKE OF THE WOODS
METAVOLCANIC-METASEDIMENTARY BELT NORTHWESTERN ONTARIO

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Potential for gold and base metals within the Lake of the Woods east trending metavolcanic-metasedimentary belt Northwestern Ontario, has been shown by past exploration activity. This paper will summarize current planetary evolutionary hypothesis and past exploration work to develop a workable metallogenic subdivision of the area.

The 1970's saw the development of plate tectonic theory and many geologists attempting to fit this type of dynamic system into Archean crustal mechanics. During the 1980's geologists are exploring the solar system by satellite. This activity may have an impact of the same magnitude as plate tectonics on geologic thinking. Planetary exploration has given us clues to the processes active in early Precambrian time. Heat flow rates, volcanic complexes on Mars and Jupiter's Red Spot as a heat transfer mechanism have been instrumental in rethinking Archean crustal evolution.

Vertical tectonics and mantle plumes may hold the key to unlocking the mechanisms in operation during this period in geologic time. Metavolcanic-metasedimentary belts until recently have been viewed as simply a mixture of rock types: today we may view them as the end result of these processes. Examples will be brought forth for examination to help develop a metallogenic pattern.

The Lake of the Woods metavolcanic-metasedimentary area can be viewed as east trending lithological belts, each with a distinct metallogeny. Internal structure may be one of the many features which provide evidence for this subdivision. The Lake of the Woods belt is represented by two base metal areas, two gold areas and an apparently unmineralized area. Boundaries to these areas are marked by structural deformation zones or batholithic intrusions.

Implications for mineral exploration in the Wabigoon Metavolcanic-metasedimentary belt and all other such belts in the Superior Province are highly significant. Planetary information and its effect on metallogenic subdivisions may give the exploration geologist a rational way of determining exploration targets in the Precambrian Shield of Canada. Following this rationale, the Lake of the Woods area may contain a gold camp, which at the turn of the century produced 55% of Ontario's gold, and a base metal area which have both been over looked until recently by explorationists.

U-Pb geochronology and tectonic history of the Shebandowan belt, northwestern Ontario.

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The Shebandowan belt, west of Thunder Bay, exhibits evidence for two major periods of deformation. The first period, which caused regional folding across the belt, may have accompanied initial development of a granitoid complex to the south. The second produced a regional transpression across the northern half of the belt which reflects a major shortening across the Quetico metasedimentary subprovince to the north and dextral shearing along the Quetico Fault. Igneous and sedimentary activity, which accompanied or succeeded one or the other of these deformation periods, permit us to set absolute time constraints on this sequence of events.

The stratigraphy of the greenstone belt was not dated directly, but a zircon age of 2732^{+10}_{-2} Ma for a quartz-feldspar porphyry sill sets a minimum date for the extrusion of its host volcanic rocks north of Middle Shebandowan Lake.

The first period of deformation (D_1) preceded or coincided with the intrusion of the Shebandowan Lake pluton dated at $2696.1^{+2.4}_{-2.3}$ Ma. This pluton appears to have been formed prior to the extrusion of "Timiskaming-type" calc-alkalic and alkalic pyroclastic rocks and the deposition of associated alluvial-fluvial sedimentary rocks. This late supracrustal sequence occurs south of the pluton in two parallel groups that unconformably overlie older Keewatin volcanic rocks. A maximum date for the deposition of the sediments is established by a zircon age of $2704.1^{+1.8}_{-1.6}$ Ma for a quartz-phyric

trondhjemitic clast in a conglomerate. A trachytic pyroclastic breccia from this "Timiskaming-type" suite yields a zircon age of $2689.3^{+2.5}_{-2.2}$ Ma, which slightly but significantly postdates the

crystallization of the Shebandowan Lake pluton.

All of the above units have been affected by the second period of deformation (D_2). The Burchell Lake pluton, an undeformed circular stock of granitic to trondhjemitic composition, postdates the D_2 -deformation event, and appears to be one of a set of post-tectonic plutons within, and south of this belt. Preliminary zircon and titanite data from this intrusion indicate an age of 2684^{+10}_{-7} Ma. Because of the relatively large error the age is

indistinguishable from that of the deformed "Timiskaming-type" volcanic rocks. Considering their errors, the two ages allow for a maximum time span of 10 Ma for "Timiskaming-type" volcanism, D_2 -deformation and intrusion of the Burchell Lake pluton.

This data indicate a relatively rapid succession of events, between about 2700 and 2680 Ma ago, including intrusion of major plutons, erosion, sedimentation and volcanism and a major (D_2) deformation event. The D_2 -deformation event corresponds to widely recognized late Archean crustal shortening manifested as zones of transpression near subprovince boundaries, major shear zones and late faults that border and transect the subprovinces, and shallowly-plunging upright folds that refold earlier recumbent structures throughout the metasedimentary subprovinces. Gold mineralization is related locally to the D_2 -deformation and regionally to the crustal shortening event; its age is thus closely bracketed by the presented U-Pb data.

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U-Pb geochronology and tectonic history of the Winnipeg River granitoid terrain, northwestern Ontario.

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Preliminary U-Pb geochronological data for zircon, titanite and monazite from the Winnipeg River granitoid terrain indicate a complex and protracted geological history.

Gneissic and foliated tonalites from the Cedar Lake, Daniels Lake and Kenora area are intrusive into, or contain inclusions of highly fragmented, volumetrically minor supracrustal sequences. The tonalite in the Cedar Lake area yields a zircon age of about 3170 Ma; this is the oldest reliable zircon age yet identified in the northern Superior Province. A tonalite from Kenora is about 2880 Ma old, whereas tonalites in the Daniels Lake area are about 2840 and 2710 Ma old. These new data, together with previously published ages of 3000-3040 Ma at Lac Seul and 2830 Ma at Kenora suggest that tonalite plutonism took place during at least 5 periods.

Regional tectonics and metamorphism are constrained by ages on late granitoid intrusives and metamorphic rocks:

1) Local nappe-like structures and regional upright folding observed east of Kenora post-date the foliated Daniels Lake tonalite at 2710 Ma, but is older than the crosscutting Lount Lake batholith to the north previously dated at 2702 Ma. This period of deformation is essentially coeval with regional metamorphism in Kenora dated at about 2710 Ma by zircons in an amphibolite and with the intrusion of the marginal granodiorite, a sheet-like intrusion emplaced into the subprovince interface at Kenora about 2705 Ma ago.

2) Late doming follows regional deformation. In the Kenora area the age of doming is constrained by titanite ages which indicate cooling to below about 500°C at 2700-2690 Ma ago. Doming in the Cedar Lake area was either related to or post-dated a late phase of a protracted granulite facies metamorphic history recorded by metamorphic zircons in a mafic granulite and by monazite in a tonalite and a granodiorite at about 2680 Ma. Titanite ages of 2600-2590 Ma in the Cedar Lake area show that this crustal segment remained at elevated temperatures much longer than in the Kenora region.

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STRATIGRAPHIC AND STRUCTURAL EVOLUTION OF THE CROSS LAKE SUPRACRUSTAL BELT
IN NORTHWESTERN SUPERIOR PROVINCE, MANITOBA

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The Archean supracrustal belt in the Cross Lake-Pipestone Lake area contains evidence of two distinct episodes: an early period dominated by mafic volcanism, followed by plutonic intrusion; a second period of uplift, erosion and deposition of subaerial-fluvial dominated sediments. These observations indicate that the development of the Cross Lake supracrustal belt is similar in character to other greenstone belts in the northern Superior Province where the dominantly volcanic succession (Hayes River Group) is unconformably overlain by a succession of dominantly sedimentary rocks (Oxford Lake Group, Island Lake Group).

The early supracrustal rocks comprise a sequence dominated by pillowed and massive metabasalt flows with subordinate amoeboid pillow breccia. Near the top of the basalt sequence plagioclase phyric massive and pillowed basalts occur. Mafic volcanic metasediments and minor greywacke metasediments occur within the sequence. The early supracrustal rocks are extensively intruded by mafic to ultramafic sills and dykes. On Pipestone Lake, a large layered anorthosite-gabbro complex contains titanium-vanadium enriched magnetite-illmanite layers. These rocks were intruded by tonalite (U/Pb age 2712 Ma).

Unconformably overlying the early supracrustal rocks and tonalite is a generally fining upward sequence of metasediments. Thickly bedded alluvial fan conglomerates and high energy fluvial sandstones up to 1500 m thick form the base of the sequence. Up to 250 m of thickly bedded sandstone and thinly bedded siltstone-sandstone grade upward into a thin siltstone-shale at the top of the metasedimentary sequence.

Deformation and metamorphism occurred concomitant with development of major batholithic terrains north and south of the supracrustal belt. Linear to arcuate tectonic zones, from 50 m to 100 m thick, form boundaries which divide the supracrustal belt into a series of blocks. Within these tectonic zones both ductile and brittle features are abundant. Typically one to seven meter thick shear zones occur at irregular spacing, becoming more abundant as the boundary is approached. The rock between the shears ranges from slightly deformed to completely transposed into the shear direction in the boundary zone. In these areas early mafic volcanic rocks and late metasedimentary rocks may be tectonically interlayered. Within the blocks original stratigraphic relationships are retained. However, the degree of deformation and the grade of metamorphism varies from block to block.

GEOCHEMICAL CONSTRAINTS ON THE REE DISTRIBUTION IN THE
NEGAUNEE IRON FORMATION AT THE EMPIRE MINE, PALMER, MICHIGAN

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The approximately 2.1 Ga old Negaunee Iron Formation at the Empire Mine near Palmer, Michigan provides an excellent, albeit complex, spectrum of rock types to investigate the elemental distribution and mineralogical variations of a typical Superior-type iron formation. This orebody is located on the southeast limb of the Marquette synclinorium, and metamorphism is minimal (chlorite facies). It precipitated dominantly as a chert-siderite, and shows extensive replacement. The major diagenetic alterations are chert to magnetite, and siderite to magnetite and ankerite. With post-metamorphic oxidation, magnetite was replaced by martite, and the carbonates altered to hematite or goethite.

The objective of this investigation is to evaluate the crystallochemical/environmental controls affecting the REE distribution in these low temperature chemical precipitates. Forty-five drill core samples from the Empire Mine are being examined. They represent five facies distinguished according to the major mineral assemblage: chert, carbonates, magnetite rich ore, Siamo slate, and clastic interbeds. It is anticipated that correlations of the trace elements with mineralogy will reflect the influence of partitioning coefficients on the REE distribution.

Several significant correlations exist between the trace elements, major oxides, and mineralogy. The LREE/HREE ratio is highly antipathetic to siderite, MgO, MnO and CO₂; less so with CaO. The correlation with siderite agrees with what is expected based on crystallographic controls (Morgan & Wandless, 1980). There is a high positive correlation of the REE with TiO₂ and Al₂O₃. This can be interpreted to mean that the lanthanides were adsorbed onto detrital minerals, such as chlorite, which were deposited with the chemical precipitates. Europium correlates negatively with Fe³⁺ and positively with Fe²⁺ (e.g., siderite). This is consistent with the reducing conditions proposed for the precipitation of primary siderite, and argues for the presence of Eu²⁺ in the basin water. It was expected that the diagenetically enriched magnetite would have a negative correlation with the LREE/HREE ratio because the stability of HREE-carbonate complexes exceeds that of LREE-carbonate complexes in iron-transporting solutions (Graf, 1984). The apparent LREE enrichment in magnetite is interpreted to mean that the HREE, if mobilized during diagenesis, were not deposited with the iron.

Morgan, J.W. and Wandless, G.A., 1980, Rare earth element distribution in some hydrothermal minerals: evidence for crystallographic control. *Geochim. Cosmochim.*, vol.44, p.973-980.

Graf J.L. Jr., 1984, Effects of Mississippi valley-type mineralization on REE patterns of carbonate rocks and minerals, Viburnum trend, southeast Missouri. *Jour. Geol.*, vol.92, p.307-324.

Evolution of an Archean igneous complex from high precision U-Pb geochronology: the Kakagi Lake area, N.W. Ontario.

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High precision U-Pb ages determined on 10 rocks from the Archean complex surrounding the Kakagi Lake area give a detailed picture of igneous evolution, defining a time span of at least 32 Ma for development of the complex. The earliest age is 2731.7 ± 4.0 Ma from analysis of zircon and baddeleyite in a gabbro intruding the Katimiagamak Group. This is the oldest known unit in the complex and represents an episode of high iron tholeiitic volcanism. A slightly younger age of 2727.7 ± 1.1 Ma from a dacite in the Dash Lake area probably represents the beginning of felsic volcanism in the complex. An age of 2723.2 ± 1.8 Ma on a tonalite gneiss from the interior of the Sabaskong Batholith is indistinguishable from the age of a massive border phase of the batholith (2724.4 ± 1.8 Ma) and shows no evidence of inheritance from an older sialic component. A pegmatite phase of the lowermost Kakagi sill was dated at 2724.8 ± 2.5 Ma, which may be only slightly younger than the age of intermediate volcanism in the Kakagi Lake Group. This is similar to the age of the Sabaskong Batholith and demonstrates simultaneous mafic and felsic plutonism as well as approximate simultaneity of tonalitic plutonism in the Sabaskong Batholith and intermediate volcanism in the Kakagi Lake Group.

An age of 2711.1 ± 1.3 Ma from a dacite occurring above the Kakagi Lake Group shows a 13 Ma time gap in development of the volcanic pile. The age of one of the oldest tonalitic phases of the Aulneau Batholith is 2716.8 ± 4.9 Ma, while the latest granodiorite phase is dated at 2709.6 ± 3.9 Ma. This shows that the bulk of the Aulneau Batholith was probably intruded over a time span of about 7 Ma and indicates that felsic volcanism above the Kakagi Lake Group is coeval with late plutonic activity in the Aulneau Batholith.

The conformable relationship between all of the volcanic units shows that regional deformation was a relatively late event and not due to intrusion of the large batholiths, which occurred during volcanism. The end of regional deformation in the area is given by the ages of two late tectonic plutons, the Heronry Lake stock and the Stephen Lake stock, dated at 2701.0 ± 1.2 Ma and 2699.2 ± 1.9 Ma, respectively.

U-Pb analyses of sphene in four of the samples indicates variable amounts of resetting. The oldest sphene age is from the Heronry Lake stock (2699.2 ± 1.6 Ma), whereas the youngest sphene age is from the Sabaskong gneiss (2673.7 ± 6.6 Ma), the sample most strongly affected by diapirism.

The data suggest that regional deformation occurred due to diapiric remobilization of slightly older batholiths. The centres of this remobilization are likely to be two gneiss domes near the mouth of Sabaskong Bay. These appear to have been areas of relatively long-lived heat flow as indicated by the younger sphene ages.

ANOMALOUS RADIOMETRIC AGES FROM THE SUPERIOR PROVINCE, ONTARIO:
SENSE? or NON-SENSE?

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Precise U-Pb zircon ages obtained over the last 5 years by T.E. Krogh and co-workers at the Royal Ontario Museum have provided a chronologic framework for examining the evolution of individual greenstone belts and the sub-provinces of the Superior Province in Ontario. Krogh et al. (1984) summarize the results of this work. In this paper, the significance of anomalously young and old Rb-Sr, K-Ar and Ar-Ar age determinations from the Superior Province is assessed in light of the work of Krogh et al. (1984) and a recent compilation of geochronologic data for Ontario (Easton, 1985a). In some cases, it is now possible to interpret the significance of radiometric ages hitherto regarded as curiosities. In the Superior Province, Rb-Sr, K-Ar and Ar-Ar ages are commonly 100 to 150 Ma younger than corresponding U-Pb zircon ages; a characteristic of other orogens, e.g. the Archean Slave Province and the Proterozoic Wopmay Orogen (Bear Province). Anomalous ages are those that are ≥ 50 Ma younger or older than the typical 2500 to 2600 Ma ages obtained by Rb-Sr, K-Ar and Ar-Ar methods for Superior Province rocks. Superior Province anomalous ages fall into three categories:

- 1) Reset ages which exhibit distinct associations or trends. These include:
 - a) reset ages present along subprovince boundaries, particularly K-Ar isotopic systems.
 - b) reset ages near province boundaries, including both Rb-Sr and Ar ages (e.g. resetting of Superior and Southern Province ages along the Grenville Front). Resetting may occur up to 100 km from the boundary.
 - c) zones of reset ages, e.g. the ca. 1800-1850 Ma Kenyon Structural Zone in the Sachigo Subprovince.
 - d) excess Ar ages associated with faulting or major geological structures, e.g. the Kapuskasing Structural Zone.
- 2) Isolated reset ages. In many cases, the cause of the resetting is commonly a local geologic feature that was not recognized at the time of initial sampling. This situation applies to many of the K-Ar ages determined in the late 1950's, early 1960's.
- 3) Possible primary ages that are associated with magmatic events. These include:
 - a) ages of carbonatite complexes within the Superior Province, which correspond to the time of major magmatic, volcanic and metamorphic events in the mid-continent region of North America, or major structural zones, or both (Figure 1).
 - b) ages of isolated plutonic bodies which are locally not significant, but which show regional trends (Figure 1).

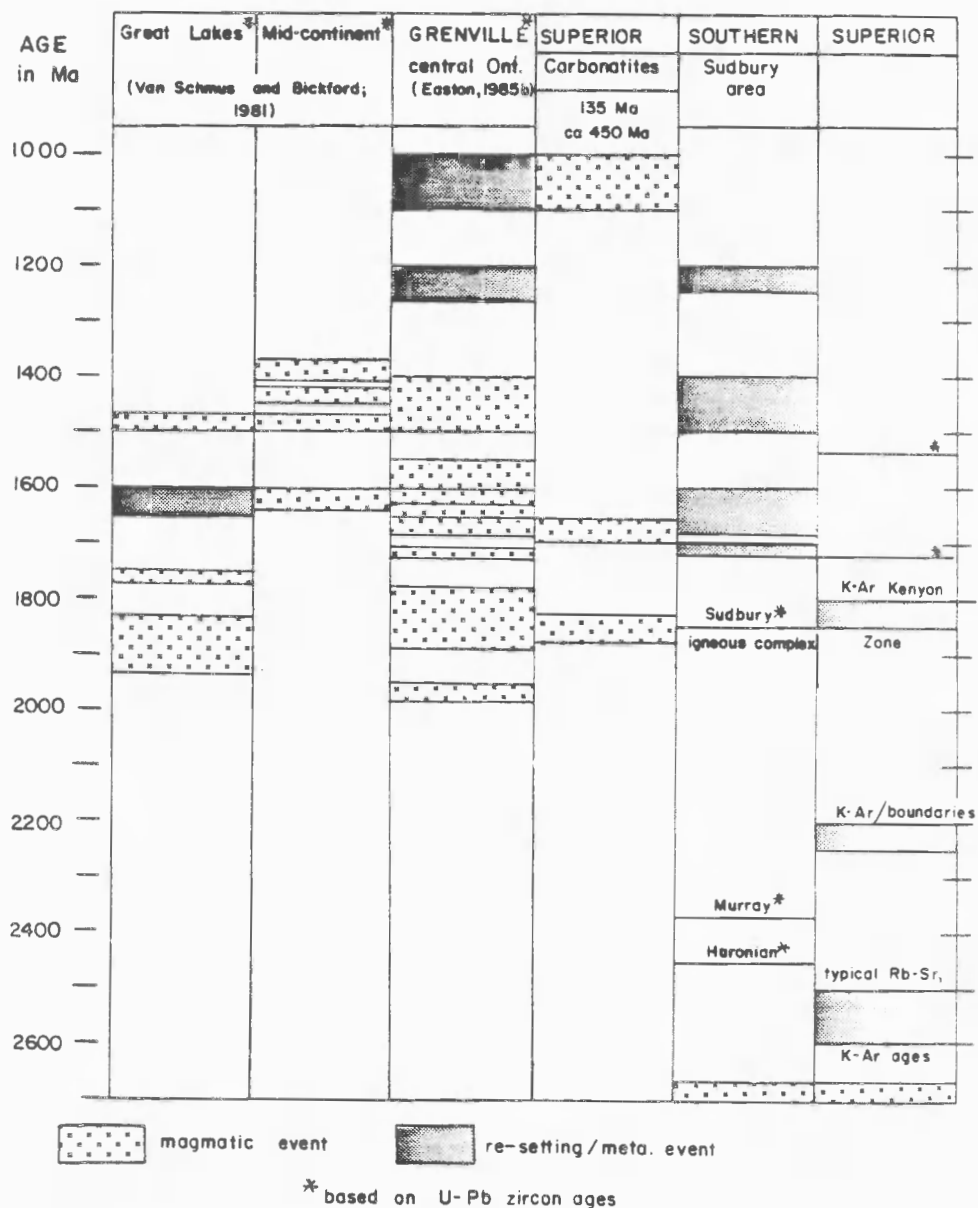
Ages within the first and third category are particularly noteworthy, in that the observed ages cluster at intervals which correlate with chronologic terranes recognized elsewhere in North America (Figure 1). Although not directly affected by these events, the Superior Province locally provides a record of North American magmatic episodes. This should be considered when interpreting future geochronologic data from the region.

Easton, R.M., 1985a, Geochronology Compilation for Ontario; Ontario Geological Survey Open File Report and 6 Preliminary Maps.

Easton, R.M., 1985b, Distribution of chronologic terranes in the Grenville

Province, Eastern North America; Geol. Assoc. Can. Abstracts, v. 10.
 Krogh, T.E., Davis, D.W., and Corfu, F., 1984, Implications of precise U-Pb dating for the geological evolution of the Superior Province; Geol. Assoc. Can. Abstracts, v. 9, p. 79.
 Van Schmus, W.R. and Bickford, M.E., 1981. Proterozoic chronology and evolution of the mid-continent region, North America; in A. Kroner, edit., Precambrian Plate Tectonics, Elsevier, p. 261-296.

Figure 1: Chronologic history of the Superior Province based on anomalous K-Ar and Rb-Sr ages compared with other North American data.



The Significance of Strain Patterns in Deciphering
the Deformational History of Archean Rocks
in the Vermilion District, Minnesota

by

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The Vermilion district of northern Minnesota comprises an E-W trending belt of multiply deformed sedimentary and volcanic rocks of Archean age. The district is separated from the higher-grade rocks of the Vermilion Granitic Complex to the north by the Vermilion fault, which has a large component of dextral strike-slip movement. An early nappe-forming event was followed by a second phase of deformation which produced all of the measured strain, cleavage, and lineations. Strain measurements in the lower-grade sedimentary rocks reveal a complex pattern of deformation, which can be used to infer the tectonic history of the belt.

Magnitude and symmetry of strain in the rocks varies in parallel bands. The symmetry of the strain varies from constrictional to flattening in ENE-trending bands which tend to be lensoid in map view, and which are oblique to the trace of the ESE-trending Vermilion fault. The largest measured strains consistently occur near the Vermilion fault. Flattening strains also predominate adjacent to the fault, then change symmetry several times to finally become homogeneous in symmetry (constrictional), orientation, and magnitude in the southern part of the district.

The maximum extension directions (X) of all samples showing constrictional strain, plunge east at angles between 30 and 65°. X in samples showing flattening strain plunges east or west, but near the Vermilion fault all plunges are west or more steeply east than they are in constrictional samples. The maximum shortening direction (Z) plunges consistently less than 25° to the north or south. A number of features in the rocks indicate a large component of dextral simple shear in the deformation history.

The significance of the strain patterns is not clear. The alternating constrictional and flattening zones preclude their origin by homogeneous coaxial strain or progressive simple shear. These strain variations also require a model which can satisfy compatibility constraints and space considerations. The area of consistent constrictional strains in the south may represent one regional component of the strain. Spatial correspondence of the flattening strains with the Vermilion fault suggests that a simple shear component was added in that area. A modified model of transpression may explain how E-plunging X axes are reoriented to become W-plunging by a concomitant inhomogeneous progressive simple shear which is clearly shown in the rock fabrics. Less than vertical plunge of the X axes may necessitate some component of oblique motion on the fault. A second zone of flattening strain may have formed in a strain field which is reflected in a smaller dextral strike-slip fault, or it may reflect strain accommodation around the more competent greenstone and iron-formation coring the major anticlinal structure in the area.

The relatively homogeneous deformation in the constrictional zones surrounded by more highly sheared and flattened zones suggests a large-scale analogue of the fabric of mylonite zones. The anastomosing geometry of such zones serves to satisfy compatibility conditions and room problems. Such patterns have been modelled theoretically and require similar anastomosing behavior in the third dimension to explain the juxtaposed variations in strain magnitude and symmetry. Similar variations in strain have been predicted in simple shear regimes, with extension in the 'b' direction to give an overall flattening strain. Perturbations of the shear produce local zones of constrictional strain at an angle to the shear plane consistent with the angle that the boundaries of zones of constrictional and flattening strain in the Vermilion district make with the Vermilion fault.

