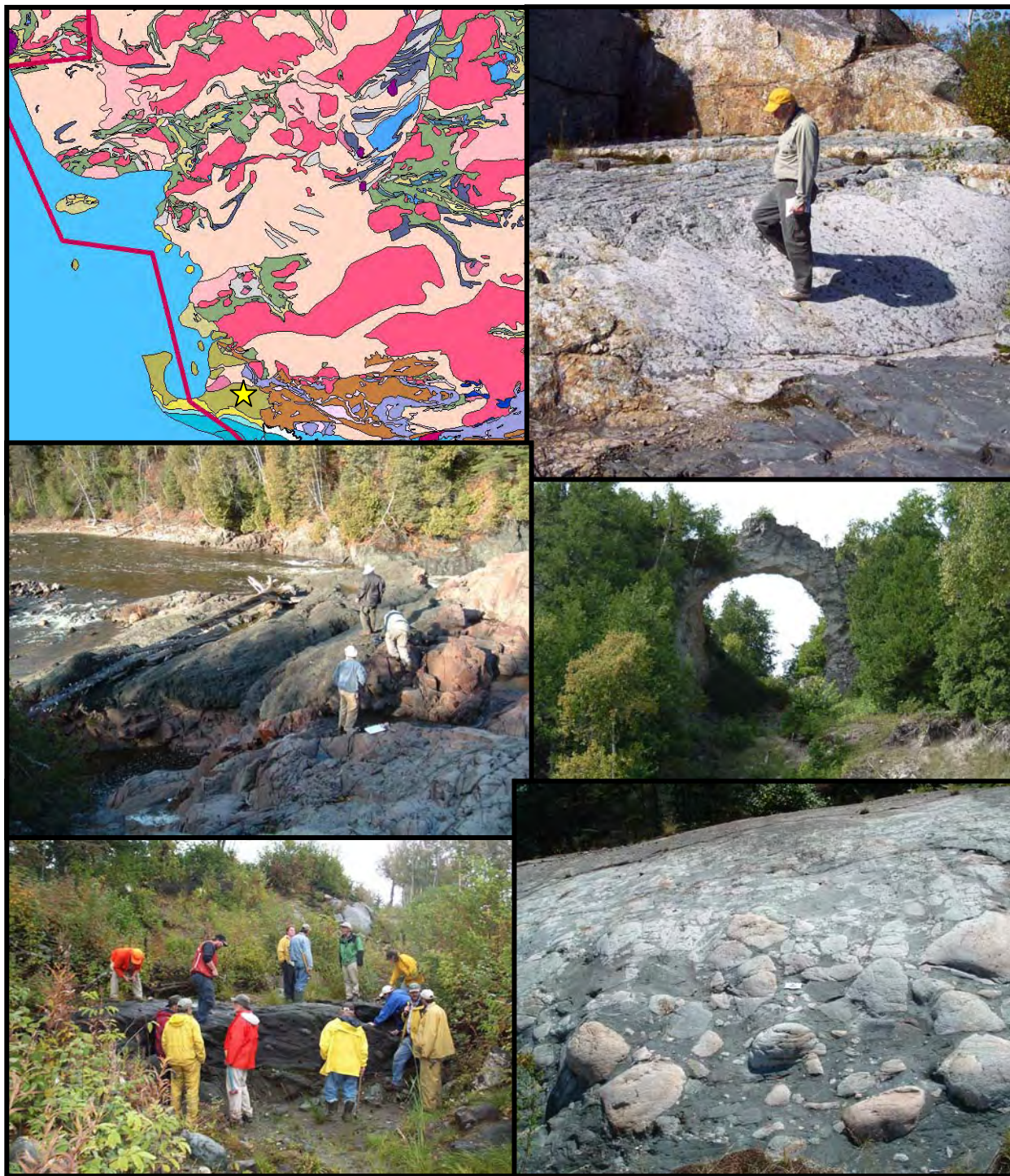


52nd Annual Meeting
Sault Ste Marie, Ontario – May 8 – 12, 2006
Institute on Lake Superior Geology
Part 1 – Proceedings and Abstracts





52nd Annual Meeting

INSTITUTE ON LAKE SUPERIOR GEOLOGY



May 8 – 12, 2006

Sault Ste Marie, Ontario

Hosted by

R. P. Sage and A. C. Wilson

Co-chairs

Volume 52

Part 1 – Proceedings and Abstracts

Edited by A. C. Wilson (Ontario Geological Survey)

Cover Photos (clockwise from upper left) – Generalized geology of the Sault Ste Marie, Ontario area (Ontario Geological Survey Map 2543); Stone quarry in nodular anorthosite of the Agnew Lake Intrusion (photo courtesy of M. Easton OGS); Arch Rock, Mackinac Island, Michigan; Gowganda Formation, Hwy. 108 Elliot Lake area; Nicholson outcrop, Arctic Star Diamond Corp. property, Menzies Township; Chippewa Falls unconformity, Hwy.17N.