In a general way the strain patterns observed in the Vermilion district can be reasonably explained by a history of N-S shortening accompanied by inhomogeneous dextral simple shear which found its last expression as the Vermilion fault. The variations of strain may be a consequence of variations in the relative intensities of shortening and shear, large perturbations of the shear, or the influences of other structures.

Large Ignimbrites in the Keweenaw North Shore
Volcanic Group in Cook County, Minnesota

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Two thick and extensive volcanic units were studied in the North Shore Volcanic Group in south-central Cook County, Minnesota. The Kimball Creek quartz latite is 335 m thick, strikes approximately east-west, dips 10 degrees south and can be traced 29 km along strike but is truncated by Lake Superior north-east of Grand Marais. It can be subdivided into two subunits based on the percentage of plagioclase phenocrysts, the lower unit being the more highly porphyritic. This is overlain by approximately 245 m of ophitic olivine basalt flows of the Red Cliff Basalts (Green, 1972) and the 225 m thick Devil Track rhyolite. The Devil Track rhyolite can be traced 35 km along strike from near the western end of Pike Lake eastward to the shore of Lake Superior where it too extends an unknown distance under the lake. Depending on assumptions as to its original extent, this unit appears to contain between 160 and 500 cu. km of rhyolite. Closely spaced vertical and horizontal joints cause the rocks to be easily eroded resulting in poor exposure and concealed contacts.

Texturally the rocks are aphanitic, holocrystalline and largely lack devitrification features. No pyroclastic textures have been found. The rocks are dominated by anhedral orthoclase and platy, randomly oriented quartz crystals that were originally tridymite. Tabular, 1-2 mm quartz crystals, also pseudomorphs after tridymite, are present in some small cavities. There are some oxidized pseudomorphs of clinopyroxene but blocky, subhedral magnetite is the dominant primary mafic mineral. It is partially weathered to hematite giving the rocks their red color.

The lack of flow banding and vesicles, the very large volumes and aspect ratios (length/thickness) of 90 and 160 for the Kimball Creek and Devil Track units respectively, suggest an origin by pyroclastic flows rather than lava flows (Walker, 1973). The interpretation of these units is that they were deposited by large, hot pyroclastic flows that crystallized after emplacement similar to the rhyolitic tuffs of the San Juan region of Colorado (Lipman, 1975a). The crystallization of tridymite and orthoclase destroyed any pyroclastic textures. The tridymite subsequently inverted to quartz during burial.

Green, John, C., 1972, North Shore Volcanic Group. In Sims, P.K. and Morey, G.B. eds. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey.

Lipman, P.W., 1975a, Evolution of the Platoro caldera complex and related volcanic rocks, Southeastern San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 852, 128 p.

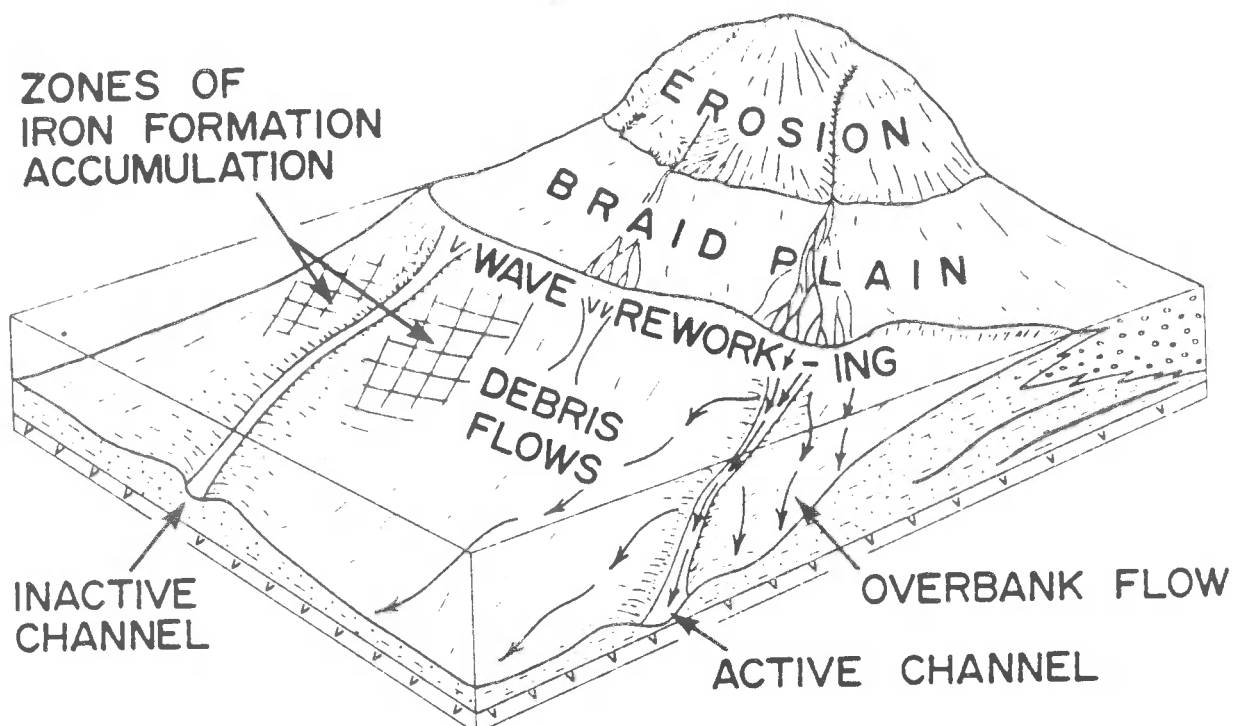
Walker, G.P.L., 1973, Lengths of lava flows. Phil. Trans. R. Soc. Lond. A. 274, 107-118.

CONTROLS ON THE GENESIS OF EPIGENETIC AURIFEROUS
VEIN SYSTEMS IN ARCHEAN CHEMICAL-SILICICLASTIC SUBMARINE
FAN DEPOSITS, GERALDTON AREA, ONTARIO

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In the 1920's and 30's a number of occurrences of gold bearing quartz vein systems were discovered in the Beardmore-Geraldton Greenstone Belt north of Lake Superior. Most vein systems are located proximal to east-west trending fault zones with mineralization localized in drag folds and dilated fractures in a variety of rock types. Auriferous vein systems and associated replacement sulphides in oxide facies iron formation were studied at the Hard Rock and MacLeod-Cockshutt Mines plus the McLellan and Solomon's Pillars occurrences to gain information on the mineralization process. In addition the depositional environment of the I.F. and associated siliciclastics was investigated throughout the greenstone belt.

The oxide facies I.F. forms thin (less than 5 mm) laminae and packages of laminae interbedded with and sometimes forming the E division of DE turbidities. The chemical-siliciclastic successions are organized into upward coarsening and thickening packages. Both chemical and clastic components represent, in varying proportions, deposition from dilute sediment gravity flows and rainout below storm wave base. The stratigraphic succession indicates I.F. was deposited in shore proximal interchannel areas on a submarine fan forming the subaqueous portion of a fan delta system.



Paleogeography of the Beardmore-Geraldton area during deposition of the sedimentary assemblage. As time progressed the coarse clastics prograded southward widening the braidplain.

The veining event occurred either concomitant with or following a regional episode of deformation. Auriferous mineralization in I.F. is spatially and probably genetically related to extensive wall-rock alteration including carbonatization and sulphidation. The mineralogy of the occurrences indicates they were deposited from sulphide rich, alkaline to neutral H_2O-CO_2 solutions. Under these conditions the gold may have been transported from depth by reduced sulphur complexes and precipitated during wall-rock alteration of the I.F. by both a pH change and the reactions:

$$2Fe_3O_4 + 6Au(HS)_2^- + 6H^+ \rightleftharpoons 6FeS_2 + 8H_2O + 6Au$$

$$Fe_3O_4 + 2Au(AsS_2)_2^- + 4H_2 \rightleftharpoons 2FeAsS + FeS_2 + 4H_2O + 2Au.$$

GEOCHEMISTRY OF THE POWDER MILL GROUP: THE EARLIEST LAVAS OF
THE MID CONTINENT RIFT IN MICHIGAN

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The Powder Mill Group represents the first lavas to be extruded during the development of the Midcontinent Rift in Upper Michigan. These Keweenaw age lava flows provide a unique opportunity to examine the initial eruptives from one of the planet's oldest and largest preserved rift systems. The Powder Mill Group is exposed over an area of about 160 km, from southern Houghton County, Michigan to Grandview, Wisconsin, and is centred around Ironwood, Michigan. Its total thickness has been estimated at about 6100 m.

The Powder Mill Group is divided into two Formations: the Siemens Creek and the Kallander Creek. The lowermost the Siemens Creek Formation represents about 1300 m of thin basalt and andesite flows which are generally less than 15 m thick. The overlying Kallander Creek Formation is believed to be about 4500 m thick although only about 1200 m is exposed. The average flow thickness is about 25 m. These flows range from basalt to quartz-bearing felsite (Hubbard, 1975). All exposures of the Powder Mill Group west of the Keweenaw Fault dip near vertical and toward the northwest. Exposures on the east side of the Keweenaw Fault are flat lying.

Preliminary isotope work on the Powder Mill Group by Wilband (1984) yielded an isochron with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.7043 ± 0.0003 and an age of 1209 ± 36 Ma. Major element data from 46 samples have been collected. Ranges of some oxides are: SiO_2 70-48%; MgO 13- $<1\%$; CaO 11- $<1\%$; Al_2O_3 16-10%; FeO (total Fe) 18-4%. There is a high positive correlation between MgO and CaO . There is also a high negative correlation between MgO and Al_2O_3 .

Nine of the sampled lavas are olivine tholeiites and eighteen are quartz tholeiites. A duality of lava types was recognized by Wilband and Wasuwanich (1980) in the overlying Portage Lake Lavas and the Keweenaw diabase dykes. These dykes are believed to be feeders for both the Portage Lake Lavas and the Powder Mill Group. This duality is also recognized in plots of MgO v. TiO_2 and Al_2O_3 : TiO_2 : P_2O_5 for the Powder Mill Group. Trace element data will be collected to substantiate these trends.

Hubbard H.A. (1975) Lower Keweenaw volcanic rocks of Michigan and Wisconsin. U.S. Geol. Survey Jour. Research 3, 529-541.

Wilband J.T. (1984) Age and source variation of volcanics associated with Keweenaw Rifting. Trans. Am. Geophys. Union 65, 1122.

Wilband J.T. and Wasuwanich P. (1980) Models of basalt petrogenesis: Lower Keweenaw diabase dikes and Middle Keweenaw Portage Lake Lavas, Upper Michigan. Contrib. Mineral. Petrol. 75, 395-406.

STRATIGRAPHIC EVOLUTION OF THE ISLAND LAKE GREENSTONE BELT, MANITOBA

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The Island Lake greenstone belt in the northwestern Superior Province consists of a lower, subaqueous, volcanosedimentary section (Hayes River Group), unconformably overlain by fluvial deposits and younger turbidites (Island Lake Group). The Hayes River Group was subjected to pre-Island Lake Group deformation, metamorphism, and plutonism and was probably subaerially eroded before deposition of the younger sedimentary rocks.

Coarse volcanic breccia and relatively shallow-water, vesicular basalt in the eastern part of the belt suggest a more proximal environment than the area further west. The abandoned gold mine in the eastern part of Island Lake occurs at a volcanic/sedimentary interface within the Hayes River Group. Silicification and carbonatization are more widespread in this area than further west. Carbonatization may be partly related to possible sedimentary carbonate units (e.g. at the gold mine) but is also extensive within 0.5 km of the Norrie Island carbonatite. This intrusion, which is associated with carbonatized peridotite and intrusive breccia containing mafic/ultramafic clasts, is emplaced close to the contact between the Hayes River and Island Lake Groups in a possible graben-like structure. A zone of ultramafic intrusions extends through the central part of the greenstone belt, and a porphyritic peridotite sill occurs close to the south margin of the belt. Regional isoclinal folding has affected both the Hayes River and Island Lake Groups and major faults are inferred where stratigraphic discontinuities occur across the axial traces of some folds.

KEWEENAWAN DIKES OF MINNESOTA

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MN 55114

Keweenawan dikes, many of which were probably feeders for plateau basalt lavas, are concentrated in several swarms in northeastern Minnesota. Their general trends probably show the direction of tensional stress at different times and in different areas as the Midcontinent Rift system evolved, and their compositions give an idea of the magmas available from melting of the subcontinental mantle as the rift progressed. Time relations are inferred both from crosscutting intrusive relations and from paleomagnetic studies of polarity and pole progression along the Late Proterozoic track (Halls and Pesonen, 1982).

The two oldest swarms show reversed polarity. The Carlton County swarm contains 43 dikes known from outcrop, trending rather uniformly N30°E. They are found in the St. Louis River valley from Carlton and Cloquet east through the Jay Cooke State Park area west of Duluth, and they cut the Lower Proterozoic Thomson Formation and some of the reversed - polarity (R) Keweenawan lavas at Ely's Peak beneath the Duluth Complex. They are mostly rather evolved, Fe-rich basalt similar in composition to many North Shore Volcanic Group (NSVG) lavas and the Columbia River plateau basalts. A few normally polarized (N) dikes, evidently younger, also occur in this same area, and several large N dikes with similar trend appear dramatically on aeromagnetic maps (Chandler 1983). The reversed swarm shows a paleomagnetic pole position that closely corresponds to that previously determined by others for reversed lavas in Cook County and Logan sills in the Thunder Bay district. The occurrence of large R dikes up to 8 km west of the nearest Keweenawan lavas or Duluth Complex suggests that the R Ely's Peak basalts or their equivalent probably covered a considerably wider area before Late Keweenawan erosion.

Another group of reversed dikes is the Grand Portage swarm (Green, 1981) which is best exposed in the coastal zone of northeastern Cook County from Hovland to Grand Portage. They cut the reversed-polarity Keweenawan lavas, the Puckwunge Sandstone, and the underlying Lower Proterozoic Rove Formation. At least 20 dikes are known, ranging from 1 to 45 m thick; about 30% are over 10 m thick. They trend E-W to ENE and dip steeply N. These too have rather Fe-rich evolved compositions. Several are plagioclase-porphyritic and they were probably feeders for the Grand Portage and Hovland lavas.

A major group of normally polarized dikes also is found in the Grand Portage area; these have been referred to as the Pigeon River intrusions by Geul (1970). Consisting of at least 30-35 dikes, (most in Canada) this group contains many very large ones over 100 m thick (some up to 500 m). Most trend N65°E but a few are transverse with N30-5°W strikes. Several can be followed for 15-20 km. They cut the Rove Fm, reversed Keweenawan lavas, and Logan sills. This group is on the whole considerably more magnesian and primitive geochemically than the R swarms just described, and represents a major tapping of new mantle melt after the R→N pole reversal.

In the City of Duluth about 44 basalt dikes are known, all N, which cut the Duluth Complex and the N lavas above it. Their trend is variable but most are N-S with a 75° W dip. The compositions of 10 analyzed samples ranges from fairly primitive to more evolved, but generally are not as Fe-rich as the R dikes of Carlton County.

Sixteen N dikes south of Babbitt cut the Duluth Complex and trend transverse to the general rift, about $N52 \pm 15^{\circ}$ W (Morey and Cooper, 1976). Their extent is not well defined nor is their chemistry. Another 16 dikes between Ely and Moose Lake in the Fernberg Trail area (Green et al., 1966) cut Archean rocks northwest of the base of the Duluth Complex. Their polarity is not established. Most strike either $N 65-70^{\circ}$ E or NW; the longest can be traced for 10 km. These have a range of basaltic compositions rather like those of the Duluth area.

The 62 Minnesota Keweenawan basaltic/diabasic dikes so far analyzed show a wide range of compositions within each swarm, reflecting those of the overlying lavas. However, in contrast to the dikes of Michigan and Wisconsin, there is a preponderance of more primitive compositions in the N group, and of dikes richer in Fe, Ti, K, and P in the R group.

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References

- Chandler, V. W., 1983, Aeromagnetic Map of Minnesota: Carlton and Pine Counties., Minn. Geol. Survey, St. Paul.
- Geul, J. J. C., 1970, Geology of Devo and Pardee Townships, Ontario Dept. Mines Geol. Rept. 87
- Green, J. C., 1981, Geol. Soc. Amer. Abstracts with Programs, v. 13, p. 271.
- _____, Phinney, W. C., and Weiblen, P. W., 1966, Gabbro Lake Quadrangle, Minn. Geol. Survey Misc. Map M-2.
- Halls, H. C. and Pesonen, L. J., 1982, Paleomagnetism of Keweenawan Rocks, in Geol. Soc. Amer. Memoir 156, p. 173-202.
- Morey, G. B. and Cooper, R. W., 1976, Bedrock geologic map of Hoyt Lakes - Kawishiwi Area, St. Louis and Lake Counties, NE Minn. Minn. Geol. Survey open-file map.

**The Central Wisconsin Archean Block:
New Evidence Suggests a Partially Reworked Granite/Greenstone Terrane**

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A recently mapped area of central Wisconsin, which includes most of Wood and Portage counties, is typified by syn- to late-kinematic granitoid plutons which intrude a predominantly volcanic terrane. The geology of this region is analogous to granite/greenstone terranes common in Archean shield areas and some younger provinces. The central Wisconsin area was previously thought to consist of an extensive basement of Archean gneiss overlain by Proterozoic volcanic rocks and intruded and deformed around 1850 Ma. These basement gneisses were grouped with other gneisses in southeastern Minnesota and the Minnesota River Valley and interpreted to constitute a distinct Archean gneiss province, separated from a granite/greenstone terrane to the north by a major tectonic boundary.

Our work in central Wisconsin suggests that the two major lines of evidence formerly used to infer the existence of a "gneiss terrane" in central Wisconsin, age and lithology, probably do not support this interpretation. Of the several available ages on Archean units, many are younger than similar rocks in southern Minnesota or northern Wisconsin. Most recent U/Pb dates from central Wisconsin are in the range 2.5 to 2.7 Ga, similar to the age of the proposed granite/greenstone terrane in northern Wisconsin and Michigan. Many of the newly designated Archean units and other potentially Archean units are metavolcanic and metasedimentary lithologies, such as those exposed at Lake DuBay in Portage County (interbedded felsic and mafic rocks) and along the Black River in Jackson County (Algoma-type iron formation and amphibolite).

There are numerous plutons of either granite-granodiorite-tonalite or tonalite-hornblende diorite-gabbro exposed in the area. Only a few ages are available for these rocks, but they are generally thought to be early Proterozoic. Rock fabric and contact relationships indicate that the intrusions were syn to late kinematic, commonly with massive cores and foliated margins. The intrusive contacts with volcanic-sedimentary country rocks are extremely complex. Many rocks previously mapped as diorites, gneisses, and syenites are actually contaminated-assimilated contact lithologies. Beyond the foliated pluton-margins there are zones of fine-grained gray "diorites" and/or mixed mafic-felsic rocks--texturally "gneisses" with alternating bands of granitic and mafic minerals. Where gneissic in aspect, these mechanically-mixed lithologies are nearly identical in appearance with dated Archean gneisses. Further away from the plutons, only dikes and stringers of intrusive material are present in the country rocks and intensity of metamorphism and deformation commonly decreases.

The presence of Proterozoic gneissic zones in central Wisconsin has possible tectonic implications for at least some of the Archean and supposed Archean gneisses. Geochronology and geology have been thus far unsuccessful in specifying the timing at which these rocks became gneisses. In only a few cases (Linwood and Pittsville) are the gneissic structures almost certainly pre-Penokean. In other cases, Proterozoic tectonism probably converted Archean granite/greenstone lithologies into gneisses and amphibolites.

Orientations of minor folds and foliations vary widely throughout the area which has a general east-west structural grain. These structures and foliation within the plutons are generally parallel near the pluton contacts. Regional structural trends are reoriented within a few kilometres of the 1.5 Ga Wolf River batholith, a 9000 km² anorogenic granite complex. Metamorphism throughout the area is generally low grade, except in the older gneisses, near the Wolf River batholith, and in some other contact zones where middle amphibolite-facies rocks occur.

Very low grade Baraboo interval metasedimentary rocks (1760 to 1630 Ma) tend to reflect the composition of granite/greenstone units which they apparently overlie in much of central Wisconsin. Ferruginous quartzite, chert, argillite, and fuchsitic quartzite are in contact or are near mafic and ultramafic lithologies. Equivalent metasedimentary rocks exposed near felsic plutons and volcanic rocks are commonly lighter colored and more sericite-rich.

Keweenawan Structural Features at the Base of the Duluth Complex in the
Dunka Pit near Babbitt, Minnesota

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A number of faults and folds affect Animikie Group Rocks of the northeastern Mesabi Range (Mullenmeister and others, this volume). Several of these are found in the Dunka Pit region. In addition to these there are structures found in Animikie Group rocks in the Dunka Pit in close proximity to the Duluth Complex that are found nowhere else in the northeastern Mesabi Range. These features include tight to isoclinal small-scale folds (amplitudes and wavelengths a meter or less), and some unusual, undulatory sub-horizontal faults, here termed detachment features.

The small-scale folds occur in the cores of larger-scale folds (amplitudes on the order of ten meters) and associated with the detachment features, in the upper plate. Fold vergence and attitude is quite variable. The folds always occur within the uppermost Biwabik Formation (the "A" layer of Erie Mining Company) or the lower portion of the Virginia Formation. In the cores of the small-scale folds there is a well-developed axial-planar foliation in the calcite matrix.

The detachment features are well-defined faults, which have variable dips (usually shallow) and can be traced for up to tens of meters across the pit wall. The lower plate rocks are typically undeformed or may contain a broad gentle anticline, and are generally of the "C" layer of the upper portion of the Biwabik Formation. The upper plate rocks are typically strongly folded, and consist of the "A" layer of the upper Biwabik, or the base of the Virginia Formation. Thus the detachment features are observed to remove stratigraphy in each case. Eight such detachment features have been defined to date.

The proximity of the small-scale folds and detachment features to the Duluth Complex and their absence elsewhere, and the axial-planar foliation in the recrystallized calcite hornfels establishes the age of these structures as Keweenawan (syn-intrusion).

These features could be the result of a regional compression, although this seems least likely. The detachment features cut out stratigraphy in the manner of the listric normal faults of the Basin and Range, and may be the result of a regional extension, perhaps associated with mid-continent rifting during the emplacement of the Duluth Complex. The folds are then interpreted as having formed under local compression in the overriding plate of the detachment fault. Alternatively, these features could be the result of body forces (gravity) forming slumps at the country rock-magma interface at the time of intrusion.

ECONOMIC GEOLOGY OF THE RARE ELEMENT
PEGMATITES AT LILYPAD LAKE, NORTHERN ONTARIO

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The tantalum potential of the Lilypad Lake pegmatite field was recognized in 1979 during an exploration program by Tantalum Mining Corporation of Canada Ltd. Exploration for tantalum and other rare metals was prompted at that time by strong demand and rising prices. Previous exploration of these pegmatites had concentrated mainly on lithium mineralization.

Bedrock geochemical surveys, using lithium as the pathfinder element, were successful in locating several mineralized pegmatite dikes. Geological mapping to determine the extent, orientation, and structural environment of these pegmatites was followed by drilling to evaluate their size and grade. The best tantalum mineralization was found to occur in albite-enriched dikes occupying late- to post-tectonic fracture systems. The limited tonnage of these pegmatites, subeconomic tantalum grades, and falling tantalum prices caused abandonment of the project in 1982.

Several geological characteristics of the Lilypad Lake pegmatite field provide important guidelines for exploration of pegmatite-hosted rare metal deposits. In common with several other pegmatite districts in the Superior Province, the Lilypad pegmatites occur on the margin of the English River gneissic belt, suggesting a genetic link to the sedimentary gneisses of this terrain. Although zoning within the Lilypad pegmatite field is not well-defined, it is believed that the tantalum-bearing dikes occupy upper marginal positions within the field. Detailed chemical data is not yet available from these pegmatites, but their mineralogy, including pollucite, lepidolite, colored tourmalines, and fluorite, indicate a high degree of magma fractionation.

FACIES INTERPRETATION OF THE BERRY RIVER FORMATION LAKE OF THE WOODS

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The Berry River formation (Warclub group) occurring along Long Bay and Lobstick Bay in the Lake of the Woods area is a 2 km thick sequence of calc alkaline dacite pyroclastic rocks. Sub units within the sequence were deposited by a variety of volcanic processes. Facies mapping and the development of a facies model has allowed assessment of base metal potential.

The formation was deposited by two phases of volcanism. The older event has a base of redeposited tuff overlain by proximal to distal coarse and fine pyroclastic rocks including units of ash flow tuff. Overlying the proximal to distal pyroclastic facies on the west are redeposited coarse pyroclastic rocks with interbedded wackes. On the east the proximal to distal pyroclastic rocks were intruded by subvolcanic rocks. A thick ash flow tuff unit is associated with this younger event. Outward from the subvolcanic rocks and overlying the ash flow tuff are proximal coarse pyroclastic rocks.

The extensive proximal to distal deposition facies varies from debris flows in the east, doubly graded subaqueous pyroclastic flows and fall-out units in the central portion, to debris flows in the west. Debris flows are massive, indistinctly bedded, in the east and poorly bedded in the west. Subaqueous pyroclastic flows are doubly graded with a tuff breccia base overlain by thickly laminated tuffs. The fall-out units consist of thinly bedded tuffs and pumiceous lapilli tuff horizons.

Interbedded with the proximal to distal deposition facies are conformable, discontinuous massive quartz-feldspar and feldspar porphyry ash flow tuffs with varied grain size, a range of quartz/feldspar phenoclast ratios, and horizons of lithic clasts.

The distal redeposited facies is reworked tuff, lapilli tuff, heterolithic debris flow and lahar with interbedded wacke. Epiclastic feldspathic wacke and quartz-feldspar wacke is correlative with the pyroclastic deposits.

The eastern portion of the Berry River formation is vent facies chaotic, massive, quartz-feldspar porphyry containing rafts, blocks and xenoliths of pyroclastic material.

Outward from the vent facies is the proximal depositional facies coarse homolithic pyroclastic rocks with thin interbedded ground surge or cloud surge tuffs. The surge deposits suggest pyroclastic flow deposition in a shallow water environment.

OLDER UNITS

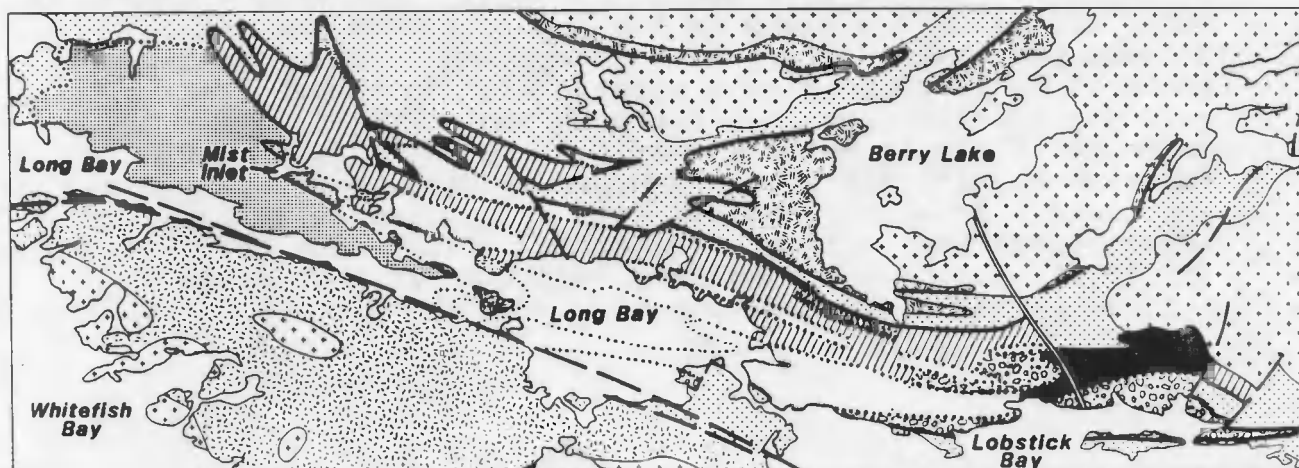
-  Point Bay Group
-  Warclub Group
-  Snake Bay Formation
-  Granitoids

BERRY RIVER FORMATION

-  ash flow tuffs
-  vent facies
-  proximal deposition (shallow water)
-  proximal-distal deposition (component of redeposition)
-  distal redeposition
-  epiclastic facies

-  diabase dike
-  fault
-  lithologic contact
-  stratigraphic contact
-  facies boundary

0 1 2 3 4 5
kilometres



Documentation of a Subaqueously Emplaced Volcanic Horizon
in the Upper Portage Lake Volcanics,
Keweenaw Peninsula, Michigan.

Rodney C. Johnson (Dept. of Geol. and Geol. Engrg., Michigan Technological University, Houghton, MI 49931)

The Portage Lake Volcanics are a series of subareal flood basalts in which to date no subaqueous igneous activity has been documented. This paper documents the existence of a hyaloclastic horizon within the Portage Lake Volcanics (Figure 1). This horizon has a minimum lateral extent along strike of approximately 24 km from Owl Creek in the northeast to Seneca Lake in the southwest part of the Keweenaw Peninsula and a thickness of between 10 and 20 m.

The hyaloclastic horizon typically lacks any textural homogeneity either vertically or horizontally over distances of more than a few meters. In general, the hyaloclastic horizon lies anywhere between two textural end members--a pillowed lava sequence and a true hyaloclastite. Pillowed lava sequences are composed of elliptical to amoeboid vesicular pillows. Vesicles are commonly concentric and occasionally form pipes. These pillows frequently exhibit chill margins or "rinds", concentric cracks and radial joints. The hyaloclastite is composed of vesicular, angular fragments. Fragments range in size from ash-sized to "rinds" and blocks from pillows. The smaller fragments are frequently finely fractured resembling perlitic texture. The hyaloclastite is very colorful due to the secondary minerals: prehnite, epidote, microcline, chlorite, calcite, quartz, and native copper.

Field work was conducted at outcrops on Owl Creek, near the Copper Falls Mine, and on Eagle River. The outcrop on Eagle River is a pillowed lava sequence with hyaloclastite draped on top. The pillows are approximately 50 cm in diameter, have well developed chill margins that are accentuated by red oxidation, sparse concentric vesicles, and contain few pipe vesicles. The outcrop on Owl Creek is a pillow-bearing hyaloclastite. Pillows range in size from 10 cm up to 1 m and are unoriented in a matrix of hyaloclastite. Pillows occur singularly or in interdigitated masses. They generally exhibit well developed chill margins, concentric vesiculation, concentric cracking, radial joints, and occasionally internal cavities. The hyaloclastite occasionally exhibits crude layering and grading. An accurate estimation of the thickness of the hyaloclastite on Owl Creek was not possible since the horizon is cut by a fault.

The hyaloclastic horizon has, in the past, been included in a unit called the Ashbed, a frequently mined horizon. The Ashbed includes rocks that have been characterized as a pyroclastic flow with scorreaceous, highly oxidized, and frequently welded textures. Thus, as currently shown on published geological maps the Ashbed is sometimes the pyroclastic horizon and sometimes the hyaloclastic horizon. On Eagle River both horizons occur with the pyroclastic horizon identified as the Ashbed and the stratigraphically separated hyaloclastic horizon unrecognized.

The hyaloclastic horizon may crop out on Isle Royale. A description by Huber (1975) of a pyroclastic unit similar to the Ashbed and a picture suggests it may be the hyaloclastic horizon. The stratigraphic position of the Isle Royale unit is similar to that of the hyaloclastic horizon/Ashbed on the Keweenaw Peninsula. Although not seen by the author this Isle Royale unit may be correlatable with the hyaloclastic horizon on the Keweenaw Peninsula.

The presence of the hyaloclastic horizon is significant in that it confirms the existence of a body of water concurrent with volcanism. This might be consistent with Livnat's (1983) hypothesis, based on oxygen isotope data, that the fluids which mineralized the Portage Lake Volcanics were sea water, at least in part. However, whether or not the body of water related to the hyaloclastic horizon was sea water or fresh is not known.

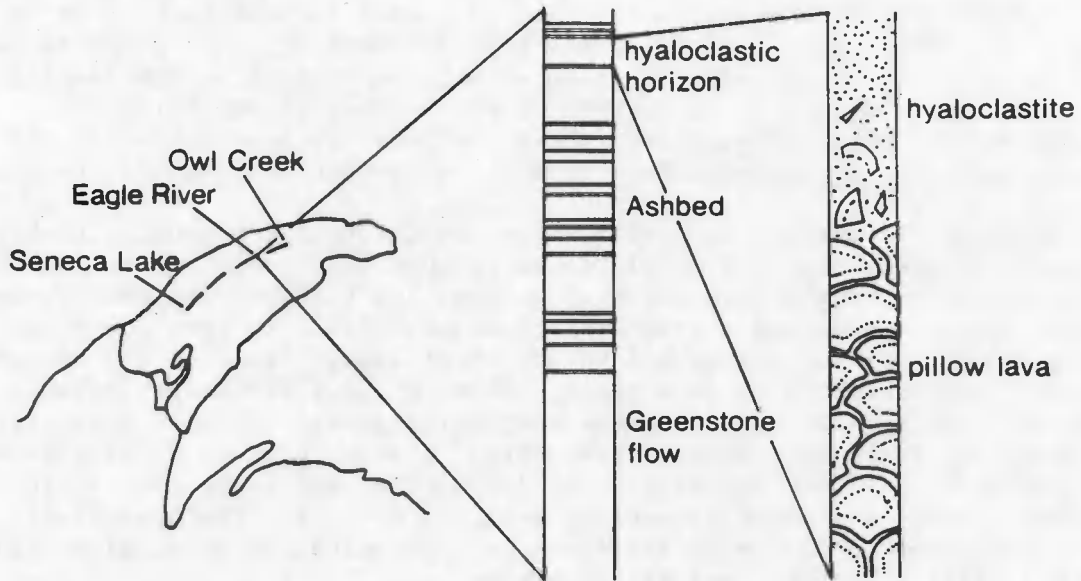


Figure 1. Approximate location of hyaloclastic horizon (dashed line) and generalized stratigraphy near Eagle River.

References:

- Huber, N.K., 1973, USGS Prof. Paper No. 754-C, p. C1-C32.
- Livnat, A., 1983, Ph.D. Dissertation, University of Michigan, 225.p.

The Petrology and Sedimentation of the Lower Proterozoic
Barron Quartzite, Northwestern Wisconsin

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The Barron Quartzite of northwestern Wisconsin is a fine-grained, quartz-cemented, buff to red quartz arenite with scattered quartz pebbles and a thin basal quartz-pebble conglomerate. The thickness of the Barron is at least 225 m (as shown by drill core) and may be greater than 400 m. Mafic dikes cut the Barron Quartzite but are as yet undated.

The primary framework component of the Barron Quartzite is common quartz (75%). Polycrystalline quartz (grains with 2 to 5 component crystals), stretched polycrystalline quartz (composites of numerous, sutured crystals), recrystallized quartz (grains made up of numerous, small, polygonal crystals) and vein quartz together make up approximately 16% of framework grains. Multicycle quartz grains (common quartz grains which have optically continuous overgrowths of quartz that have been abraded and surrounded by other overgrowths) are also present. Chert and iron-formation rock fragments occur but are rare. Feldspar is absent. Quartz cement, which occurs as optically continuous overgrowths on quartz grains, is common (approximately 9%) and hematite cement constitutes less than 1%. The heavy mineral suite is composed almost entirely of rounded zircon with minor rounded tourmaline and rutile, and minor magnetite.

A possible depositional environment for the Barron Quartzite is a braided alluvial plain which was superseded by a marine shelf environment. Paleocurrent data are variable. Most localities show a unimodal pattern towards the south, indicating sediment transport from north to south. However, polymodal and bimodal-bipolar patterns are also present at some outcrops. A unimodal pattern probably indicates a fluvial depositional environment while a bimodal-bipolar pattern could suggest a tidally-influenced marine depositional environment.

The Barron Quartzite is probably correlative with several of the other Precambrian quartzites in the Lake Superior region, including the Baraboo, Sioux, Flambeau, Waterloo, and McCaslin Quartzites. Of these, the Baraboo is the best dated, probably having been deposited between 1760 and 1630 Ma (Van Schmus, 1978; Van Schmus and Bickford, 1981).

Van Schmus, W.R., 1978, Geochronology of the southern Wisconsin rhyolites and granites: *Geoscience Wisconsin*, v. 2, p. 19-24.

Van Schmus, W.R., and Bickford, M.E., 1981, Proterozoic
chronology and evolution of the midcontinent region
North America: in Kroner, A., ed., Precambrian Plate
Tectonics, Elsevier, New York, p. 261-296.

Caliche Paleosol in the Lower Part of the Calumet and Hecla Conglomerate,
Centennial Mine, Calumet, Michigan

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The Calumet and Hecla Conglomerate, a Keweenawan interflow sedimentary unit that is about 1.1 b.y. in age consists at the Centennial Mine of a felsitic conglomerate upper part and of about 1-2 m of siltstone and shale along the base (Figure 1A). In these fine-grained sediments there is a complex sub-mature caliche soil profile represented by an upward increase in calcite and corresponding changes in calcite structures (Figure 1B) (Welch, 1977). There is also caliche calcite in the felsitic conglomerate. All of this calcite predates the period of regional epidote alteration as demonstrated on parts of the 35-level where this calcite has been altered to epidote.

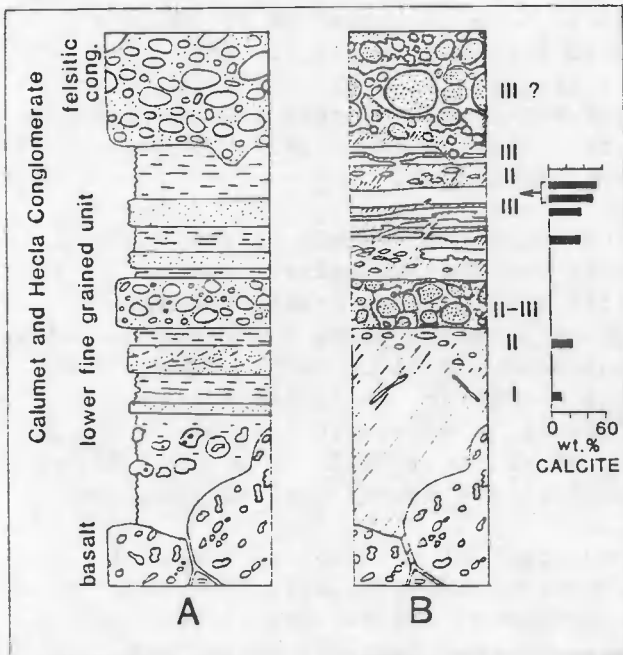
Introduced calcite varies from about 50 to 60 weight percent in some upper layers of the basal unit to 10 weight percent and less in faintly veined mudstone (Figure 1B). The introduced calcite occurs in an upward grading sequence as microscopic veinlets, thin rims on basalt clasts, 3 cm oval nodules, horizontal lenticles that may represent coalesced and flattened nodules, multi-generation veinlets, and as layers with K-fabric. K-fabric is the designation for calcite-rich layers with floating clasts, produced by replacement calcite under shallow overburden conditions (Gile et al., 1965). The above textural sequence is overlain locally by a second similar sequence.

In thin sections the major features are the partial to complete textural replacement of feldspar by calcite and the corresponding relative increase in the proportions of the quartz and opaque components, and the exfoliation of biotite clasts and clay chips by introduced calcite. Textures and structures suggesting carbonatization at a shallow depth are the K-fabric, and a soil microrelief structure -- a local antiformal flexure in calichified shale. Subsequent compaction is suggested by the lensoid shape of calcite nodules, and wrinkles in vertically oriented calcite veinlets.

The fine-grained basal unit has undergone chemical alteration during carbonatization under ambient surface conditions so that a soil forming process and a profile can be identified. However, in the conglomerate the calcite occurs in a less-recognizable form. White sparry calcite rims pebbles and fills interstices between pebbles, generally along subhorizontal zones (Figure 1B). This texture resembles that described by Gile and others (1966) as an intermediate stage of caliche in gravelly soils. Such cemented gravel can be described also as calcrete. A bed of it occurs in the lower fine-grained unit (Figure 1B). These kinds of calcite-cemented conglomerates have been reported from an area that extends from 30 km east of Centennial (Davidson et al., 1955) to about 20 km southwest of Centennial, and are very common in the Copper Harbor Conglomerate both on the peninsula and on Isle Royale (Wolff and Huber, 1973). Because native copper is not abundant in calcite-rich portions of conglomerates, there is the suggestion that the quantity and distribution of native copper in the C and H conglomerate may have been controlled by a pre-existing pedogenic calcite.

New analysis on a hand-picked sparry calcite from a calcite rich layer in the basal unit gave values ($\delta^{18}\text{O}$: +20.9; $\delta^{13}\text{C}$: -1.0) that are indistinguishable from those obtained by Livnat (1983) on all types of calcites in the Portage Lake Volcanics and the Copper Harbor Conglomerate. He concluded that the calcites had undergone homogenization and that their narrow ranges in $\delta^{13}\text{C}$ values denoted a CO_2 source from either single magma or from two sources, one a Precambrian limestone. This probably was the caliche.

The caliche is interpreted to have developed in slowly aggrading sediments that were deposited on a basalt-floored fluvial plain. This took place during the initial stages of slope reversal of the lava plain, from southerly to northerly. Such carbonate accumulation in sediments requires a highly seasonal temperature or tropical climate and represents about 15,000 years of weathering. The corresponding Keweenaw paleolatitude has been reported to be about 30 degrees north.



Generalized sections at the base of the Calumet and Hecla Conglomerate. A, stratigraphy; thickness about 1.5 m; B, Modes of occurrence of caliche (unpatterned). Numbers denote morphologic stage of the caliche; calcite abundance by chemical analysis.

References

- Davidson, E.S. and others, 1954, Bedrock geology of the Mohawk Quadrangle, Michigan: U.S. Geol. Quadrangle Map GQ54, scale 1:2400.
- Gile, L.H. and others, 1965, The K horizon: a master soil horizon of carbonate accumulation: Soil Science, v. 99, p. 74-82.
- Gile, L.H. and others, 1966, Morphological and genetic sequences in carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.
- Livnat, Alexander, 1983, Metamorphism and copper mineralization of the Portage Lake Lava Series, northern Michigan: unpub. Ph.D. thesis, Univ. of Mich., Ann Arbor, 270 p.
- Welch, Edwin J., 1977, Origin of the caliche-bearing mudstone at the base of the Calumet and Hecla Conglomerate, Centennial Mine, Houghton County, Michigan: Unpub. M.S. thesis, Mich. Tech. Univ., Houghton, Mi, 53 p.
- Wolff, R.G., and Huber, N.K., 1973, The Copper Harbor Conglomerate (middle Keweenaw) on Isle Royale, Michigan and its regional implications: U.S. Geol. Sur. Prof. Paper 754-B, p. B1-B15.

STRUCTURE OF THE BEARDMORE - GERALDTON FOLD BELT

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Between Beardmore and Geraldton, complexly folded Archean meta-sedimentary and metavolcanic rocks form an intervening terrain bounded on the north and south by structures of the Wabigoon and Quetico sub-provinces respectively.

The Beardmore - Geraldton fold belt is divisible into several narrow, east-west trending segments, based on the structural facing direction of folds. Structural facing directions are either east or west. Depending on fold hinge line orientations, folds face upward, sideways, or downward. Where the structural facing is upward, individual folds are either anticlines or synclines. Where the structural facing is downward, these structures are synformal anticlines or antiformal synclines. Sideways structural facing is associated with neutral folds.

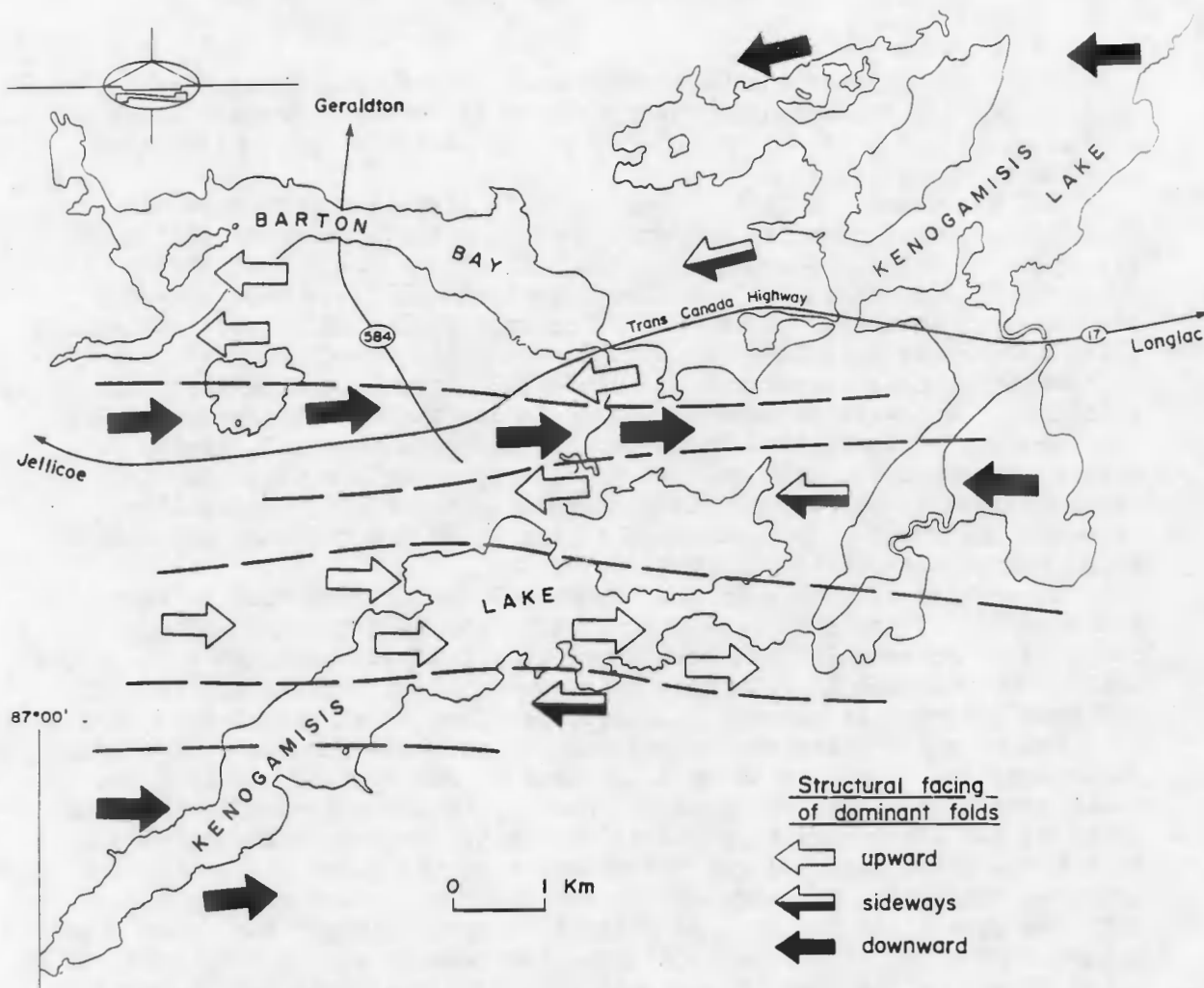
Because of variations in structural facing within and between narrow segments, the fold belt as a whole represents a disrupted and discontinuous stratigraphy. Discontinuities separating distinctive segments are zones of pronounced shearing which are coplanar with the axial schistosity of the dominant folds.

Documented reversals in the structural facing direction between the segments of the fold belt suggest that the last folding episode occurred in rocks which had been previously folded. Although no refolded folds were observed in outcrop, the presence of an earlier schistosity has been recorded in several thin sections from widely separated localities.

The second folding was in response to an inhomogeneous fold-forming shear component accompanied by a homogeneous compressive strain. The shear component formed folds of various amplitudes and wavelengths with shear planes everywhere parallel to the axial surface of these folds. Fold hinge lines parallel the intersection of the shear planes and the surfaces undergoing folding. Where the shear direction lies in the surfaces undergoing folding, no folds developed although the rocks show evidence of internal deformation. The homogeneous strain component acted normal to the shear planes and preserved the similar fold forms. Maximum extensive strains parallel the shear direction, and shear discontinuities are most evident in fold hinge zones and less so on fold limbs where the layering and axial planar schistosity are commonly sub-parallel.

The structural history of the Beardmore - Geraldton fold belt may be summarized as follows:

- D₁ Deformation and metamorphism of sedimentary and volcanic rocks producing, at least in part, folds and an accompanying axial planar schistosity. Gravity tectonics including thrusting may have been responsible for the inversion of portions of the stratigraphy.
- D₂ Development of similar folds by inhomogeneous shear and homogeneous strain in surfaces of variable orientation. Shear discontinuities became locally concentrated as shear zones in thin competent layers. Large scale transposition of individual, shear zone bounded segments led to the disruption of the stratigraphy of the fold belt.



Eastern portion of the Beardmore-Geraldton fold belt. Individual segments reflect variations in the plunge direction of hinge lines and the structural facing of folds. The segments are separated from each other by shear discontinuities.

STRUCTURAL GEOLOGY AND KINEMATICS OF EARLY PROTEROZOIC SHEAR ZONES IN CENTRAL WISCONSIN

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Rocks at Eau Claire Dells, March Rapids, and Athens in central Wisconsin have numerous structural features that lend themselves to field analysis of the nature and kinematics of deformation. At EAU CLAIRE DELLS deformation has produced a partially developed sigmoidal pattern in foliation trends in which ENE foliations are progressively overprinted and finally replaced by the NNE foliation. Strain features in the Dells shear zone show vertical elongation and WNW horizontal compression. Kink bands and crenulation folds of foliation indicate multiple periods of deformation. Xenoliths of intensely deformed rock in the Wolf River batholith near the Dells suggest that deformation at the Dells predated intrusion of the batholith. Structural measurements near MARCH RAPIDS indicate that tonalitic gneiss at the rapids is separated from metasedimentary and metavolcanic rocks to the north by a zone of intense brittle deformation. Foliation at March Rapids south of the breccia zone strikes WNW and dips steeply N. Axes of folds in the foliation plunge steeply to the E as do the long axes of ellipsoidal shaped clasts in the gneiss. The foliation and E-trending fold axes were refolded into steep N-plunging open folds. Foliation north of the breccia zone strikes ENE and dips steeply S. Folds in bedding plunge 30° to the E as do the long axes of ellipsoidal clasts. Foliation has been deformed by kink bands. At ATHENS conspicuous foliation in felsic mylonite strikes NE and dips steeply NW. Its orientation differs from structural orientations in all other rocks in the region. The structural relationship between nearby bedded rocks and mylonitic shear foliation is nearly identical with a ductile shear zone on highway U. S. 51 near Brokaw. Foliation in metavolcanic rocks south of the Athens shear zone strikes ENE and dips steeply NW. Fold axes in this region plunge gently ENE and the X axes of ellipsoidal clasts are nearly vertical. Migmatitic gneiss at Goodrich Dells, about 7-miles north of Athens, has an ENE-trending, nearly vertical foliation and SW-plunging folds.

All three areas are characterized by linear zones of intense deformation that diverge from the regional structural fabric and that separate regions with different structural pictures. Eau Claire Dells and Athens are ductile shear zones. The March Rapids area is a zone of brittle deformation; it is possibly a ductile-brittle zone of shear. These shear zones are believed to have resulted from stresses that were different from those that produced the regional structural fabrics in the three areas.

GEOLOGICAL SETTING OF GOLD MINERALIZATION
IN BEARDMORE-GERALDTON
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As is typical for most Archean greenstone belts, gold mineralization in the Beardmore-Geraldton camps is hosted by almost all lithologic types, thus specific lithological associations cannot be used as a common denominator. This is a fundamental genetic feature of Archean gold mineralization. The host rocks represent a broad spectrum of geologic time and events, from the oldest volcanic and sedimentary rocks to the youngest Archean intrusions. Uniform gold distribution in all lithologic types suggest that the mechanism of gold concentration is independent of the processes associated with these rocks. It does, however, suggest that a single process was active throughout the belt and affected all lithologies uniformly on a regional scale. However, on a local scale each lithology responded differently to the process. This process affected young intrusions which post date the supracrustals and subsequent isoclinal folding. In Geraldton, field relationships have clearly established that the relative timing of those hydrothermal processes responsible for gold mineralization, with respect to the host rocks, were the last events in the evolution of the greenstone belt. The formation of supracrustals was succeeded by the following sequence of events; isoclinal folding, regional dextral shear, mafic magmatic activity, felsic magmatic activity and finally gold mineralization. Dextral shear was an ongoing process from its onset thru to the last stages of gold mineralization.

The common denominator to all gold mineralization in this belt is the association with zones of high strain, regional in extent. This entire greenstone belt has undergone pronounced dextral ductile shear. This has produced the rather unique linear, E-W trending volcanic and sedimentary belts. This is distinct from lower strain greenstone belts in which lithologic packages do not have regional preferred orientation. The present configuration of the belt can only be produced as the result of extremely high stress. The E-W trending contacts between all major lithologic units are zones of high strain. Zones of high strain also occur within these lithologic packages. Gold mineralization is found exclusively within these zones of high strain. In Geraldton, these zones also contain an anomalously high proportion of both felsic and mafic intrusives. It appears therefore that strain induced permeability focused magmatic and hydrothermal activity which resulted in alteration and mineralization. These zones of high strain are easily identified; all primary volcanic, igneous and sedimentary textures have been either modified or obliterated. These zones may also be identified by tight repeated folding and the presence of an anomalously high proportion of intrusions. In conjunction with the identification of high strain, the presence of hydrothermal alteration, serve to identify areas with high gold potential.

RANIER, MINNESOTA, MINERAL POTENTIAL EVALUATION: OUTCROP
SAMPLING, GEOPHYSICS AND SOIL GEOCHEMISTRY

The Ranier area is located east of International Falls, Minnesota, just south of the Canadian border. Outcrops in the area display many of the same structural, lithologic and metamorphic characteristics as large Canadian gold deposits. At Little American Island 500 tons of gold bearing rock was mined and milled in 1894, which would be ore grade at present day prices.

Very low frequency electro-magnetic traverses at Little American Island, map a distinctive profile. The profile defines silicification in a fault zone. Magnetometer observations show a vague indication of geologic units. These characteristic VLF-EM profiles are repeated at several locations. Detailed induced polarization surveys, coincident with VLF-EM surveys, define structural features and locate near surface disseminated sulfides. Refraction seismic profiles tested one such structural feature and clearly mapped a fault zone. They also help interpret I.P. results.

One of the goals of this mineral potential evaluation is to compare three geochemical sample media over gold bearing lithologies. These three media are: vegetation; "Ao" (humus) horizon, and "A₁" soil horizon. A limited number of samples from all three media correlate to help locate areas of interest and select drill sites. These are defined by anomalous samples as high as twenty times background.

Two diamond drill holes confirm structures, silicification and sulfides. Mineralization is indicated by assays of short core intersections with anomalous gold content. These include one six inch intersection from DDH RR-1 of 3.56 ppm gold. The fault structure defined by refraction seismic methods was further tested by DDH RR-2. The highest gold assays for this hole were located in intersections flanking the indicated fault zone.

Mineral potential evaluation methods for Ranier area include: (1) a literature search; (2) geophysical and geochemical surveys of a known mineralized area; (3) extension of these surveys along a mapped area of interest; (4) tests of geophysical data with outcrop and collaborating geophysical methods; (5) drill holes with assays. This evaluation indicates an area of excellent precious metal mineral potential. If more information is desired, it can be obtained from the D.N.R. Minerals Division, P.O. Box 567, Hibbing, MN 55746, phone (218) 262-6767.

By: T. L. Lawler
J. M. Sellner

The Petrology of the Longnose Peridotite
Deposit and its Relationship to the Duluth Complex

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The Longnose Peridotite deposit is a funnel shaped, titaniferous oxide rich, layered ultramafic body located 8 km. N.E. of Hoyt Lakes, Minnesota. The Peridotite lies 780m. above the base of the Partridge River Troctolite--a basal, middle Proterozoic intrusion of the Troctolitic Series in the Duluth Complex. Eight units were distinguished in mapping the surrounding country rocks of the deposit. They range in composition from troctolitic anorthosite to feldspathic dunite, with anorthositic troctolite to troctolite being the most abundant. The units trend N.E., and dip 10-25 degrees to the S.E., younging eastward. This trend is concordant with the Virginia formation-Partridge River Troctolite contact. No contact was seen between the country rocks and the Longnose Peridotite. These strata are stratigraphically high in the Partridge River Troctolite, which has been postulated to have formed by multiple intrusion of magma from the S.E. along the lower Proterozoic Virginia contact and middle Proterozoic North Shore Volcanic group.

The deposit is "tear drop" in plan view, trends N.W.-S.E., and is approximately 762m. long by 90m. to 488 m. wide. In longitudinal section it forms an asymmetrical funnel; the contact on the N.W. dips approximately 15-20 degrees to the S.E., and the contact on the S.E. dips approximately 70 degrees to the N.W.. The Peridotite appears to be layered with an outer shell of relatively oxide poor clinopyroxenite and an inner core of layered, anomalously rich ilmenite-magnetite dunite, peridotite, and picrite, with massive oxide zones occurring within some of the dunitic zones, the largest of which is 40m. thick. Troctolitic anorthosite inclusions are common.

The dunitic zones are weakly to strongly serpentized with minor secondary magnetite, hematite, chlorite, talc and carbonate. The clinopyroxenite zone consists of titanaugite and is slightly altered to hornblende, actinolite-tremolite, and talc. Plagioclase may be altered to chlorite or clay. The oxides remain unaltered except for some occasional minor martitization of magnetite. The Peridotite is riddled with near vertical fractures which commonly have slickensides.

Ilmenite and magnetite constitute the bulk of the ore mineralogy with minor (less than 5% combined) ulvöspinel?, chalcopyrite, and an isotropic grey mineral. Ilmenite-magnetite most commonly occur in a broken net-textured fashion, but may also be disseminated or massive. The contacts between these textures can be gradational or sharp. The crystallization sequence between ilmenite and magnetite varies within and

between units where either may be cumulate and the other interstitial or both may be cumulate or interstitial in relation to the silicate minerals. Ilmenite exsolution lamellae commonly occur along octahedral cleavage in magnetite. An isotropic grey mineral (spinel?) commonly occurs in both ilmenite and magnetite. In magnetite it can form along cleavage or as vermicular intergrowth with ilmenite along magnetite-ilmenite grain boundaries. Ilmenite may contain faint white bands which are interpreted to be ulvospinel. Chalcopyrite is the major sulfide mineral averaging 1%.

The troctolitic anorthosite inclusions appear to be Partridge River Troctolite which were rafted upon intrusion of the Longnose Peridotite into the Duluth Complex.

Minor Folds in the Soudan Iron Formation,
Northeastern Minnesota

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Minor folds in the Soudan Iron Formation (SIF), part of an Archean greenstone/granite terrane in northeastern Minnesota, have been examined in detail. Previous work suggests the presence of a large recumbent nappe structure. This structure and associated minor folds (F1) have been reformed during a second tectonic event (F2). This study attempts to elucidate the geometry and nature (soft-sediment or tectonic?) of folds of both generations, with a particular emphasis on trying to understand better the nature of the early folds and the large nappe-like structure. The SIF is especially useful for this sort of study since it is made up of layers of different composition and competence that became folded on a small scale during both deformational events.

A wide variety of fold shapes is observed, ranging from broad warpings of the layering to concentric, similar, and chevron shapes. Using appropriate quantitative techniques, these shapes are described in detail. F1 folds tend to be of Class 1C or Class 2 shape, with wide variations in interlimb angle. F2 folds tend to be Class 1C in shape, with fairly consistent orientations and a much narrower range in interlimb angle. White cherty layers consistently behaved more competently than lean jasper or jaspilite layers.

Detailed mapping and measuring of fold axes, axial surfaces, and other structural elements has been done in an outcrop showing exceptionally fine fold interference patterns of F1 and F2. Field relationships suggest sheath folds are present, and that they are F1 in age. Fortuitous XY and XZ cross-sections of sheaths, and intersections of fold axes on opposite sides of YZ cross-sections of sheaths suggest that high strains were suffered during F1. Shear direction during F1 is more difficult to assess due to movements during F2.

Several lines of evidence seem to support earlier views that the large fold arose at least in part due to downslope soft-sediment movement. This evidence includes: wide variety of fold style and orientation of F1 folds; non-uniform distribution of F1 folds; intrafolial nature of these folds; the likely development of sheath folds and associated high shear strains during F1.

Unconformity-Type Uranium Mineralization at the Groveland Iron Mine, Central Dickinson County, Michigan

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A significant radiometric anomaly and uranium mineralization were detected immediately beneath the unconformity between Cambrian sandstone and underlying Lower Proterozoic metasediments and metadiabases at the Groveland Iron Mine, Dickinson County, Michigan. Chemical analyses of 23 samples taken from 0.1 to 1.0 meters below the unconformity yielded uranium values ranging from 0.8 to 28.0 ppm. (Background averages approximately 2 ppm.) This uranium mineralization can be compared to the unconformity-type uranium ore deposits in the Athabasca Basin of Northern Saskatchewan.

The Groveland Iron Mine is located 16 miles northeast of Iron Mountain in Central Dickinson County, Michigan. The Lower Proterozoic rocks of the Groveland Mine area are found in the Felch Trough, and are bounded to the north and south by Archean gneisses and granites. The rocks in the trough consist of amphibolite, garnet mica schist, iron formation, marble and quartzite which strike approximately E-W and dip nearly vertically. These metasediments were folded, faulted, intruded by both granitic and gabbroic rocks and metamorphosed to the amphibolite facies during the Penokean Orogeny (1.85 b.y.). Flat lying Upper Cambrian sandstone and Pleistocene glacial drift overlie the Precambrian rocks. The sandstone is the Miner's Castle Member of the Munising Formation which is the upper member of the Upper Cambrian Lake Superior Sandstone Group.

The Lower Proterozoic rocks underwent extensive erosion and weathering after the Penokean Orogeny and prior to the deposition of the Cambrian Sandstone. The weathering produced a paleoregolith that is up to 30 meters thick. The most important mineral changes were alteration of feldspars and mafic minerals to illite, kaolinite and chlorite. Analysis of the paleoregolith immediately below the unconformity yielded values ranging from 0.1 to 0.5% reductant calculated as organic carbon.

As a working hypothesis, the following genesis is proposed: Oxidizing ground waters, carrying uranium in solution in the U +6 state which was derived from weathering of local Archean granite and gneiss highlands, passed through the oxidized Upper Cambrian sandstone aquifer without reaction. However, the altered basement rocks below the unconformity presented a major break in structure, mineralogy and chemistry and a sudden decrease in porosity and permeability. The U +6 in the oxidized fluids reacted with the reductant in the regolith immediately below the unconformity reducing the uranium to the U +4 state which was deposited as uraninite.

THE ATIKOKAN COBALT-BASE METALS-PLATINUM GROUP ELEMENTS PROJECT

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The project was initiated in May, 1984 to examine and document the cobalt, base metal and platinum group element occurrences in the Atikokan Area, to study in detail the most significant of these occurrences and to stimulate exploration. The detailed research will attempt to outline the geological and structural setting, ore and silicate petrology, petrochemistry and potential of the occurrences.

Initial reconnaissance sampling, assaying and geological mapping were done during the 1984 field season and concentrated on three locations: the Finlayson Lake Area, the Sapawe Lake-Plateau Lake Area, and the Crooked Pine Lake Area. This work has revealed the presence of five preliminary 'deposit' or 'occurrence' types. They were determined on the basis of lithology, structure and associated sulphide mineralogy, which might host cobalt, base metal or platinum group mineralization.

1) 'The Quetico Fault-Hosted Intrusions' contain significant cobalt, copper and nickel sulphides closely associated with disseminated to massive magnetite lenses within sheared, syntectonic gabbroic to ultramafic intrusive rocks. A similar potential for cobalt, copper and nickel should exist within other intrusions of this type. The possibility of platinum group enrichment is high in the presence of copper and nickel sulphides.

2) 'The Quetico Intrusions' are mafic to ultramafic bodies exhibiting high local concentrations of copper, nickel, cobalt, platinum and palladium. The base metals occur in disseminated pods of chalcopyrite, pyrite and pentlandite. The, as yet unidentified, platinum group minerals are probably closely associated with the chalcopyrite and pentlandite. The potential for base metal and platinum group mineralization in these and other similar bodies is high and should be investigated further.

3) The deformed, banded chert and iron-rich chemical meta-sediments of the Finlayson Lake Area locally contain copper, cobalt and minor zinc and silver within primary exhalative (?) sulphides. The sulphides, composed of pyrrhotite, pyrite, chalcopyrite and sphalerite, are fine to coarse-grained, banded to nodular, and disseminated to massive in appearance.

4) and 5) Shear zones and quartz veins throughout the Atikokan Area exhibit localized disseminated copper, lead and zinc mineralization. Auriferous quartz veins generally have associated base metal mineralization occurring either as semi-massive lenses or as disseminated blebs. Cobalt was observed in association with a possible splay fault of the Quetico Fault Zone.

Detailed research is planned during 1985 on the Quetico Intrusions and the Quetico Fault-Hosted mafic bodies. Reconnaissance work will be done in the Calm Lake Area, the Lumby Lake-Old Man Lake Belt, and portions of the Shebandowan Area.

CHEMICAL CHARACTERIZATION OF THE UNNAMED FORMATION
A CENTRAL VOLCANIC COMPLEX OF KEWEENAWAN AGE

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The Unnamed Formation provides a unique opportunity to study the evolution of a Proterozoic volcanic system throughout its waning stages. The Unnamed Formation is the youngest of the Keweenawan volcanics in Michigan. It is a sequence of subaerially extruded andesite, felsite, and quartz-porphyry lava flows interbedded with subordinate sedimentary rocks. The upper 770 m of the Formation forms the uplands of the Porcupine Mountains. Regionally the the Formation is a volcanic pile which reaches its maximum thickness measurable at the surface of 2400 m in the Bergland and Thomaston quadrangles, about 8 km. south of the Porcupine Mountains. It wedges out in the Greenland quadrangle to the east and in the Little Girl Point quadrangle to the west.

The Unnamed Formation is conformable with the underlying Portage Lake Lava (PLL) series and is distinguishable from it by differences in rock type. The mafic PLL are predominantly basalts, whereas those of the Unnamed Formation are finer grained and contain a greater proportion of porphyritic and felsic rocks. The Copper Harbor Conglomerate conformably overlies, and is interbedded with, the Unnamed Formation (Hubbard 1975).

There is a large spectrum of major element variation within the rocks of the Formation. Silica content, which varies from 45.8 to 76 %, can be used to discriminate basic, intermediate, and acidic flows. On the basis of other characteristic oxides, $\text{CaO} - \text{TiO}_2 - \text{P}_2\text{O}_5 - \text{MnO}$, and the $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio, there is a strong dichotomy between the basic + intermediate flows and acidic flows. In the former group the $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio increases to a maximum which corresponds to a SiO_2 content of 65%, whereas this ratio decreases with increasing silica content in the acidic rocks. Major element modeling cannot adequately explain these oxide abundances on the basis of crystal fractionation models. Although trace element data are not complete, it is suggested that crustal melting would best explain the origin of the acidic flows.

Hubbard H.A. (1975) Lower Keweenawan volcanic rocks of Michigan and Wisconsin. U.S. Geol. Survey Jour. Research 3, 529-541.

**THE INFLUENCE OF SHEAR ZONE GEOMETRY AND VEIN PARAGENESIS
ON GOLD-PYRITE MINERALIZATION AT CAMERON LAKE,
NORTHWESTERN ONTARIO.**

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The history of gold exploration in the Kenora-Fort Frances area of northwestern Ontario dates back to the mid-1800's. Activity peaked between 1890 and 1910 when the area accounted for over 55 percent of Ontario's total gold production. Although the area hosts no presently producing gold mines, optimism is again high in view of the recent Cameron Lake gold rush.

The Cameron Lake gold deposit, located 80 km south-southeast of Kenora, was originally discovered in 1960 by prospectors working for Noranda Mines. Low gold prices at that time coupled with a complex subsurface geometry and poor outcrop exposure discouraged investment and development. Four separate diamond drilling programs were conducted on the property prior to the discovery of a major zone of gold mineralization in 1983 by the Nuinsco/Lockwood joint venture. Proven reserves at that time totaled 1,287,000 tons grading 0.154 oz/ton Au, including 807,000 tons grading 0.194 oz/ton Au.

The Cameron Lake gold deposit is situated near the stratigraphic transition between a lower, mafic volcanic succession (Rowan Lake Volcanics) and an upper mixed mafic to felsic, partly pyroclastic succession (Cameron Lake Volcanics), but within the latter. The deposit is epigenetic, structurally controlled and occurs in sheared mafic metavolcanic rocks adjacent to the sheared intrusive contact with a metagabbroic sill. The shear zone hosting the gold deposit is a brittle-ductile, dextral strike slip system with an attitude of 315/70° W and a displacement vector pitching 5° W. Ore shoots pitch approximately 70° W within the plane of the shear zone. There is limited evidence to suggest that the Cameron Lake Shear Zone is related to the regionally prominent Pipestone-Cameron Fault.

Three distinct veining episodes have been recognized cutting the carbonatized mafic metavolcanic rocks of the Cameron Lake Shear Zone:

- (i) early, barren extensional quartz-carbonate veins which have been buckled;
- (ii) a major system of gold-bearing pyritic, quartz breccia veins;
- (iii) late cross-cutting quartz-carbonate-chlorite-hematite-gold, en-echelon extension veins.

The significance of the stage (ii) breccia veins has been previously underestimated. They represent a specific ore type which generally grades greater than 0.19 oz/ton Au. The other, lower grade ore type, consists of pervasively altered carbonate-sericite-pyrite rich phyllonitic rocks and occupies a large volume of the Cameron Lake Shear Zone enveloping the breccia veins.

The transition from ductile cleavage development to brittle processes within the Cameron Lake Shear Zone is manifested in the formation of veins and vein breccias. The change from ductile to brittle behavior may be the result of local increases in hydrothermal fluid pressure which facilitates brittle deformation and vein formation by reducing the effective normal stresses. The phyllonitic rocks formed a sink for the gold-bearing fluids, while the breccia veins formed major conduits enhancing fluid circulation.

The localization of economic quantities of gold along the Cameron Lake Shear Zone corresponds to the development of oblique, secondary, dextral, bedding-controlled sympathetic shear zones. At the confluence of these two shear systems a steeply pitching, dilatant zone was created in which ascending hydrothermal solutions precipitated gold. The shear zone model serves to explain the complex subsurface geometry of the deposit, as well as the existence of hanging wall and footwall zones on either side of the main zone of gold mineralization.

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PETROGENESIS OF ANORTHOSITIC ROCKS OF THE DULUTH COMPLEX

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The mafic plutonic rocks of the Middle Proterozoic Duluth Complex in northeastern Minnesota include a wide variety of plagioclase-rich (Pl >85%) rocks belonging to the early-formed Anorthositic Series, as well as younger rocks dominated by troctolite and olivine gabbro (Troctolitic Series). Understanding the petrogenesis of the anorthositic rocks, which could not have crystallized directly from basaltic liquids, is requisite to understanding the origin of the Duluth Complex. Field, petrographic, and petrochemical studies of the Duluth Complex in the Snowbank Lake quadrangle have been useful in characterizing the kinds of anorthositic rocks that are present and in establishing their genetic relationship to one another and to the younger Troctolitic Series rocks.

The major anorthositic rock types are distinguished by modal composition, plagioclase grain size, and olivine habit (granular vs. poikilitic; Miller and Weiblen, 1982). Field observations of complex internal structures (based on lamination) and intrusive and stratiform contact relationships imply that the Anorthositic Series rocks formed from diverse magma types during at least three major stages of episodic intrusion. Reported here are: 1) what are believed to be the physical and chemical characteristics of the magmas that produced the suite of anorthositic rocks and how these characteristics changed over the intrusive history of the Anorthositic Series; and 2) the presumed difference between the magmas that produced the Anorthositic Series and the younger Troctolitic Series.

All Anorthositic Series magmas were intruded into subvolcanic chambers at depths of about 5-10 km as crystal mushes containing as much as 50 percent intratelluric plagioclase. Consequently, the sequential intrusions of these viscous magmas considerably disrupted the internal structure of previous crystal accumulations. The compositional range of complexly zoned, intratelluric plagioclase (An 50-70) is the nearly same for all anorthositic rock types.

Textural, modal, and mineral compositional data imply that the compositional diversity of the plagioclase-laden magmas varied in two general ways: 1) in their MgO/MgO+FeO ('mg') composition and other compositional parameters indicative of the degree of differentiation; and 2) in degree to which the magmas were olivine-saturated. In general, olivine-undersaturated magmas were more differentiated (i.e., lower 'mg') than those with olivine on the liquidus upon intrusion. Most of the compositional diversity was apparently a primary characteristic of the Anorthositic Series magmas as they were intruded into the Duluth Complex as opposed to having resulted from differentiation within the Complex chambers.

The earliest stage of Anorthositic Series magmatism produced medium- to medium-coarse-grained troctolitic anorthosites and poikilitic olivine anorthosite. These early magmas had the highest average 'mg' composition (25-30 mole%) and varied in the degree to which they were olivine-saturated upon intrusion. Olivine-saturated magmas crystallized granular olivine interstitial to plagioclase in troctolitic anorthosite, whereas those that were undersaturated in olivine produced poikilitic crystals. Poikilitic olivine probably formed by rapid growth after magmas became supersaturated with olivine to the extent

necessary to nucleate crystals. In contrast to the early stage, main stage magmas produced generally coarser grained and more gabbroic rock types. Although the average 'mg' composition of the main stage magmas was lower, the degree of olivine saturation was similar to that in the early stage magmas. During late stage magmatism, olivine-undersaturated magmas decreased in relative abundance such that predominantly troctolitic anorthosite was produced. The modal compositions of many of these late stage troctolitic anorthosites approach those of "normal" troctolite (Pl <85%) implying a decrease in the amount of plagioclase initially entrained in the magmas. Moreover, these magmas were more consistently saturated with both olivine and plagioclase upon intrusion into the Duluth Complex. The late stage Anorthositic Series magmatism is interpreted to be transitional to those events which produced the Troctolitic Series.

Petrochemical data from both rock series of the Duluth Complex and from a variety Keweenawan mafic volcanics imply that the parent magmas were derived by open system fractionation of more primitive magmas in mid- to lower crustal magma chambers (15-40 km). Although Anorthositic Series magmas were enriched with plagioclase crystals and were, on average, more compositionally evolved than Troctolitic Series magmas, both series were derived from the same primary magma type. Its composition can be approximated by the primitive high-Al olivine tholeiites of the North Shore Volcanic Group (Green, 1981) and is similar to MORB except that it is considerably enriched in incompatible elements. Major element data indicate that clinopyroxene and spinel, in addition to olivine and plagioclase, were important fractionating phases, as would be expected under deep crustal pressures (5-10 Kb). Plagioclase was enriched in the early magmas in part because of the effect of pressure on the buoyancy of plagioclase in mafic magmas. A decrease in the amount of entrained plagioclase and a trend toward more primitive magma compositions with time may be related to a decrease in the depth of source magma chambers and a decrease in the residence time of primary magma in the crust, respectively. This is consistent with crustal attenuation as rifting progressed. The transition from Anorthositic to Troctolitic Series magmatism is comparable to that observed at modern rift systems where the rate of spreading increases (Flower, 1984).

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- Miller, J.D. and Weiblen, P.W., 1982, 28th I.L.S.G., p. 26.
Green, J.C., 1981, Basalt Volcanism Study Project, LPI, p. 30.
Flower, M.F.J., 1984, *Geology*, v. 12, p. 651.

STRATIGRAPHY AND HYDROTHERMAL ALTERATION IN AN ARCHEAN STRUCTURAL ZONE, THE KATISHA LAKE AREA, WABIGOON SUBPROVINCE, N.W. ONTARIO

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The Katisha Lake area (92 30'00" - 49 22'00"), displays an exceptionally well preserved Archean stratigraphic section comprising five discrete volcanic episodes centered around a major uplift zone. This tectonic zone was the focus for associated shear zone development, intrusive activity and hydrothermal alteration.

The basal portion of the stratigraphy comprises the Wapageisi Lake Group of tholeiitic basalts overlain by heterolithic breccias, intruded by a layered gabbro sill and capped by quartz porphyritic felsic volcanics. Uplift and erosion prior to, and during the capping felsic volcanism, led to production of an angular unconformity. The overlying Stormy Lake Group comprises a thin basal polymictic conglomerate, overlain by some 500 m of dacitic breccias, followed by a thick sequence of polymictic conglomerates. After dacitic volcanism, a series of vertical, conjugate, ductile shear zones trending 120 and 180 formed in the Wapageisi Lake Group rocks. Widespread carbonate veining and alteration occurred in and adjacent to, these shear zones. Synchronous carbonate alteration in the Stormy Lake Group consisted of non-shear/vein related areas of widespread pervasive carbonate-pyrite and magnetite-chlorite-pyrite alteration. A series of composite, mafic to ultramafic dykes intruded into the shear zones during active carbonate alteration maybe related to subaqueous trachy-basalt flows which extruded, as part of the Stormy Lake Group, some 600 m above the active shear zones. Later silicification with associated py, asp and Au overprinted the carbonate-bearing zones. East-west trending dextral fault zones with associated quartz diorite dykes marked the end of Stormy Lake Group sedimentation and maybe associated with batholith emplacement and northward tilting of the entire package. Late northeasterly trending sinistral faults associated with the Manitou Fault system to the west cut all the above rock types and structures.

THE MULCAHY LAKE GABBRO AND RELATED INTRUSIONS

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The Mulcahy Lake gabbro is a 63 square km layered mafic intrusion which resembles the Skaergaard in many respects. The intrusion is centered at 93.25W and 49.35N, about 50 km southwest of Dryden at the southwestern limits of Eagle Lake. The gabbro intrudes basaltic to siliceous units of the Lower Wabigoon Series, part of the Crow Lake-Savant Lake greenstone belt. Two mafic to siliceous sequences may be represented in the volcanics. Diorites and granodiorites of the Atikwa batholith intrude both gabbro and volcanics. Zircon from the gabbro yield a U/Pb age of $2733.2 \pm 1.0/-0.9$ my. (1). Previously published zircon data (2) indicate crystallization of the batholith at $2731.8 \pm 1.6/-1.3$ my. to 2732.3 ± 2.9 my., one to five million years at most younger than the gabbro. The volcanics vary from 2743 to 2735 my. approximately (2). Sm-Nd analyses show that the gabbro was derived from a source depleted in light rare earth elements (1). The initial Sr ratio of the gabbro is 0.7007, consistent with other intrusives and extrusives from the Wabigoon and Quetico subprovinces, including the Atikwa batholith, and suggestive of a moderate Rb depletion in the source compared to the Abitibi.

The intrusion consists of a lower and middle zone each about two km thick, a one km thick upper zone and marginal zones of variable thicknesses. Each zone represents a distinct cooling and fractionating regime. The lower and middle zones fractionated from the floor upward whereas the upper zone fractionated from the roof downward towards the interior of the intrusion. Marginal zones fractionated from the walls toward the interior. The primary phases are plagioclase, pyroxenes including pigeonite, hornblende and oxides. Olivine occurs in ultramafic units at the base of the lower zone and in the upper zone, in iron-rich units at the top of the lower zone, and in a meter-thick marker horizon near the base of the middle zone. The oxides are chromite to chromian spinel and later magnetite. Plagioclase, pyroxenes and olivine form cumulates. Hornblende and magnetite are intercumulus phases. The bulk composition is tholeiitic and fractionation follows an iron-enrichment trend with a decreasing Mg/Mg+Fe ratio with stratigraphic height and a relatively constant silica content.

Reversals in the Mg/Mg+Fe ratio in pyroxenes and concomitant changes in other phases show that the middle zone represents an influx of relatively pristine liquid following nearly complete fractionation of the pre-existing liquid in the chamber. Smaller scale reversals within the middle zone itself indicate further introduction of liquid as the middle zone melt crystallized. The contacts between zones are complex interleavings of fractionated and less fractionated assemblages. Relatively dense liquids produced by crystallization near the walls (as liquid moved past them) appear to have been convected downward to form anomalously fractionated horizons in the middle zone and possibly the lower zone as well.

Dike-like ultramafic cumulates of olivine and pyroxenes with minor plagioclase and chromite outcrop in Straight Lake, south of the Mulcahy Lake gabbro. Similar cumulates occur in the upper zone of the gabbro. These latter cumulates contain cumulus chromian spinel and intercumulus magnetite. The presence of intercumulus magnetite indicates that the ultramafics are co-magmatic with the gabbro. The presence of chrome-rich species in both the Straight Lake and Mulcahy Lake ultramafics alike suggests a correlation between the two. If so, both the floor and the roof of the intrusion are characterized by the presence of ultramafic cumulates representing the first products of crystallization of the initial liquid.

Layered intrusions closely resembling the Mulcahy Lake gabbro in bulk composition, crystallization sequences and which are identical in stratigraphic age occur on the northern periphery of the Atikwa batholith at Trap Lake, Nabish Lake and Denmark Lake, a distance of 80 km. (Chromite is a prominent phase in the Trap Lake ultramafic). These mafic intrusions represent centers of basaltic magmatism active simultaneously, presumably during the waning stages of development of the Crow Lake-Savant Lake greenstone belt. The activity of the mafic centers was eclipsed by emplacement of the batholith. The development of calc-alkaline liquids must have accompanied the mafic magmatism or succeeded it on a very short time scale.

A direct petrogenetic link between the gabbro and the intruded volcanics has not been demonstrated. The gabbro is somewhat fractionated compared to intruded pillow basalts which have light rare earth element depleted patterns. Isotopic signatures allow a co-magmatic relationship but do not require one. Whether or not the Mulcahy Lake gabbro and its companion intrusions represent end members in the volcanic cycle or initial representatives of a plutonic cycle petrogenetically distinct from the former is an interesting question (3).

(1) Morrison D., Davis D.W., Wooden J.L., Bogard D.D., Maczuga D.E., Phinney W.C. and Ashwal L.D., 1985, Age of the Mulcahy Lake intrusion, NW Ontario, and implications for the origin of greenstone-granite belts. In press, *Earth and Planet. Sci. Letts.* (2) Davis D.W., Blackburn C.E. and Krogh T.E., 1982, Zircon U-Pb ages from the Wabigoon-Manitou Lakes area, Wabigoon subprovince, northwest Ontario, *Canadian Jour. Earth Sci.* 19 p. 264. (3) Davis D.W. and Edwards G.R., 1983, Zircon U-Pb ages from the Kakagi Lake area, Wabigoon Subprovince, northwest Ontario, *Canadian Jour. Earth Sci.* 19 p. 1235.

Volcanic stratigraphy and nature of the semi-conformable alteration zone beneath the Mattabi massive sulphide deposit, Sturgeon Lake, Ontario

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Subaerial and shallow subaqueous mafic hyalotuffs, lava flows and flow breccias, and felsic lava flows and pyroclastic flow and fall deposits form a 2 km thick succession beneath the Mattabi massive sulphide deposit. The lowermost part of the succession is composed of massive and amygdaloidal mafic flows and flow breccias which are interlayered with repetitive sequences of thinly bedded felsic tuff; pillow lavas and hyaloclastites are absent from this succession. Amygdaloidal felsic lavas overlie the mafic flow succession and are locally capped by a coarse explosion breccia. This breccia is believed to have initiated a period of mafic hydrovolcanic activity which produced ash-laden falls, surges, and flows; these deposited thin to thickly bedded hyalotuffs. Periods of water exclusion resulted in the formation of scoria-rich beds. These eruptions constructed a tuff cone and represent a submergent hydrovolcanic cycle.

Pyroclastic flow deposits form the immediate mine footwall strata and include a) massive basal and overlying bedded ash tuffs, and b) massive pumiceous units. These deposits overlie and are intercalated with the mafic hyalotuff sequence.

The volcanic rocks beneath the Mattabi deposit have undergone hydrothermal alteration and subsequent regional greenschist metamorphism. Within the footwall volcanic sequence four chemically and mineralogically distinct alteration types have been defined: least altered, iron carbonate-chlorite, chloritoid, and sericite. Least altered rocks have been affected primarily by regional greenschist facies metamorphism and are thus the freshest rocks to be found in the area. They are largely confined to mafic flows and hyalotuffs. Iron carbonate-chlorite and chloritoid-type alteration form a widespread, semi-conformable zone beneath the Mattabi deposit; these assemblages are largely confined to felsic pyroclastic flows and lavas. Chloritoid is believed to have formed from the interaction of iron-rich chlorite and a hydrous aluminum silicate during metamorphism. Sericite-type alteration envelopes and/or crosscuts the earlier iron carbonate-chlorite type alteration. It is semi-conformable to stratigraphy and is most abundant within felsic pyroclastic flow deposits.

An alteration model is proposed in which seawater, trapped within a thick, submerged pile of mafic lava flows and breccias, was heated by the Beidelman Bay intrusion.

Thin, impermeable felsic lava flows overlie the mafic succession and produced a cap to the hydrothermal reservoir. High fluid temperatures and low water/rock ratios within the reservoir resulted in the formation of a fluid rich in Fe, Mn, Na, and, presumably, CO₂. The CO₂ is believed to have been derived from diagenetic carbonate.

Deep-seated tectonism within the volcanic pile produced high-angle faulting which allowed the sudden release of fluids from the reservoir. Migration of the fluids through permeable pyroclastic rocks resulted in base-fixing reactions and the formation of the semi-conformable, ankerite-chlorite alteration zone. The fluids boiled as they neared the seafloor, and siderite was deposited throughout the rocks beneath the discharge area. Sulphide minerals then accumulated on the seafloor. Later, near surface interaction of felsic rocks and warm seawater at high water/rock ratios produced the sericitic alteration assemblage.

STRUCTURAL ANALYSIS OF THE NORTHEASTERN MESABI RANGE AND ADJACENT BASAL DULUTH COMPLEX

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Information on the structural geology of the Biwabik Iron Formation (BIF) and the base of the Duluth Complex for this poster session has been compiled from state geological maps, mining company maps, structure contour maps based on drill hole data, drill core logs and field observations. The data covers a 24 mi. long portion of the northeastern Mesabi Range of Minnesota, extending from the Embarras mine west of Aurora (T59N, R16W), to the Dunka Mine on the south side of Birch Lake (T61N, R12W) and the adjacent Duluth Complex to the southeast. A total of 31 faults in the BIF and 16 faults in the base of the Duluth Complex and several folds are inferred. Both the BIF and Duluth Complex are affected by six of the faults. Displacement along the faults, fold amplitude and wavelength were estimated from the structure contour maps.

Displacements along faults occurring in the iron formation range from 7 ft. in the Peter Mitchell Mine to 450 ft. along the Siphon Fault west of the Spring/Siphon Mine. The displacement is greater than 80 ft. along seven of the faults and 50 ft. or less along the remaining 24.

For nine northeast-trending faults (N10E to N80E) in the BIF, the downthrown side is to the southeast for five and to the northwest for three with one unknown. For 20 northwest-trending faults (N15W to N50W), the downthrown side is divided evenly to the northeast for 10 and to the southwest for 10. There are two N-S trending faults, one with the east side down and one with the west side down. A total of 16 faults give a cumulative east side down displacement of about 1222 ft. and 14 faults give a cumulative west side down displacement of about 705 ft.

Folding occurs in the iron formation north of Aurora and to the east through the Wentworth Mine. A broad anticline north of Aurora trends generally E-W for approximately 4 mi. It has an amplitude of about 150 ft., and a map distance from crest to trough of its attendant syncline to the north of about 0.5 mi. The anticline flattens out for about 1.0 mi. west of the Knox Mine. It is apparent again east of the Knox Mine and continues for about 2.5 mi. on a general E-W trend through the Wentworth Mine. The amplitude increases to 250 ft. and the map distance from crest to trough decreases to 600 ft. at the Wentworth Mine. Although the general trend of the anticline is E-W, it is offset to the north in several places giving it a sinuous axial trend.

Only one structure, the Siphon Fault, is observed to affect the stratigraphic thickness of Animikie Group rocks. It trends N40W and has a vertical displacement of about 450 ft., down to the northeast. There is an abrupt decrease in thickness of the Lower Cherty Member of the BIF from west to east across the fault, from 140 ft. west of the fault to 60 ft. east of the fault. The Lower Cherty continues to thin gradually to the east until it disappears completely near the south side of Birch Lake. The fault corresponds to a lithologic boundary in the Archean basement between Knife Lake Group metamorphosed sedimentary and volcanoclastic rocks to the west and Giants Range Granite to the east.

Displacement along faults occurring in the Duluth Complex is estimated for 11 of the 16 faults and range from 1 ft. in the Dunka Mine to 360 ft. at the Minnamax Project. The displacement is greater than 100 ft. for five of the faults and 30 ft. or less for the remaining six.

For nine northeast trending faults (N05E to N55E) in the Duluth Complex, the downthrown side is to the southeast for four, to the northwest for three and unknown for two. For six northwest trending faults (N30W to N50W), the downthrown side is to the northeast for four and to the southwest for two. There is one N-S trending fault with the west side down. The east side down displacement for six of eight faults totals an estimated 630 ft. The west side down displacement for five of six faults totals an estimated 650 ft.

Undulations at the base of the Duluth Complex are shown by structure contour maps in the Dunka Mine and the Minnamax Project area. An antiform structure begins at the northwest end of the Minnamax Project and trends S40E for about 0.5 mi. At this point the trend changes to N70E for about another 2.5 mi. The attendant synform to the north is parallel to the antiform structure for about 1.5 mi. to the east and changes to a N-S trend over the next 0.7 mi. The maximum amplitude of this antiform structure is about 350 ft. with a map distance from crest to trough of 1500 ft. Several E-W trending undulations occur at the southeast end of the prospect. They can be traced for about 2000 ft. Amplitudes range from 100 ft. to 450 ft. with a wavelength of 900 ft. A N70W trending antiformal structure occurs in the Dunka Mine area. It has an amplitude of about 550 ft. and coincides with an anticline observed in outcrop of the underlying BIF in the Dunka Mine. The highest grade of sulfide mineralization in the area is associated with this structure.

The pattern of faulting appears to be affected by Archean basement lithologies.

All seven faults occurring in the BIF over an 11 mile stretch from the Siphon Fault to the east end of the Peter Mitchell Mine trend to the northwest. Here and in the Dunka Mine to the east the iron formation overlies Archean granite. The northwest trend is still present east of the Peter Mitchell Mine into the Dunka Mine but it becomes more complicated where the BIF is intruded by the Duluth Complex. West of the Siphon structure, the dominant northwest fault pattern is present but complicated by a northeast component. Here the iron formation is folded and overlies Archean Knife Lake Group metamorphic rocks. This indication that the style of deformation was controlled to some degree by the basement rocks was suggested earlier by White (1954).

Grateful appreciation is extended to Erie Mining Co., Reserve Mining Co., LTV steel Corp., U.S. Steel corp. and Bear Creek Mining Company for providing access to data and mine properties and to the Minnesota Department of Natural Resources for providing funding and data for this project.

White, D.A., 1954, The Stratigraphy and Structure of the Mesabi Range, Minnesota: Minn. Geol. Survey Bull. 38, 92 pp

Proterozoic Diabase Dike Swarms in Wisconsin

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Regional geologic mapping and analysis of regional aeromagnetic maps have identified two areas of mafic dike swarms in Wisconsin: (1) a central Wisconsin area, and (2) a northern area adjacent to Keweenawan intrusive suites. There appears to be little difference in major element chemistry between the two swarms, although the northern swarm and some of the central swarm dikes have been weakly metamorphosed.

The dike swarm in central Wisconsin is defined principally from regional aeromagnetic maps and generally trends east to northeast. Individual dikes are identified by strong magnetic lows that can be traced for over 260 km and continue beyond the limits of the available aeromagnetic data. The swarm is at least 120 km wide and is lost at its southern margin by the limits of aeromagnetic coverage. Isolated outcrops of this swarm are known to the south. Some individual dikes exceed 80 m in width. Where sampled, these large dikes are dominantly olivine gabbro to anorthositic troctolite and are continental tholeiite, based on major element chemistry. In detail, the dikes can be divided into a suite rich in iron and titanium with a strong reversed magnetic polarity and a more average continental tholeiite suite with a weak normal polarity signature. Alteration is minimal. Most of the recognized swarm is hosted in Proterozoic rock.

The northern dike swarm is defined from outcrop with supplemental definition from regional aeromagnetic data. Aeromagnetic data are not as useful in defining the extent of this swarm because of the proximity to strongly magnetized Keweenawan intrusives. The swarm generally trends northwestward and does not appear to be as continuous as the central swarm. Some individual dikes appear to be offshoots of the Keweenawan Mellen and Mineral Lake intrusive suites and related rock. Locally some of these dikes are altered to uralite and chlorite, probably by subsequent metamorphism of the adjacent gabbroic complexes. A few dikes cut the Mellen granite.

Another older, poorly defined set of diabase dikes is known in the central area, and is known to cut the 1,760 Ma rhyolite and granite in southern Wisconsin. This suite is metamorphosed to hornblende-chlorite-biotite assemblages, has a weak tectonic fabric, and is calc-alkaline in composition. Some individual analyses contain nepheline in the norm. This sodic series may occupy the same fracture system as the younger, fresher swarm, but generally appears to have a more northwesterly trend.

Other post-Penokean dikes are known and include a weakly tectonized andesitic suite in the Penokean orogen and a granitic suite in southern Wisconsin. These are probably related to the 1,760 Ma post-Penokean magmatic event.

A few diabase dikes are known in the area between the northern and central swarms. This area is well covered by detailed aeromagnetic surveys; however, no strong magnetic lineaments are recognized, suggesting that no magnetically distinctive swarm exists.

- 6 Paleozoic cover
- 5 Keweenaw terrane
- 4 Proterozoic anorogenic plutonic rock = Wolf River sequence
- 3 Proterozoic quartzite = Baraboo sequence
- 2b Proterozoic metavolcanic and plutonic rock = Wisconsin magmatic terrane
- 2a Proterozoic metasedimentary rock = Proterozoic epicratonic cover
- 1 Archean terrane



	A	B	C
SiO ₂	49	49	51
TiO ₂	2.3	1.4	1.0
Al ₂ O ₃	13.8	13.6	16.4
FeO _T	14.6	11.7	8.8
MnO	0.2	0.2	0.2
MgO	5.1	5.9	6.3
CaO	8.6	9.0	8.6
Na ₂ O	2.7	3.2	3.2
K ₂ O	1.1	0.9	1.2
P ₂ O ₅	0.4	0.1	0.3

A avg. of 5 high-Fe-Ti dikes, reversely polarized (incl. Rib Mountain).

B avg. of 6 low Fe-Ti dikes, weakly normally and reversely (?) polarized (incl. Monico, Morse, Biron, Dudley).

C avg. of 5 sodic dikes, weakly polarized (incl. Montello, Prairie Dell).

METAMORPHISM OF THE DUNBAR GNEISS AND ASSOCIATED SUPRA-CRUSTAL
ROCKS: NORTHEASTERN WISCONSIN, USA

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The Quinnesec Formation crops out in northeastern Wisconsin and surrounds the core zone of the Dunbar dome. Metamorphic grade varies across the structure and decreases away from the contacts with the Dunbar Gneiss and its late stage intrusive components. The Quinnesec Formation is dominantly mafic to felsic volcanics and volcanoclastics (Schulz, 1984). Local occurrences of restricted basin sediment are present and have been explored for massive sulfide mineralization. Their high sulfide and graphite contents have resulted in a poor outcrop record, but samples were obtained from several drill cores from the West Bass Lake area of Florence County. The supra-crustal rocks and the Dunbar Gneiss record a similar sequence of fabric development and late stage vein emplacement.

The supra-crustal sequence is characterized by prograde metamorphic assemblages including:

- 1- biotite - garnet - plagioclase - quartz $\pm$ cordierite in meta-sediments
- 2- garnet - hornblende - plagioclase $\pm$ quartz in metabasalts and,
- 3- diopside - tremolite - calcite $\pm$ quartz in marbles.

Late stage metamorphic effects are present in most samples. The most prevalent alteration includes:

- 1- garnet $\rightarrow$ biotite + chlorite
- 2- cordierite $\rightarrow$ pinite + sericite
- 3- hornblende $\rightarrow$ biotite + actinolite + chlorite and,
- 4- Plagioclase $\rightarrow$ epidote + albite

Beds enriched in S have pyrite + pyrrhotite + chalcopyrite and show a loss of Fe from the silicate phases due to sulfidation reactions. The supra-crustal sequence and the Dunbar Gneiss are cut by late stage pegmatites and quartz-tourmaline veins.

In thin section, an S_1 foliation defined by biotite is parallel to bedding planes (S_0). Retrograde biotite defines a weak S_2 foliation which is inclined to S_1 by up to 90° . Deformation of the Quinnesec Formation probably corresponds to D_2 and D_4 (Sims et al, 1984) in the Dunbar dome.

The prograde metamorphic assemblages restrict peak metamorphic conditions to $500-550^\circ\text{C}$ at low to intermediate lithostatic pressure. Based on the abundance of graphite and pyrite + pyrrhotite, $P_{\text{H}_2\text{O}} < P_{\text{total}}$ and CO_2 and H_2S were (at least locally) major components in the fluid phase.

The Dunbar Gneiss ranges in composition from granite-granodiorite to biotite tonalite, and locally contains abundant mafic inclusions (Schulz et al, 1984). In many outcrops, the gneiss grades into migmatite.

The similarity between the deformational and metamorphic histories of the Quinnesec Formation and the Dunbar Gneiss suggests that they were coeval. The lower metamorphic grade recorded in the Quinnesec Formation is attributed to a smaller extent of erosion due to higher density. The core of the Dunbar dome was formed at the peak of metamorphism by bouyant emplacement of the hotter and lower density Dunbar Gneiss. The time required to form the Dunbar Gneiss protolith, the Quinnesec Formation and their deformation and metamorphism was on the order of 30 million years (Sims et al, 1984).

Schulz, K.J., 1984, Volcanic rocks of northeastern Wisconsin, in: Guide to the Geology of the Early Proterozoic Rocks in Northeastern Wisconsin, Field Trip 1, Thirtieth Annual Institute on Lake Superior Geology, p. 51-81

Schulz, K.J., Sims, P.K., and Peterman, Z.E., 1984, Geochemistry of the Dunbar Gneiss Dome, N.E. Wisconsin, in: Guide to the Geology of the Early Proterozoic Rocks in Northeastern Wisconsin, Field Trip 1, Thirtieth Annual Institute on Lake Superior Geology, p. 24-42

Sims, P.K., Peterman, Z.E., and Schulz, K.J., 1984, Dunbar Gneiss - Granitoid Dome, in: Guide to the Geology of Early Proterozoic Rocks in Northeastern Wisconsin, Field Trip 1, Thirtieth Annual Institute on Lake Superior Geology, p. 1-23

GEOLOGY OF PRECAMBRIAN-HOSTED PRECIOUS METAL PROSPECTS IN THE
FIRE CENTER AND HOLYOKE MINES AREA, MARQUETTE COUNTY, MICHIGAN

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During the summer of 1984 a 6 km² area, located about 19 km northwest of Marquette, Michigan was geologically mapped at a scale of 1:2,400. Mapping included all of section 35, T49N, R27W and the top part of section 2, T48N, R27W, including the inactive Fire Center gold mine and Holyoke silver mine. An outcrop density of about 30% allowed a detailed analysis of the field geologic relationships of a sequence of metamorphosed Archean and Lower Proterozoic volcanic, sedimentary and intrusive rocks. From oldest to youngest, the Archean metavolcanic units are: pillowed basalt flows, a schistose pyroclastic horizon, banded iron formation, and laminated phyllitic and schistose volcanics and sediments. The latter unit is in fault contact with a tectonized breccia of possible Archean-age; this unit could be lower Proterozoic in age. The Archean metavolcanics and metasediments are intruded by gabbro and rhyolite porphyry dikes of probable Archean age; field evidence indicates the rhyolite porphyry is the younger of the two. The bedded units described above are overlain by lower Proterozoic slates and phyllites. Near the northern boundary of section 35, quartzite of the lower Proterozoic Michigamme Formation is in fault contact with Archean pillowed basalt flows. East-west trending Middle Proterozoic diabase dikes of Keweenaw age intrude the Archean rock units.

The strike of the Archean and Lower Proterozoic units is approximately N60°W to N70°W. Where exposed, contacts between units are near vertical and commonly show evidence of faulting and shearing. Foliations are manifested by slaty and phyllitic cleavages and schistosity in both the Archean and Lower Proterozoic rocks. Except in the Michigamme Formation, strike and dip of foliations (and bedding) are generally N60°W to N75°W and are near vertical. Evidence of intense deformation and shearing include phacoidal and schistose structures, tight folds, transposed layering and folded quartz lenses, and boudinage. These rocks have been subjected to greenschist facies metamorphism.

Mineralization occurs primarily in quartz veins and in silicified shear zones, and tends to be spatially associated with the rhyolite porphyry dikes and banded iron formation. Primary ore minerals are dominated by widespread pyrite with minor occurrences of chalcopyrite, galena, and sphalerite. No visible gold was found. The main non-metallic alteration minerals include nearly ubiquitous quartz, locally intense sericite, chlorite and biotite. Late stage carbonate and quartz-carbonate veins cross cut all previous mineralization. The Fire Center gold mine consisted of two vertical shafts, both located on the same rhyolite porphyry dike. The south shaft was sunk along the sheared, silicified contact with gabbro, while the north shaft was apparently sunk along the contact with schistose basalt. The Holyoke silver mine was a horizontal tunnel about 550 feet long dug in a N19°E direction. The host rocks are silicified, carbonatized, brecciated and schistose metavolcanics and metasediments, including minor banded iron formation. Evidence to date suggests that mineralization was probably epigenetic.

Geology and Geochemistry of Lava Flows Within the Copper Harbor
Conglomerate, Keweenaw Peninsula, Michigan

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The Keweenaw Copper Harbor Conglomerate is a rift-related, basin-ward thickening succession of terrestrial, coarse- to fine-grained clastic sediments which interfinger with and conformably overlie the Portage Lake Volcanics (Daniels, 1982). Northeast of Calumet, Michigan, the middle portion of the Copper Harbor Conglomerate includes a succession of lava flows known collectively as the Lake Shore Traps (Lane, 1911). This unit has a strike-length of over 90 km and was deposited in a basin. The thickest section (approx. 600 m) is located between Copper Harbor and the eastern end of the Keweenaw Peninsula. The Lake Shore Traps are of petrologic importance because they represent some of the youngest volcanic material erupted throughout the Lake Superior Basin.

A 594 m section through the Lake Shore Traps at the eastern end of the Keweenaw Peninsula was mapped in detail. A total of 31 individual lava flows were identified (flow 1 at base, 31 at top). Flow thickness varies from 4.4 to 42.4 m with an average of 18.3 m. A 27 m thick interflow conglomerate bed is present between flows 10 and 11. Individual flows show features typical of other Keweenaw sub-aerial flood basalts including: amygdaloidal flow bottoms, massive flow interiors, vesicular, smooth, pahoehoe flow tops and fragmental, rubblely flow tops. Many flows also exhibit vertically-oriented vesicle cylinders in the lower portion of the flow interior and thin, discontinuous, horizontally-oriented, pegmatoid layers in the upper portions. Zeolite-grade alteration is common in permeable flow tops but is minimal to non-existent in most flow interiors.

Geochemically, the Lake Shore Traps exhibit tholeiitic evolutionary trends on AFM, normative, SiO_2 , and immobile trace element discrimination plots. In general, lavas become more evolved from the base upwards. The lowest flows (1, 2, 3, and 4) are Fe-rich olivine tholeiitic basalts (47-50 wt. % SiO_2), followed by Fe-rich olivine-bearing, tholeiitic basaltic-andesites with 50-53 wt. % SiO_2 (flows 5-22) and tholeiitic andesites with SiO_2 of 54-58 wt. % (flows 23-31). In thin section, all rocks are largely aphyric with only small amounts of plagioclase phenocrysts. Groundmass minerals in the basalts include 35-40% plagioclase (An_{45-65}), 15-25% clinopyroxene (Wo_{30-40} , $\text{Fe/Mg} = 40-50$), 10-20% olivine (Fo_{40-60}), and 5-10% Fe-Ti oxides (mineral composition determined by electron microprobe). Groundmass minerals in the andesites are 40-50% plagioclase (An_{45-60}), 10-20% clinopyroxene (Wo_{30-40} , $\text{Fe/Mg} = 30-40$), 5-15% orthopyroxene, 5-10% Fe-Ti oxides and 5-10% late-stage intergranular K-feldspar. Devitrified intersertal glass is present in all massive flow interiors (10-20%). Diktytaxitic cavities are common in most flows. Flows 12 and 13, located just above the interflow conglomerate, contain distinct phenocrysts of highly resorbed plagioclase and quartz.

Most major and trace elements show coherent patterns of variation when plotted versus stratigraphic height. Generally, SiO_2 , Al_2O_3 , Na_2O , K_2O , and Rb increase from bottom to top of the sequence, whereas FeO , MgO , CaO ,

TiO₂, P₂O₅, V, Ca/Al, Cr, Ni, and Sr decrease. Though these trends apply to the succession in general, in particular, numerous inconsistencies rule out simple evolutionary patterns. The flows below and above the interbedded conglomerate can be grouped together on the basis of repeating or anomalous chemical-stratigraphic trends. Also, the two flows (12 and 13) directly above the conglomerate are anomalous with particularly high Si, K, Rb and Zr and low Al, Fe, Ca, Ti, V and P. As a whole, the Lake Shore Traps are geochemically more evolved than the Portage Lake Volcanics which are almost exclusively hi-Al olivine and hypersthene tholeiitic basalts. For similar SiO₂ contents, the Lake Shore Traps contain substantially more Ti, V, P, Zr, and Y and less Al and Ni (large compositional gaps). A continuum exists, however, for Fe, Mg, Ca, Ca/Al, Cr, total alkalis, and Rb.

Qualitative petrogenetic interpretation of the present geochemical data suggests that crystal fractionation exerts at least a partial control over the magma compositions of the Lake Shore Traps. Major and trace element geochemical trends suggest that clinopyroxene, Fe-Ti oxide, plagioclase and apatite were significant fractionating phases. Zircon eventually also reached the saturation limit. However, in addition to fractionation, some trace and major elements also suggest open system behavior. Petrographic and geochemical evidence supports the occurrence of upper crustal contamination of several lava flows of the Lake Shore Traps (flows 12 and 13). Within the remaining flow succession, magma mixing may be required to explain differences in fractionation trends between the two geochemical groups: lower flows (1-9) and upper flows (16-31). The petrogenetic relationship between the Lake Shore Traps and the Portage Lake Volcanics is currently under investigation.

Reference

- Daniels, 1982, Geol. Soc. Amer. Mem. 156, p. 107-133.
 Lane, 1911, Mich. Geol. Surv. Pub. 6, 983 p.

THE PALEOMAGNETISM OF THE POWDER MILL GROUP: ITS RELEVANCE TO CORRELATION
WITH OTHER KEWEENAWAN SEQUENCES AND TO TECTONIC DEVELOPMENT OF THE SOUTH RANGE
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The Keweenawan Powder Mill Group crops out as a 150 km-long dominantly east-west striking belt in Michigan and Wisconsin. A primary Keweenawan reverse magnetization has been isolated after extensive AF and thermal demagnetization from 33 sites distributed along a strike length of 100 km within the belt. This reverse magnetization yields a pole (142°W , 39°N , $A_{95}=6.0^{\circ}$) which plots close to the apex of the Logan Loop. A subset of these reversely magnetized sites from localities within the outcrop belt having E-W strike yield a pole (147°W , 42°N , $A_{95}=6.4^{\circ}$) which is within the cluster of other reversely magnetized Keweenawan paleopoles. Mellen Complex magnetizations and Powder Mill magnetizations from ENE-trending segments within the dominantly E-W trending outcrop belt suggest that these segments have undergone counterclockwise rotations. Normal magnetizations have been isolated at four sites. Poles derived from these sites also plot on the western arm of the Logan Loop. The normal magnetizations are in sites near the base of the stratigraphic sequence but the distribution of these sites is not stratigraphically continuous. This lack of stratigraphic persistence, together with a higher metamorphic grade at the normally magnetized sites, lead us to believe that the normal magnetizations are secondary. The polar signature and the reversal stratigraphy of the Powder Mill Group are similar to those of other Keweenawan volcanic sequences. The paleomagnetic results of Books (1968, 1972) which led to the belief that the South Range Traps (Powder Mill Group) were older than other Keweenawan volcanic sequences are no longer valid. The eastern arm of the Logan Loop is undefined by Keweenawan data.

References:

- Books, K.G., Magnetization of the lowermost Keweenawan lava flows in the Lake Superior area, U.S. Geological Survey, Professional Paper 550-D, p.D117-D124, 1968.
- Books, K.G., Paleomagnetism of some Lake Superior Keweenawan rocks, U.S. Geological Survey, Professional Paper, 760, 42 p., 1972.

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THE GEOLOGICAL SETTING OF GOLD MINERALIZATION OBSERVED
AT THE SCRAMBLE MINE, DISTRICT OF KENORA, N.W. ONTARIO

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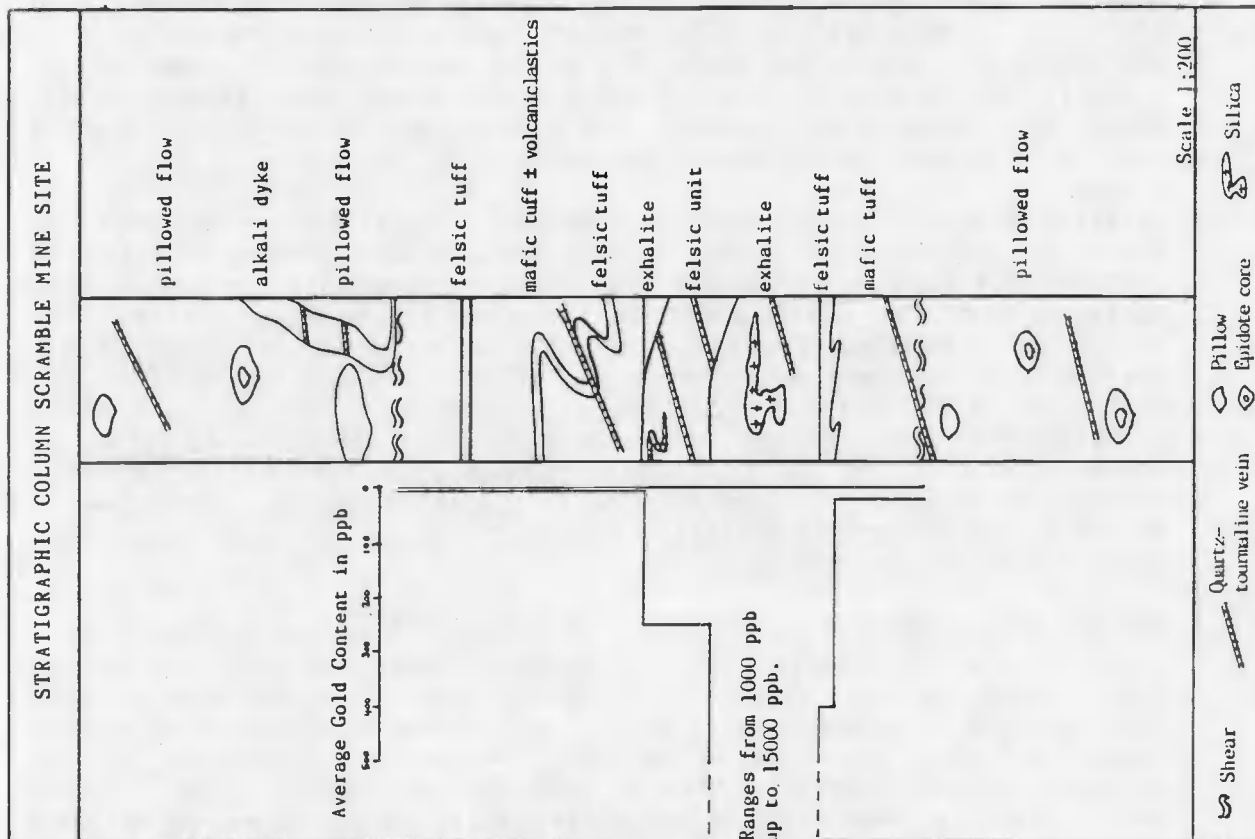
The Scramble Gold Mine, located ten kilometres east of Kenora, was originally developed in the late 1890's by the Scramble Gold Mining Company Limited and intermittantly to 1914 by the Canadian Homestake Gold Mining Company Limited. Although a shaft was excavated to about seventy metres there is no record of production beyond bulk sampling and mill testing.

The deposit is located at the northwest end of the Wabigoon Volcanic-Plutonic Belt within metavolcanics and metasediments which outcrop in a northeast trending wedge extending from Lake of the Woods. North of this wedge are the gneisses of the English River Subprovince whilst southeast of the area is the Island Lake diorite, a unit of the Dryberry Batholith which in turn is part of the Wabigoon Subprovince.

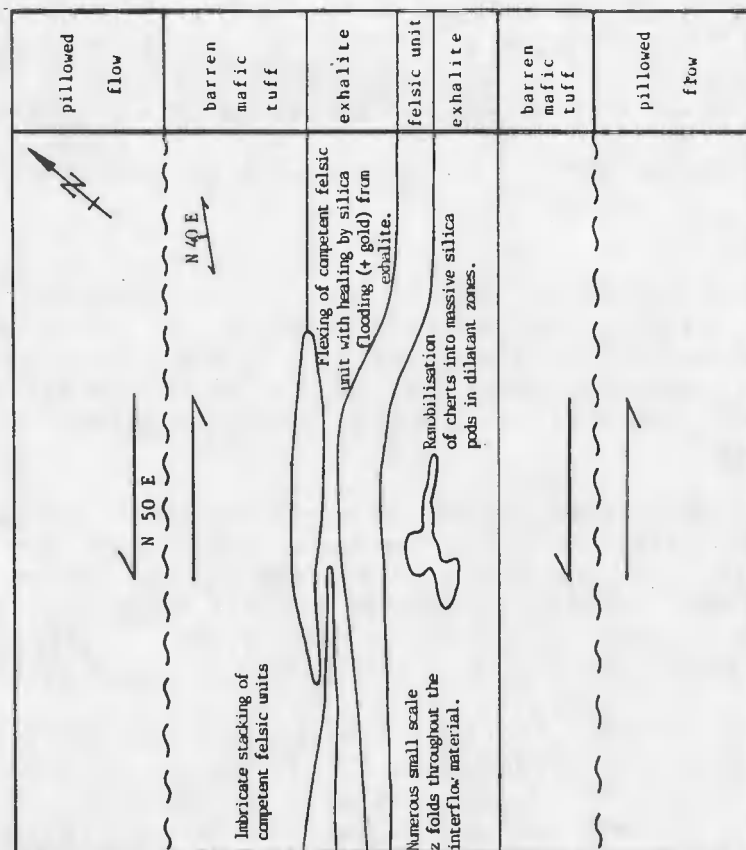
The Scramble Mine is underlain predominantly by tholeiitic pillowed flows, minor mafic tuffaceous units, exhalites and occasional felsic units (see diagram of the stratigraphic succession). All the volcanics on the property face and dip to the northwest. Foliation tends to subparallel bedding and also dips steeply to the northwest. Deformed pillows, shearing and shear folding occur throughout the property and are well exposed at the mine site. Quartz-tourmaline veins both concordant and discordant to foliation are ubiquitous. Nowhere on the property has there been observed any areas of significant alteration due either to a primary volcanogenic hydrothermal system or to a secondary shear zone related hydrothermal system.

Detailed studies of the nature of the gold mineralization are underway but as yet incomplete. Observations made to date, based on detailed sampling and mapping of the ore zone along strike, indicate that a high percentage of the gold is within the exhalite unit. This could be either as very fine grained free gold or tied up with sulphides. Visible gold has been observed in the silica flooded felsic unit just northeast of the shaft. Since the gold content of the felsic unit is generally less than 200 ppb it would appear that the enriched values in the felsic unit are due to remobilization of silica and gold under particular structural controls (see cartoon). Trace chemistry carried out on twelve selected mineralized samples from the ore zone indicate a typical tholeiitic gold system.

Genesis of the gold mineralization as inferred from outcrop mapping is summarized as follows. Pillowed flows followed by mafic tuffs and felsic volcanism with distal tuffs and auriferous chemical precipitates are preserved by renewed mafic volcanism. Intrusion of a felsic sill, a possible feeder to a stratigraphically higher felsic centre, causes remobilization of gold. Finally, deformation, regional folding and shearing along interflow boundaries results in small scale folding within the interflow unit and major remobilization of gold and silica into dilatant zones within the competent felsic units.



Stratigraphic column, Scramble Mine, showing gold distribution with respect to rock types.



A cartoon of the structural elements observed at the Scramble Mine site.

METAMORPHISM AND PLUTONISM IN THE QUETICO BELT, N.W. ONTARIO

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Reconnaissance study of 350 km of strike length of the 1200-km-long Quetico belt reveals regional patterns of metamorphism and plutonism. Located between the Wabigoon and Wawa greenstone-granite belts, the Quetico belt consists of a marginal metasedimentary schist unit and an interior complex of metasedimentary schist and gneiss and plutonic rocks. Metamorphic grade in marginal pelitic schists varies from a chlorite-muscovite zone at the outer margin to a garnet-sillimanite zone toward the interior. Common assemblages of garnet-andalusite throughout the marginal unit and in the interior in the Lac La Croix area indicate low-pressure metamorphism (bathozone 2). Assemblages of staurolite-sillimanite and rare kyanite some 60-150 km east of Lac La Croix suggest bathozone 3 conditions. Mineral assemblages in peraluminous granitoid leucosome, dykes and plutons also vary regionally along strike. Sillimanite, in association with garnet and muscovite, is common in the west; cordierite is present only to the east. Leucosome in migmatites is mainly intrusive in the west and locally derived in the east. These features together suggest a deepening level of erosion from west to east.

Two large plutonic complexes characterize the interior of the western Quetico belt: the Vermilion complex of Minnesota and the Quetico Park complex of Ontario. The Vermilion complex consists mainly of biotite granite and leucogranite with metasedimentary schist inclusions. A zonation in plutonic rock types characterizes the Quetico park complex across its 20-50 km width. Peraluminous white granite of the Sturgeon Lake batholith occurs in the centre of the complex and is flanked by small (10-km-wide) plutons of pink biotite + magnetite leucogranite, rarely with inclusions of monzonite-diorite-hornblendite. Small (5 km) plugs of diorite-monzonite cut marginal metasedimentary schists.

A composite section through the belt shows steeply inward-dipping margins and tadpole-shaped plutons derived from a metasedimentary source in the centre and tonalitic rocks of the greenstone-granite terranes toward the margins. A back-arc basin environment is postulated to account for early development of an elongate sedimentary trough characterized by high heat flow which led to later deep crustal melting and magma rise to high structural level. Underplating by mafic magmas possibly contributed to heat transfer from the mantle to the lower crust.

The Tectonic Significance of the Porphyritic Red Granite,
Dickinson County, Michigan

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The Porphyritic Red Granite is exposed near Felch in Dickinson County, Michigan and has been dated by the Rb/Sr whole rock method at 1970 Ma old (Van Schmus, per. Comm.). Strain studies using the grain center method of Fry (1979) and the deformed dike method of Talbot (1982) indicates two episodes of deformation. The first is an intrusive deformation controlled by the geometry of the pluton while the second appears to be a regional deformation. New major element chemical analysis indicates the granite has a low structural water content, a high K_2O content, $Al/(Na+K+Ca/2) = 1.3$, and it is normative quartz saturated. These chemical trends are consistent with S- or A-type granites; however, major element data cannot differentiate between them.

The granite is composed of potassium feldspar megacrysts with lesser amounts of quartz, biotite, and magnetite in the groundmass. The feldspar megacrysts, quartz, and biotite are all elongated within the foliation. The biotite defines a well developed LS fabric where the foliation is everywhere parallel to the pluton's margin and the lineation is steeply plunging. These are very common features among diapiric structures.

Relative strain was determined using the grain center technique of Fry which records the shape and orientation of grain distributions. This study shows the long axes of the feldspar megacrysts are steeply plunging. The strain pattern indicates plane strain ($\lambda_1 > \lambda_2 = 1 > \lambda_3$) at the margin but becomes constrictional ($\lambda_1 > \lambda_2 = \lambda_3$) just inward. Modeled diapiric structures (Dixon, 1975) and many natural examples using deformed xenoliths (Schwerdtner et al., 1983; Pitcher and Berger, 1972) display a wide zone of very strong marginward flattening ($\lambda_1 = \lambda_2 > \lambda_3$), a narrow neutral surface, and a weak constrictional strain toward the middle. The different pattern of strain in the Porphyritic Red Granite may be due to the methods used in measuring strain in that its geometry is controlled by the growth patterns of the feldspars.

Both the pluton and its associated pegmatites show signs of a post-intrusive deformation. A large 25 m wide east-west left lateral shear zone occurs in the southern part while smaller shear zones (3-40 cm wide) are common in several areas. The northeastern region of the pluton displays fabric crenulations and highly contorted dikes with steeply plunging fold axis.

A strain analysis using deformed metadiabase dikes (Talbot, 1982) which have intruded the pluton were used to record the post-intrusive deformation. These dikes cut across the pluton's fabric and have foliations oblique to their margins. This oblique foliation is produced by layer parallel shearing as the dike rotates in response to the strain within the country rock. Connecting the pole of the margin to the pole of the foliation on a stereonet produces an approximation of the structural movement path. The coherent pattern displayed by these paths have been used with lineations found on the dikes to describe the type of strain and the strain axes. This analysis indicates λ_1 plunges steeply to the south while λ_3 is gently plunging to the northeast. A companion study using Proterozoic-X dikes in the basement rocks adjacent to the pluton suggests a similar style of deformation. This style in the Felch area contrasts with that found to the north

in the Marquette, Michigan region where the basement has behaved rigidly (Myers, 1984). The general trend of the compression axis is the same, however. Figures 1 and 2 show the results of these strain studies for the granite and basement rock, respectively.

There have been several recent studies which suggest the chemistry and mineralogy of granites are functions of their tectonic setting (Chappel and White, 1974; Pitcher, 1984; Pearce et al., 1984). Major element chemical analysis indicates the granite is strongly peraluminous, has a high K_2O and low H_2O content, and is normative quartz saturated. These are characteristic of Hercynian S-type (continental collision) and anorogenic A-type (continental rift or intraplate) granites. Major element data of these two types is equivocal; however, they strongly contrast with the 1820-1840 Ma old granites of Wisconsin by their lower CaO , MgO , Al_2O_3 , and higher K_2O content.

The 1970 Ma age for the Porphyritic Red Granite suggests it may be related to the formation of the Felch trough. In this case the pluton may represent a rift type granite subsequently intruded by diabase dikes. These dikes intruded this region up until deposition of the Michigamme Formation at 1900 Ma (Sims et al., 1980). This would suggest a very short time sequence from rift to collision.

Figure 1

$$\lambda_1 = 64/177$$

$$\lambda_2 = 15/303$$

$$\lambda_3 = 20/39$$

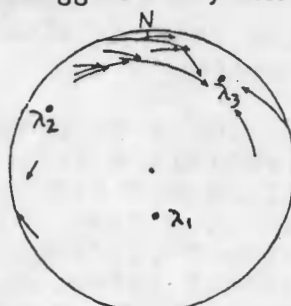
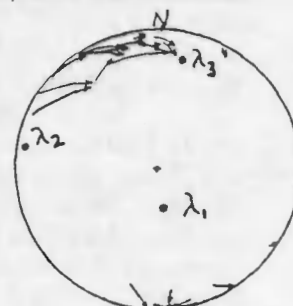


Figure 2

$$\lambda_1 = 68/168$$

$$\lambda_2 = 5/277$$

$$\lambda_3 = 21/10$$



REFERENCES

- Chappell, B. W. and White, A. J. R., 1974. Two contrasting granite types. *Pacific Geology*, 2:173-174.
- Dixon, J. M., 1975. Finite strain and progressive deformation in models of diapiric structures. *Tectonophysics*, 28:89-124.
- Fry, N., 1979. Random point distributions and strain measurement in rocks. *Tectonophysics*, 60:89-105.
- Myers, G. A., 1984. Structural analysis of foliated Proterozoic metadiabase dikes in the Marquette-Republic region of northern Michigan. M.S. Thesis, Michigan State University, 78p.
- Pearce, J. A.; Harris, N. B. W.; and Tindle, A. G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Jour. Petrology*, 25(4):956-983.
- Pitcher, W. S., 1984. Granite type and tectonic environment, in *Mountain Building Processes*, Hsu, K. J. (ed.). Acad. Press, London, United Kingdom, p. 19-40.
- Pitcher, W. S. and Berger, A. R., 1972. The geology of Donegal: a study of granite emplacing and unroofing. Wiley Interscience, London, 435p.
- Sims, P. K.; Card, K. D.; Morey, G. B. and Peterman, Z. E., 1980. The Great Lakes tectonic zone - a major crustal structure in central North America. *Geol. Soc. Amer. Bull.*, part 1, 91:690-698.
- Schwerdtner, W. M.; Scott, G. M. and Sutcliffe, R. H., 1983. Strain patterns of crescentic granitoid plutons in the Archean greenstone terrane of Ontario. *Jour. Struct. Geol.*, 5:419-430.
- Talbot, C. J., 1982. Obliquely foliated dikes as deformed incompetent single layers. *Geol. Soc. Amer. Bull.*, 93:450-460.

GEOLOGY OF A LOWER PROTEROZOIC VOLCANICLASTIC SEQUENCE
MARATHON COUNTY, WISCONSIN

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Geologic mapping of approximately 21 km² just north of Wausau, Wisconsin has aided in interpreting the depositional environment of a sequence of dominantly felsic-intermediate volcanic rocks and the associated volcaniclastic rocks. This sequence has been dated at ~1860 m.y. (Van Schmus, 1980) and lies in Central Wisconsin near the southern margin of the exposed Lower Proterozoic volcanic-plutonic belt. These rocks have been metamorphosed to lower greenschist facies and are generally only mildly deformed, dipping to the west at 10-30°. The volcanic succession consists of rhyodacitic to andesitic flows, pyroclastic flows and intrusives. Volcanic and pyroclastic textures are locally well preserved and include perlitic cracks, devitrified shards and pumice fragments, and fiamme within welded tuffs. Massive to amygdaloidal basalt flows are minor components of the sequence.

Volcaniclastic sedimentary rocks represent a major portion of the exposed section and exhibit a wide variety of textures. These sedimentary rocks include massive to laminated argillites and siltstones, possibly of lacustrine origin, which exhibit graded bedding and soft sediment (including dewatering) deformation. "Red beds" consisting of interbedded volcanic sandstones and conglomerates are present but are poorly exposed. The dominant epiclastic rock is a dark, greenish-black, cross-bedded volcanic sandstone with discontinuous interbeds of conglomerate, composed mainly of locally derived volcanic pebbles but also including clasts of quartzite and tonalite. These cross-bedded sandstones and interbedded conglomerates are interpreted as fluvial deposits.

This succession is interpreted to represent an intermediate-source facies (Fisher and Schmincke, 1984) characterized by rocks formed by pyroclastic flow, lava flow, airfall, and their reworked products. The tectonic interpretation is based on Dickinson's (1974) model of magmatic arcs. This model places volcanic rocks of intermediate-felsic composition in an arc having continental affinities (crustal thickness >15-20 km). Using this model, the described sequence would represent rocks deposited in an intra-arc basin (graben) and characterized by volcaniclastic red beds, subaerial tuffs, lacustrine deposits and conglomerates.

REFERENCES

- Dickinson, W.R., 1974, Sedimentation within and beside ancient and modern magmatic arcs. In: Dott, Jr., R.H. and Shaver, R.H., eds., Modern and ancient geosynclinal sedimentation, Soc. Econ. Paleont. Mineral. Sp. Publ. 19, p. 230-239.
- Fisher, R.V. and Schmincke, H.-U., 1984, Pyroclastic Rocks. Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 472p.
- Van Schmus, W.R., 1980, Chronology of igneous rocks associated with the Penokean Orogeny in Wisconsin. Geological Society of America Special Paper 182, p. 159-168.

PETROGENESIS OF THE BARDON PEAK PERIDOTITE, DULUTH COMPLEX

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An area of ~ 2.5 sq. km was mapped along the basal contact of the Duluth Complex around Bardon Peak, southwest of Duluth, Minnesota. Three bands of unlayered gabbro paralleling the contact were located in an extensive sequence of rhythmically layered troctolites. The band of gabbro nearest the basal contact is interpreted to be a marginal phase, which crystallized on the wall of the magma chamber. The other two bands of gabbro possess gradational lower contacts and sharp upper contacts with the host troctolites, and are hypothesized to be layers dipping east at approximately 28° . The layers of gabbro and underlying troctolite represent macro-rhythmic layers formed by replenishment of magma in a sill-shaped chamber, with fractionation and higher crystal growth rates responsible for formation of the gabbro. The increase in crystal growth rates is hypothesized to be the result of an increase in the amount of volatiles, through diffusion into the magma chamber from dewatering of country rock basalts.

Also mapped in the Bardon Peak field area were irregular bodies of peridotite found in both the troctolite and gabbro units. Most of the bodies are circular in geometry, and are often in gradational contact with their host rock. Dike-like peridotite bodies were found which cut but do not disrupt layering in host troctolite. The petrographic textures and crystallization sequence of the peridotite were markedly different from the troctolite and gabbro. The primary differences are the mafic minerals exhibit an interlocking texture, and plagioclase is always anhedral and interstitial to the other minerals. It was determined

that the compositions of the olivine and clinopyroxene in the peridotite crystallized from a magma that was slightly more fractionated than the melt which formed the troctolite and gabbro. Compositions of the plagioclase in the peridotite were found to contain significantly higher An contents than plagioclase in the troctolite and gabbro. It was concluded that the peridotite was formed by a volatile-rich metasomatizing melt that replaced plagioclase in the host rock with olivine and clinopyroxene. Additionally, it is hypothesized that the source of the metasomatizing melt was intercumulus melt, which had been fluxed by volatiles from dewatering of the country rock. The metasomatizing fluid is envisioned to have been localized in a dilation zone, and moved upward in channelways forming pipe-shaped peridotite bodies.

As a part of this study, two drill cores from the Water Hen intrusion, a layered mafic intrusion along the basal contact of the Duluth Complex south of Hoyt Lakes, Minnesota, were examined. The many similarities between the peridotite in the Water Hen cores and at Bardon Peak suggest that the peridotite in the Water Hen intrusion may have also been produced by a replacement process.

Platinum Group Element Minerals in the Duluth Complex

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Platinum group element (PGE) minerals with trace amounts of Au and Ag from the Duluth Complex are described. The minerals were found at two different locations within oxide-rich portions of a drill core. The PGE minerals occur in an oxide(65%)-plagioclase(25-30%)-olivine(5%) host and an olivine(40%)-oxide(30%)-plagioclase(25%) host. Titaniferous magnetite is the dominant oxide and is associated with minor hercynite and ilmenite. Sulfide mineralization in these rocks is minor and is primarily of the finely disseminated type. Chalcopyrite, bornite and pentlandite are the main sulfide phases.

The PGE minerals were identified by energy dispersive x-ray analysis (EDS) using both an electron microprobe and a scanning electron microscope. They consist of five monomineralic grains and two locked composite grains. EDS spectra were collected from each of the individual mineral grains and from numerous points within the composite grains. Approximate chemical compositions of the phases were obtained by computer-processing the net peak counts of the elements present in each spectrum. The analyses were then correlated with published microprobe data on PGE minerals in order to identify the phases. The mineral names proposed in this paper are pending positive identification by quantitative analysis.

The five monomineralic grains occur in the olivine-oxide-plagioclase rock. Four of the five grains consist of a Pt-Fe alloy. They are subhedral to euhedral and range in size from 2x5 to 34x36 micrometer. Two grains are associated with magnetite, chalcopyrite, bornite and silicate alteration products. One grain occurs as an inclusion in ilmenite. The fourth grain forms a composite sulfide grain (70x16 micrometer) with pentlandite, bornite and chalcopyrite and occurs in plagioclase. The Pt-Fe alloy is distinguishable from the sulfides in reflected light microscopy by its high reflectivity and white color. The four grains have similar compositions and consist mostly of Pt with minor Fe and lesser amounts of Pd, Cu and Ni. The fifth grain is a Ru sulfide with minor Os and traces of Ir and Fe. It has a high reflectivity and is white with a grey tint. The mineral resembles laurite in both its composition and optical properties. The 10x20 micrometer grain is euhedral and occurs as an inclusion in plagioclase.

The composite grains were found in the oxide-plagioclase-olivine host. The grains measure 13x5 and 12x8 micrometer and occur in a Fe-Mg-Al-Si alteration product associated with biotite and plagioclase. One grain consists of Pt-Fe alloy and three compositionally distinct Pd phases. EDS spectra of the Pd minerals indicate the presence of the following elements (not listed in order of abundance): Pd-Pt-Fe-Cu-Ni-Sn-Bi-As, Pd-Pt-Cu-Sn-Bi and Pd-Fe-Sn-Bi-As. The Pt-Fe alloy is compositionally similar to the other Pt-Fe alloy grains found and constitutes 85% of the grain. The second grain contains very fine-sized complex intergrowth of numerous PGE minerals. Six phases were identified by EDS

analysis. The texture of the grain indicates the presence of additional phases but they were too fine-grained to be resolved by the scanning electron microscope. The phases identified in this grain are an Ir-Rh sulfarsenide or irarsite, two Pt sulfarsenides with significant Fe and Os and traces of Ag (one of which also contained Pd and trace amounts of Au), a Pt-Fe-Os phase with minor Cu and As and traces of Pd, Rh and Ag, a Pd arsenide with Fe, Cu, Sn and Sb, and a Pd-Pt-Pb arsenide. Ag may be present in the Pd minerals as well but was difficult to detect due to peak overlap in the EDS spectra for Pd and Ag. Similarly, Au in other Pt minerals may not have been detected because of peak overlap for Pt and Au.

This is the second reported occurrence of PGE minerals in the Duluth Complex and the first identification of Pd, Ir, Ru, and Os- and Rh-bearing phases. This find is also significant because the minerals described here occur in rock containing disseminated sulfides. The sperrylite reported previously (1) was found in massive sulfide ore.

Considerably more mineralogical work is required to evaluate the potential of the Duluth Complex as a producer of platinum group metals. The evaluation of ore recovery procedures is also needed. The flotation responses of PGE minerals have not been documented. Of particular concern are the floatabilities of alloys, especially of iron-platinum, which may not be as floatable as sulfides, arsenides and sulfarsenides.

References:

- 1) Ryan, P.J. and Weiblen, P.W., 1984, Pt and Ni Arsenide Minerals in Duluth Complex (abs), Ann. Inst. Lake Superior Geol., 30th, Wausau, Wisconsin, 58-60.

A Study Of Vein Mineralization and Wall Rock Alteration at
the Delaware Mine, Keweenaw County, Michigan

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The Delaware Mine is located in the northern half of the Keweenaw Peninsula of Upper Michigan. It opened in 1848 and is one of the oldest copper mines in the Michigan Native Copper District. Mining originally centered on a mass copper-bearing fissure known as the Stoughtenburgh vein and later production was from the Allouez Conglomerate, a copper-bearing conglomerate which is cut by the Stoughtenburgh. The mine closed in 1887 and remained so until 1977 when Tom Poynter purchased the mine and reopened the first level for public tours.

The mine was geologically mapped at a scale of 1:1080. The Allouez Conglomerate is an 8 meter thick stratified conglomerate consisting of rounded to subangular pebbles and cobbles of mostly rhyolite and rarely amygdaloidal basalt. Exposed in two crosscuts below the Allouez are two thin basalt flows. The Greenstone Flow is stratigraphically above the conglomerate but not exposed in the mine. These rocks generally strike E-W and dip 25 degrees north.

Numerous mineralized tension fractures with generally northerly strikes and near vertical dips transversely cut the beds. Stereographic projection of poles to planes for the fractures indicate that the major stress field, sigma one, was approximately N-S, parallel to the tension fractures. The general paragenetic sequence for mineralization in the fractures is, oldest to youngest: 1) drusy subhedral to anhedral grains of quartz; 2) euhedral to anhedral microcline; 3) fine grained muscovite, in part replacing microcline; 4) native copper; 5) coarse grained anhedral calcite; and 6) rare copper sulfide.

Fluid inclusion studies of calcite from eleven veins were conducted to constrain the temperature of the mineralizing fluids. Homogenization temperatures of 136 inclusions ranged from 80°C - 280°C, uncorrected for pressure. Analyzed inclusions were isolated, did not follow obvious fractures, and showed no evidence of necking down. A histogram suggests two and possibly three temperature peaks: (A) 110-130°C, (B) 160-200°C (?), and (C) 230-260°C. Fluid inclusion homogenization temperatures must be corrected for pressure. Livnat's (1983) inferred pressure of 1.5 kb for this part of the stratigraphic column yields a pressure correction of +125° (peak C 325-385°C). The pressure corrected temperature for peak C seems too high in light of wall rock alteration mineralogy, Livnat's (1983) probable temperature of lode copper mineralization, and comparison to calcites in Tertiary veins where temperatures ranging from 230-260°C are common. This suggests that the pressure was less than 1.5 kb and perhaps little if any pressure correction is needed. At the present time no firm conclusions can be drawn from the fluid inclusion data.

Wall rock adjacent to veins is mildly to intensely chloritized, sericitized, carbonatized, and silicified. Plagioclase in basalt is generally albitized out where the basalt is cut by veins plagioclase

is altered to sericite and chlorite. Olivine is wholly or partly altered to serpentine. Interstitial material in the basalt (glass?) has been predominantly altered to chlorite, or replaced by minor amounts of calcite. Rhyolite clasts in conglomerate adjacent to veins tend to be less altered, dominantly carbonatized and silicified, with calcite and quartz filling minute voids and fractures in the clasts. The rhyolite clasts are also moderately to intensely stained with a coating of iron oxide. Samples of wall rock taken perpendicular to the veins from directly adjacent to and up to a maximum of one meter away were chemically analyzed for a suite of 23 elements in order to determine element mobility during alteration. All analyses were corrected for volume changes. Element mobility calculations indicate that Cu and Ca were massively added to both rhyolite and basalt adjacent to the veins by the mineralizing fluids. This is consistent with the formation of calcite and native copper or copper sulfide. K and Mg were generally added by the fluid to the most altered rock and were incorporated into sericite and chlorite, respectively. Na was massively depleted from the rhyolite and depleted only in the most altered basalt directly adjacent to the vein; Na was removed by the solution. Na depletion probably reflects the breakdown of plagioclase. Ni was mobile but was only redistributed within the conglomerate. The elements Ba, Y, Zr, V, and Ti were relatively immobile during alteration. At the present time a model is being developed to determine the nature of the hydrothermal system for vein mineralization at the Delaware Mine. This will allow for a comparison with the more economically significant lode deposits.

Reference

Livnat, A., 1983, (Ph. D. Dissertation), University of Michigan, Ann Arbor, 225 p.

THE GEOLOGICAL SETTING AT THE DUPORT MINE, CAMERON ISLAND, SHOAL LAKE

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The Duport Mine has been explored and developed several times since its discovery in 1896. Recent drilling has increased the reserves, now estimated 1,927,000 tons grading 0.30 ounce Au per ton over 9.75 feet (Northern Miner, October 13, 1983). Recently an 1185m decline has been driven to intersect the two main mineralized zones at three levels.

Located on the western limb of a northwest-trending anticline, the deposit is hosted by tholeiitic and komatiitic basalts and by ultramafic flows/sills. The mafic volcanics are overlain to the west by a series of andesitic and felsic flows and tuffs. The volcanic package has been intruded west of the deposit by the Snowshoe Bay granodiorite batholith, and immediately to the east by the Stevens Island diorite. Late felsic and mafic dikes cut all lithologies. The regional metamorphic grade is upper greenschist to lower amphibolite facies; however, mineral assemblages in close proximity to the ore zones are indicative of lower greenschist grade metamorphism.

The mine lithologies consist of metabasalt, metapyroxenite, and varieties of chlorite schist. Lithologies close to the ore zones are anomalous in chlorite, talc, sericite, biotite, epidote, carbonate, magnetite, and pyrite; the ore zones themselves are quartz and sulphide rich and contain varying amounts of feldspar, muscovite, sericite, pale-brown biotite, epidote, carbonate and chlorite. The two main ore zones, the East and Main zones, lie within a zone which has recorded intense deformation, the Duport Deformation Zone (DDZ). The DDZ is a reverse fault system, several hundred metres wide, trending northeast, and dipping about 75 degrees northwest. From east to west the DDZ is characterized by chlorite-talc-carbonate schist and amphibolite, grading to zones of actinolite-chlorite-sericite schist and finally to basalt breccia. Deformation styles reflect these transitions, ranging from ductile in the east to brittle +/- ductile in the west. Gold is hosted by well-defined quartz- and sulphide-rich zones. It displays a strong association with arsenopyrite, but is also found with pyrite, pyrrhotite and chalcopyrite. There are at least two ages of pyrite; the younger containing inclusions of gold, while the older is plated by gold. The ore zones show a pronounced, but discontinuous sulphide-silica layering. Commonly a well-developed biotite (+/- pyrite) halo surrounds the ore, and in places extends past ore lens terminations. In general the ore parallels the schistosity,

but locally it fills branching interconnecting fractures and does not form discrete zones. Where felsic dikes intersect the ore-bearing system, dike margins are brecciated to mylonitized and are replaced by quartz, sulphides and gold. Recent underground work has suggested that the ore zones are not continuous as previously believed, rather they are a series of enechelon, almond-shaped lenses, which step left in the horizontal sense and up and into the footwall in the vertical sense.

The extensive deformation, associated pervasive alteration, and vein orientations, suggest that the ore-bearing zones are structurally controlled. It is proposed that ore is hosted by zones of high permeability, either by brittlely deformed felsic dikes or by permeable channels created by brittle failure within basalt, and concentrated into openings created by movement over irregular fault planes.

VOLCANIC FACIES OF THE ANDREW BAY AREA, LAKE OF THE WOODS, ONTARIO

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Basalt lava flows and intermediate to felsic pyroclastic rocks of Archean age crop out on either side of an east-trending syncline in Andrew Bay, 20 km south-southeast of Kenora, Ontario. The basaltic assemblage reaches 5.4 km in thickness north of Andrew Bay, whereas the pyroclastic rocks overlie 0.9 km of basalt and are up to 1.7 km thick south of Andrew Bay. Massive and pillowed basalts are products of non-explosive volcanism, whereas tuffs, lapilli tuffs, and debris flows represent products of explosive volcanism.

The tuffs and lapilli tuffs are massive deposits that contain up to 40% crystals by volume. These rocks carry lithic fragments, some of which may be welded tuffs or flow-banded lavas that have been transported from near-vent areas. Many of the least-altered tuffs indicate the presence of relict pumice in the interstices between crystals and lithic fragments. The presence of pumice provides evidence for contemporaneous explosive volcanism and sedimentation. By analogy with modern-day environments, the tuffs were likely erupted in a shallow marine to subaerial environment but deposited in a marine environment below wave base. The variable crystal content of the tuffs and the lack of high-temperature indicators in the deposits implies (1) magmatic and/or post-magmatic loss of fine vitric material and (2) emplacement as resedimented deposits rather than as hot pyroclastic flows.

The debris flows are heterolithic, poorly-sorted, and matrix-supported. They can be ungraded, normally-graded, and reversely-graded for the coarse fraction, with subrounded to subangular clasts of all sizes to one metre in diameter. No bedding is observed in these breccias. The poorly-sorted, unstratified nature of the deposits indicates emplacement as mass flows. The debris flows may have a shallow marine to subaerial volcanic provenance but subaqueous depositional setting. The rounding and reworking of clasts, heterolithic nature of the rocks, and presence of essential pumice that appears vesiculated all point to an origin by shoaling to subaerial explosive eruptions. However, the debris flows rest upon a partly pillowed platform and are intimately associated with turbidite beds. This implies the heterolithic material has been mixed and transported into deeper water by mass flow processes.

In sum, the basalts were erupted and deposited subaqueously, whereas the pyroclastics probably were erupted in a shallow marine to subaerial environment but deposited subaqueously. The pyroclastics are complexly interbedded and exhibit rapid facies changes. The pyroclastic deposits may become more proximal to the west, but subaerial vent-facies rocks are not present in this area.

MULCAHY LAKE GABBRO: A WELL-PRESERVED ARCHEAN LAYERED INTRUSION

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The Mulcahy Lake gabbro is an iron-rich, tholeiitic layered intrusion located in the Wabigoon Subprovince 45 km southwest of Dryden, Ontario. The gabbro is one of several mafic to ultra-mafic intrusions which are intrusive into tholeiitic to calc-alkaline metavolcanics around the periphery of the Atikwa-Lawrence granitoid batholith. The exceptionally well preserved nature of the Mulcahy gabbro makes it an ideal location to study the relationship of mafic plutonism with crustal development in the Archean.

The intrusion has a thickness of 7 km and is composed of three zones and a marginal facies which are the result of distinct cooling regimes and fractionating systems (Morrison et al., 1982). The lower and middle zones represent separate magma pulses which crystallized from the bottom upward and are characterized by iron enrichment trends. These zones are dominated by orthopyroxenes and plagioclase cumulates. The lower zone has a stratigraphy defined by the appearance of cumulus phases in the following order: orthopyroxene-plagioclase, clinopyroxene, inverted pigeonite, magnetite and olivine. The middle zone has a similar stratigraphy but in addition contains a 20 meter thick layer of olivine - clinopyroxene - plagioclase cumulate which occurs in the lower part of the middle zone and can be traced for the full 10 km length of the intrusion.

The upper zone of the Mulcahy gabbro is not clearly related to the sequence in the lower and middle zones. These rocks are interpreted to represent a roof zone of mafic to intermediate volcanic or subvolcanic protolith which has been metamorphosed to a pyroxene hornfels and partially melted. Sills ranging in composition from peridotite to gabbro and granite intrude the hornfels of the roof zone.

The iron-rich nature of the Mulcahy gabbro indicates that the magma was fractionated prior to emplacement into the metavolcanic sequence. Late peridotitic rocks, occurring along zones of deformation in the vicinity of the Mulcahy gabbro, contain cumulate magnesian olivine and chromite which crystallized from a more primitive magma. These rocks do not appear to be part of the Mulcahy gabbro cumulate sequence, however, they are interpreted to be derived from a common parental magma.

Although no rocks from the Mulcahy gabbro clearly represent liquid compositions, the sequence of cumulate phases provides information on the density relationships of the liquid. Fractionation of olivine from the magma results in a decrease of density of the residual liquid. If the peridotites are olivine cumulates from a parental magma, then the magma pulses forming the lower and middle zones may represent liquids at or near a density minimum. Further fractionation of plagioclase and pyroxene, as developed in the lower and middle zones, causes the density of the residual liquid to increase. This apparent control of density on the emplacement of the two magma pulses suggests that crustal filtering has restricted the access of more primitive magmas to high crustal levels.

These density relationships and the regional geology suggest the following sequence of events: 1) Ponding of mantle derived parental magma at the base of the crust. 2) Fractionation of olivine lowering the density of the liquid allowing gabbro plutons to rise through the crust. 3) Emplacement of granitoid magmas which are derived from melting of crustal rocks with the heat source provided by mafic magmatism. 4) Emplacement of late peridotitic dikes and sills along fault zones. This process implies that mafic metavolcanic rocks in the Wabigoon Subprovince are underlain by less dense material and may also explain the paucity of magnesian basalts and komatiites in the region.

Morrison, D.A., Ashwal, L.D., Henry, D.J., Maczuga, D.E., and Phinney, W.C., 1982, The Mulcahy Lake layered norite, 12th Lunar and Planetary Science Conference, Lunar and Planetary Science Institute, Houston.

MAGMA SERIES AND THEIR RELATIONSHIP TO
GREENSTONE GOLD METALLOGENY IN THE LAKE SUPERIOR REGION

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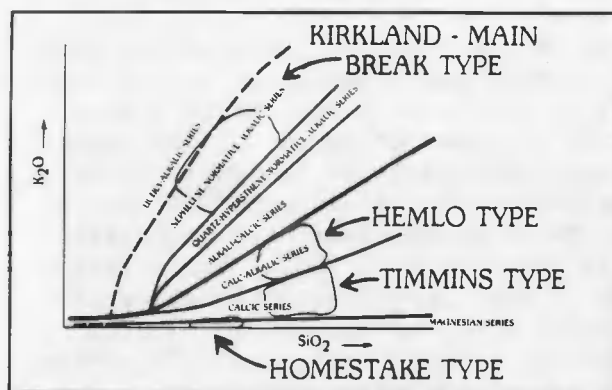
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Metal and trace element content of greenstone gold deposits of the Lake Superior Region display clear empirical relationships with magma series chemistry of spatially and temporally related igneous rocks. These empirical relationships, along with similar empirical relationships based upon a world-wide data base of 2500 mineral deposits, is the basis for a fundamentally new petro-chemical serial classification of igneous rocks and associated co-genetic mineral deposits that has serious mineral exploration as well as earth model implications. According to the magma series classification, gold deposits of the Lake Superior Region can be grouped into 4 distinct magma series: 1) magnesian, 2) calcic, 3) calc-alkalic and 4) nepheline normative alkalic (See Figure 1). Less fundamental breakdowns can be made based upon depositional environment (e.g. vein vs. chemical sediment).

The notion of magma series - a suite of co-magmatic igneous rocks linked by differentiation to an initially homogeneous mafic parent - is the core concept upon which the magma series classification is built. Before serial classification is attempted spilitization and/or phyllic and argillic hydrothermal alteration are filtered out by use of the $Al_2O_3/Na_2O + K_2O + CaO$ vs. SiO_2 variation diagram (See Figure 2). The classification first divides igneous rock series into 2 fundamental megaseries based on their aluminum content (See Figure 2). A given rock suite is thus first determined to be aluminum-rich (peraluminous) or aluminum-poor (metaluminous). After the megaserie is determined, the igneous rock is further classified in terms of its alkalinity into one of 14 magma series. In addition to conventional petro-chemical criteria, these series are defined by a priori "off plot" empirical knowledge about metal contents of temporally and spatially associated mineral systems. Integration of metal chemistry of mineral deposits with alkalinity aspects of associated magma series allows the determination of the overall metallogenic bias of the magma series. The series are further divided into subseries based upon oxygen, water and iron content of the magma series. Additional divisions, that of rock systems, is accomplished by use of the Differentiation Index of Thornton and Tuttle (1960) to determine levels of differentiation within a magma series, to integrate conventional rock names to the magma series classification and to refine the metallogenetic bias of a magma series to the system level. Once the serial geochemical character of the associated magma series is determined any associated ore deposit can be further classified in terms of its emplacement environment.

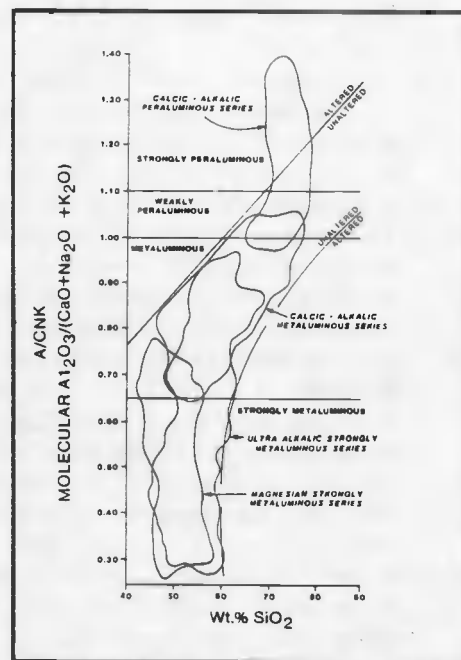
By classifying gold deposits of the Lake Superior Region according to magma series, their bulk metal and trace element content up to 40 elements can be predicted. These elements are listed in the Table below by gold deposit type. Means and ranges of these elements for each gold system type will be presented at the poster session. Also, ore and gangue mineralogy, wall rock alteration, element zoning, geophysical characteristics and ultimately engineering and

economic parameters can also be predicted from magma chemistry. In greenstone gold exploration greenstone belts can be subdivided according to magma series to predict which terranes are capable of hosting a given gold deposit type. The immediate implication for gold exploration in the Lake Superior Region is that this practical approach can streamline the mineral exploration process, save time and money and ultimately increase gold deposit discovery rates.



K₂O-SiO₂ variation diagram showing approximate chemical position for igneous rocks associated with gold deposit types in the Lake Superior region.

Figure 1



A/CNK VARIATION DIAGRAM FOR WORLDWIDE IGNEOUS ROCKS

Figure 2

Table

CHEMICAL NATURE OF GOLD DEPOSITS OF THE LAKE SUPERIOR REGION

Magma Series	Mineral Deposit Type	Elements	Elements
		Commonly Enriched In	Commonly Depleted In
Magnesian Series	Homestake (Cheminis-Omega)	Au, Ag, Ni, Cu, Cr, Fe, Mg, W, (Co, Zn, B)	Pb, U, Th, Sn, Be, Li, Hg, Nb, Zr, Y,
Calcic Series	Timmins and Grass Valley (La Maque)	Fe, Au, Ag, Cu, B, Zn, Pb, C, Co, Ni, W, Platinoids, Se, Cd, S, Mn, Li (Cr, Mo, As), K, Mg, Na	U, Th, Rb, Ce, Be, Hg, Sb, Ba, F, Nb, Ta
Calc-alkalic Series	Hemlo and Red Lake	Fe, Cu, Zn, Pb, Ag, Au, Sb, Hg, S, Ba, W, Mo, Re, Mn, (As, Se, Tl), K	Ni, Cr, Sn, F, U, Th, Ti, B, Li, Be, Ba, Y, Nb, Ta, (Co, platinoids), Na
Nepheline Normative Alkalic Series	Kirkland Lake Main Break	Au, platinoids, Cu, Pb, Zn, Ag, Mo, Te (LREE Nb, Rb, La, Te, Co, Ni, As) U, F, W, K, Sr, Ba	Hg, Sb, Tl, Mg (B, S)

THE HEMLO BARITIC HORIZON; A POSSIBLY SYNGENETIC ARCHEAN BARITE OCCURRENCE

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A baritic horizon occurs within Archean supracrustal rocks of the Hemlo area, northwestern Ontario, which exhibits characteristics that suggest a syngenetic origin is likely. This baritic unit crops out in 4 or 5 locations situated 5 to 13 km east of the town of Marathon, and appears to parallel the regional stratigraphy, occurring between pillowed mafic metavolcanics to the south and intermediate to felsic pyroclastics and metasediments to the north. The barite is thinly laminated to massive and is generally interlaminated with chert, pyrite and/or carbonate, forming a unit 1 to 2 m thick which is conformable with the associated rock units. Rock lithologies associated with the baritic unit include deep water/starved basin-type sediments (pyritiferous graphitic schists and DE turbiditic siltstones), siltstones with green mica-rich (rip-up?) clasts, metapelites, green mica schists, sericite schists, biotite-amphibolite schists, mafic metavolcanic flows and fragmentals, a very thin tuffaceous unit, and quartz-feldspar porphyry dikes. Although these rock units have likely been transposed relative to one another, their persistent presence at all the barite occurrences suggests that their association with the barite is real.

In comparing the characteristics of the Hemlo baritic horizon with those of other documented Paleozoic to Archean syngenetic and epigenetic barite occurrences throughout the world, it becomes evident that the Hemlo occurrence more closely resembles syngenetic than epigenetic deposits. These characteristics include: regional and local conformability of the baritic unit with associated lithologies; lateral continuity of the baritic horizon of possibly 8 km; associated deep water/starved basin-type sedimentary units and pillowed mafic metavolcanics; thinly laminated to thinly bedded character of the barite and interlamination with chert, pyrite and carbonate; and the presence of rip-up clasts of green mica schist in siltstones which stratigraphically overlie the baritic unit.

Geology of the Jap Lake Area of the
Eastern Vermilion District, Northeastern Minnesota

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The Jap Lake area, located at the eastern end of the Vermilion district in northeast Minnesota, contains a volcanic-sedimentary succession typical of many Archean greenstone-granite complexes of the Canadian shield, as well as lithologies representative of the lower to middle Proterozoic seen elsewhere in northern Minnesota.

Structurally, this Archean sequence represents the southern limb of a large antiform. The bedding trends NW-SE and stratigraphic indicators give tops to the SW. The lowest stratigraphic unit, here named the Jap Lake Volcanic unit, consists of massive and pillowed tholeiitic basalts locally intercalated with thin mafic tuffs, pillow breccias and hyaloclastites. Numerous mafic to ultramafic sills are regularly interlayered with the basalts and are apparently penecontemporaneous. The base of this unit has been intruded and apparently removed by the 2.7 Ga Saganaga Tonalite. Capping the thick greenstone unit locally are calc-alkaline dacitic lava flows and an associated fragmental unit. The entire volcanic sequence is then overlain by a thick blanket of volcanogenic sediments and later capped in the early Proterozoic (~2.0 Ga) by the Gunflint Iron Formation and Rove greywackes of the Animikie Group. Intruding the top of this sequence is the Keweenaw Duluth complex (~1.1 Ga).

Chemical analyses performed on 17 samples from the Jap Lake Volcanic unit indicate that these rocks range in composition from high-Mg tholeiitic basalts to ultramafic komatiites as defined by the Jensen cation diagram (Jensen, 1976). These rocks are characterized by moderate to high MgO% (7-11% in the basalts to 20-32% in the peridotite sills) and low TiO₂ (0.6-1.0% in the basalts to 0.3-0.4% in the peridotite sills). The ultramafic sills are also characterized by low Al₂O₃ (2-7%), high Mg values (.74 to .83), high CaO/Al₂O₃ ratios (0.9 to 3.1) and high Ni (700-1100 ppm) and Cr contents (2300-3500 ppm).

Contact metamorphism has been locally moderate to severe in the Jap Lake area. Adjacent to the Saganaga batholith hornblende hornfels facies assemblages can be seen in the basalts (now hornblende + plagioclase + biotite) as well as in the peridotites (now tremolite + talc + secondary forsteritic olivine + dusty magnetite + chlorite + serpentine + calcite). Adjacent to the Duluth complex, pyroxene hornfels facies assemblages are seen in the basalts (augite + plagioclase + hornblende) and in the iron formation (fayalite + hedenbergite + ferrohypersthene + magnetite + grunerite). Metamorphic effects from the Duluth complex can be seen as far as 3000 feet (map distance) away from the contact.

Based on field, petrographic and geochemical evidence, the following model is proposed for the origin of the archean volcanic-sedimentary pile. Tholeiitic basalts were erupted subaqueously at significant water depths and subsequently intruded by thin synvolcanic mafic to ultramafic sills at

shallow levels in the volcanic pile, as evidenced by the common occurrence of quench textures on the sill margins. The cessation of tholeiitic volcanism also signalled the end of subaqueous eruptions. When volcanism resumed it had a decidedly different character: all later eruptions appear to be subaerial and have calc-alkaline affinities, possibly signifying genesis in an island arc setting. This largely dacitic volcanism is believed to be genetically related to the intrusion of the Saganaga batholith, which not only served as the magma source for the felsic flows, but also was presumably responsible for the uplift of the overlying volcanic pile. This was followed by rapid erosion and deposition of the thick pile of volcanogenic sediments.

References

- Jensen, L. S., 1976, A New Cation Plot for Classifying Subalkalic Volcanic Rocks, Ont. Dept. Mines, Misc. Paper No. 66, 17 p.

PRELIMINARY INVESTIGATIONS INTO THE GEOLOGY OF THE GIANTS
RANGE COMPLEX, VIRGINIA-BIWABIK AREA, N.E. MINNESOTA

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Geologic mapping in the highlands of the Giants Range Complex, from east of Hwy. 53 north of Virginia to Hwy. 135 north of Aurora, has identified two distinctive units: an older migmatitic unit, and a younger hornblende-bearing unit.

The migmatite is well exposed in roadcuts along Hwy. 53 north of Virginia. Four separate phases within this body have been identified: 1) pink to grey, medium-grained, gneissic biotite tonalite; 2) agmatitic amphibolite inclusions within the tonalite host; 3) medium-grained hornblende leucotonalite dikes which crosscut both the tonalite and inclusions; and 4) later minor aplitic dikes and veinlets. A banded amphibolitic gneiss marks the southern boundary of the migmatite. Within the area mapped, the migmatite occurs only in the Lookout Mountain area.

The remainder of the Complex in the mapped area is comprised of hornblende-bearing rocks. These rocks are pink to grey, medium- to coarse-grained, weakly to moderately foliated, commonly porphyritic, and range in composition from granodiorite to diorite, with quartz monzodiorite being the dominant lithology. Amphibolite inclusions are common within these rocks. The hornblende bearing unit is clearly intrusive into the banded amphibolite gneiss. Along the southern margin of the body these rocks are in contact with greenstone. This contact, though not exposed, is relatively sharp and is probably a fault.

Foliations within both units are concordant, trending east by northeast. Folding has been recognized within the migmatite, with fold axes and mineral lineations plunging moderately to the east. Hornblende in the hornblende-bearing pluton appears to be similarly aligned. As structures in the greenstone have a similar trend, the fabric in the plutonic rocks is interpreted to be tectonic.

MAGMATIC PROCESSES DURING THE MIDCONTINENT RIFT INTERVAL
IN NORTHERN MICHIGAN:
CHEMICAL AND ISOTOPIC CONSTRAINTS

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The Keweenawan (~1.3-0.9 Ga) rocks of the Lake Superior region are preserved as several spatially and temporally separate plateau flood eruptions and/or related subvolcanic complexes. This magmatic activity was associated with the development of the Midcontinent Rift system (MCR) with its pronounced gravity anomaly, hence "the Midcontinent Gravity high".

In Michigan, two of these flood-type plateaus centers can be distinguished: the Powder Mill Group (PMG) which records the first erupted lavas with eruptive centers near the Wisconsin-Michigan border, and the Portage Lake Lavas (PLLS) and overlying "un-named formation" (see McDermott, this program) which records the abrupt cessation of rift related volcanism. Two dyke swarms which intrude Archean basement and early Proterozoic sedimentary basins, and small plug-like bodies, are the only exposed subvolcanic Keweenawan rocks in Michigan. Based on petrochemical similarities, the tholeiitic dykes are believed to be feeders for the overlying lavas of the PMG and PLLS.

New data from the PMG yield an isochron with $^{87}\text{Sr}/^{86}\text{Sr} = 0.7043 \pm 0.0003$ and an age of 1209 ± 136 Ma. The PLLS, which have eruptive centers to the northeast of the PMG, consist of two distinct, but intercalated, batches of tholeiitic (olivine and quartz) magma. Derivation of one batch from the other by mixing or fractional crystallization modeling cannot adequately explain the element abundances. Two isochrons with similar ages were obtained for each batch: olivine tholeiite yielded an age of 1013 ± 274 Ma and $^{87}\text{Sr}/^{86}\text{Sr} = 0.7028 \pm 0.0006$; and 1026 ± 191 Ma with $^{87}\text{Sr}/^{86}\text{Sr} = 0.7036 \pm 0.0005$ for the quartz tholeiite.

The "un-named" formation, with its high percentage of evolved rocks which include high potassium rhyolites and intercalated basaltic and andesitic flows, has a major element distribution which has an abrupt change at 65% silica. The origin of the acidic flows is most easily explained by crustal melting than by fractional crystallization of parent tholeiite magma.

Petrochemical and isotopic data are interpreted to mean that the heat source which generated the PMG lavas moved northeastward relative to the crust with time to produce the younger PLLS. The chemical and isotopic duality of the PLLS suggest that proximal, but separated magma chambers existed at this time, possibly derived by partial melting of REE undepleted upper mantle at different depths.

STRAIN PATTERNS IN THE KIRUNA DISTRICT, NORTHERN SWEDEN:
IMPLICATIONS FOR PROTEROZOIC DEFORMATION

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Early to middle Proterozoic supracrustal rocks occupy a large area of northern Sweden bordered on the north by rocks of an Archean gneissic terrane and on the west by the Caledonide frontal thrust. The Kiruna district includes broad belts of deformed and metamorphosed supracrustal rocks composed of bimodal volcanics, volcanoclastic sediments, and quartz arenites. A NE striking eastern belt, hosting the iron and sulfide ores, and a NW striking western belt are symmetrically disposed about an apparently younger, unfoliated granite in a manner typical of classic granite/greenstone terranes. Structural fabric and induced strains are inhomogeneously developed and are attributed to a single major phase of deformation - the Svecokarelian orogeny.

Extensive structural work in the supracrustal rocks surrounding the central granite has revealed the following significant relationships: 1.) Cleavage in rocks of the eastern and western belts is steep and aligned roughly N-S somewhat parallel with the granite boundaries. 2.) Cleavage in rocks north and south of the granite is also dominantly aligned N-S, oblique to the granite borders. 3.) Bedding/cleavage and minor fold symmetry in the eastern and western belts both indicate structural vergence towards the granite (i.e. bedding dips away from the granite and cleavage is always steeper than bedding). 4.) E-W shear zones with dextral symmetry are developed south of the granite. 5.) Stretching lineations, minor fold axes, and bedding/cleavage intersection lineations congruently plunge moderately to steeply to the south along the eastern margin of the granite. 6.) Facing directions are consistently away from the central granite. These structures suggest E-W shortening concomitant with large wavelength buckling.

Strain measurements were made in a variety of lithologies bounding the central granite and reveal the following: 1.) A considerable heterogeneity of strain magnitude between the varying lithologies ranging from highly strained schistose conglomerates to nearly undeformed major magnetite ore bodies. 2.) Higher strain magnitudes in the eastern belt than in the western and southern belt. 3.) Strain symmetry close to plane strain. 4.) Maximum shortening strains (Z axes) are dominantly E-W. 5.) Maximum elongation strains (X axes) plunge steeply south in the eastern and southern belts. Elongation strains plunge northward in the western supracrustal belt.

The strain patterns, structural symmetry, and distribution of strain intensity just described are inconsistent with an origin dominated by granite diapirism. It is proposed instead that deformation was regionally extensive producing large scale folds cored by syn-intrusive granites and a regionally homogenous

strain field. Heterogeneities are thought to result from the large ductility contrasts in the supracrustal rocks and the influence of large, stiff, newly intruded granite bodies. Superposition of late flattening strains due to diapir ballooning is possible.

Major Element Geochemistry of the Gowganda Formation, Ontario

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Over 200 major element analyses, most of which are new, are available from the Gowganda Formation, a dominantly glaciogenic sedimentary unit forming part of the Huronian Supergroup. Most of these analyses are from diamictite matrix materials and argillites. Deposition of the Gowganda Formation and succeeding Huronian formations took place under conditions of regional subsidence so that they are preserved both in the main fold belt and in relatively stable shelf areas to the north. There are three main areas of preservation of the Gowganda Formation; the Bruce Mines, Cobalt and Whitefish Falls areas. Most of the new chemical data are from the Whitefish Falls area, which had a more basinal setting than the other two.

The average major element composition of diamictite matrix materials and argillites, giving equal weight to all three areas, is as follows:-

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI
1.	64.41	0.63	15.08	2.08	3.58	0.08	3.13	1.53	4.46	1.84	0.14	2.71
2.	59.62	0.70	17.28	2.94	5.06	0.09	3.27	1.07	3.88	2.84	0.16	3.03

1. is the average of 102 analyses of diamictite matrix material.
2. is the average of 105 analyses of argillites.

With the exception of CaO, which is depleted in the diamictites, the average composition of the diamictite matrix material corresponds closely to the estimate by Shaw et al. (1967) of the average composition of the Archean basement in part of Ontario. A similar, but weaker, CaO-depletion is evident in Pleistocene tills deposited on Archean basement in the same region.

The Cobalt diamictites are enriched in CaO and FeO relative to the average Gowganda diamictite and are depleted in Na₂O. Diamictites from the Bruce Mines area show relative depletion in CaO and FeO and are Na₂O-enriched. Similar patterns are apparent when the argillites of these areas are compared with the average argillite composition. These results are compatible with the observed basement geology and suggest that the chemical composition of the diamictite matrix materials, and to a lesser extent, of the argillites, may be used as provenance indicators. The chemical composition of the Gowganda Formation in the Whitefish Falls area suggests a mixed provenance with contributions from both regions.

Comparison of the average Gowganda argillite and diamictite matrix composition indicates depletion in silica (grain size effect) and the mobile elements Ca and Na in the argillites. Comparison of the average Gowganda argillite composition with that of the average Aphebian shale (modified from Cameron and Garrels, 1980, to exclude data from the Gowganda Formation) indicates that the latter is much more chemically altered, being richer in SiO₂, TiO₂ and K₂O and depleted in CaO and Na₂O.

A chemical index of alteration (CIA of Nesbitt and Young, 1982) was used to determine the degree of weathering in the diamictite matrix materials and argillites of the Gowganda Formation. These results are interpreted to indicate that the Gowganda Formation in the southern part of the Huronian outcrop belt contains evidence of two major glaciations separated by deposits of an interglacial period.

References

- Cameron, E.M. and Garrels, R.M. 1980. Geochemical composition of some Precambrian shales from the Canadian Shield. *Chemical Geology*, v.28, p.181-197.
- Nesbitt, H.W. and Young, G.M. 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature* v.299, p.715-717.
- Shaw, D.M., Reilly, G.A., Muysson, J.R., Patterden, G.E. and Campbell, F.E. 1967. An estimate of the chemical composition of the Canadian Precambrian Shield. *Can. Jour. Earth Sci.* v.4, p.829-853.