52nd INSTITUTE ON LAKE SUPERIOR GEOLOGY

VOLUME 52 CONSISTS OF:

- PART 1:** PROGRAM AND ABSTRACTS
- PART 2:** GLACIAL LAKES ALGONQUIN AND NIPISSING SHORELINE BEDROCK FEATURES: MACKINAC ISLAND, MICHIGAN - FIELD TRIP GUIDEBOOK
- PART 3:** UNUSUAL DIAMOND-BEARING BRECCIAS OF THE WAWA AREA - FIELD TRIP GUIDEBOOK
- PART 4:** THE HURONIAN SUPERGROUP BETWEEN SAULT STE MARIE AND ELLIOT LAKE - FIELD TRIP GUIDEBOOK
- PART 5:** KEWEENAWAN ROCKS OF THE MAMAINSE POINT AREA - FIELD TRIP GUIDEBOOK
- PART 6:** GEOLOGICAL GUIDEBOOK TO THE PALEOPROTEROZOIC EAST BULL LAKE INTRUSIVE SUITE PLUTONS AT EAST BULL LAKE, AGNEW LAKE AND RIVER VALLEY, ONTARIO - FIELD TRIP GUIDEBOOK

Reference to material in Part 1 should follow the example below:

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Institutes on Lake Superior Geology, 1955-2005

#	Date	Place	Chairs
1	1955	Minneapolis, Minnesota	C.E. Dutton
2	1956	Houghton, Michigan	A.K. Snelgrove
3	1957	East Lansing, Michigan	B.T. Sandefur
4	1958	Duluth, Minnesota	R.W. Marsden
5	1959	Minneapolis, Minnesota	G.M. Schwartz & C. Craddock
6	1960	Madison, Wisconsin	E.N. Cameron
7	1961	Port Arthur, Ontario	E.G. Pye
8	1962	Houghton, Michigan	A.K. Snelgrove
9	1963	Duluth, Minnesota	H. Lepp
10	1964	Ishpeming, Michigan	A.T. Broderick
11	1965	St. Paul, Minnesota	P.K. Sims & R.K. Hogberg
12	1966	Sault Ste. Marie, Michigan	R.W. White
13	1967	East Lansing, Michigan	W.J. Hinze
14	1968	Superior, Wisconsin	A.B. Dickas
15	1969	Oshkosh, Wisconsin	G.L. LaBerge
16	1970	Thunder Bay, Ontario	M.W. Bartley & E. Mercy
17	1971	Duluth, Minnesota	D.M. Davidson
18	1972	Houghton, Michigan	J. Kalliokoski
19	1973	Madison, Wisconsin	M.E. Ostrom
20	1974	Sault Ste. Marie, Ontario	P.E. Giblin
21	1975	Marquette, Michigan	J.D. Hughes
22	1976	St. Paul, Minnesota	M. Walton
23	1977	Thunder Bay, Ontario	M.M. Kehlenbeck
24	1978	Milwaukee, Wisconsin	G. Mursky
25	1979	Duluth, Minnesota	D.M. Davidson
26	1980	Eau Claire, Wisconsin	P.E. Myers
27	1981	East Lansing, Michigan	W.C. Cambray
28	1982	International Falls, Minnesota	D.L. Southwick
29	1983	Houghton, Michigan	T.J. Bornhorst
30	1984	Wausau, Wisconsin	G.L. LaBerge
31	1985	Kenora, Ontario	C.E. Blackburn

#	Date	Place	Chairs
32	1986	Wisconsin Rapids, Wisconsin	J.K. Greenberg
33	1987	Wawa, Ontario	E.D. Frey & R.P. Sage
34	1988	Marquette, Michigan	J. S. Klasner
35	1989	Duluth, Minnesota	J.C. Green
36	1990	Thunder Bay, Ontario	M.M. Kehlenbeck
37	1991	Eau Claire, Wisconsin	P.E. Myers
38	1992	Hurley, Wisconsin	A.B. Dickas
39	1993	Eveleth, Minnesota	D.L. Southwick
40	1994	Houghton, Michigan	T.J. Bornhorst
41	1995	Marathon, Ontario	M.C. Smyk
42	1996	Cable, Wisconsin	L.G. Woodruff
43	1997	Sudbury, Ontario	R.P. Sage & W. Meyer
44	1998	Minneapolis, Minnesota	J.D. Miller & M.A. Jirsa
45	1999	Marquette, Michigan	T.J. Bornhorst & R.S. Regis
46	2000	Thunder Bay, Ontario	S.A. Kissin & P. Fralick
47	2001	Madison, Wisconsin	M.G. Mudrey & Jr., B.A. Brown
48	2002	Kenora, Ontario	P. Hinz & R.C. Beard
49	2003	Iron Mountain, Michigan	L. Woodruff & W.F. Cannon
50	2004	Duluth, Minnesota	S. Hauck & M. Severson
51	2005	Nipigon, Ontario	M. Smyk & P. Hollings
52	2006	Sault Ste Marie, Ontario	R. P. Sage & A. C. Wilson

Constitution of the Institute on Lake Superior Geology

(Last amended by the Board—May 6, 2004)

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 insure 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

Minn. Stat. Anno. 290.05(9)

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

Article IV - Membership

The membership of the organization shall consist of persons who have registered for an annual meeting within the past three years, and those who indicate interest in being a member according to guidelines approved by the Board of Directors.

Article V - Meetings

The organization shall meet once a year. 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 Chair, Secretary, Treasurer, and the last three past Chairs; but if the board should at any time consist of fewer than six 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 Chair so as to bring the membership of the board to six members.

Article VII - Officers

The officers of this organization shall be a Chair, a Secretary and a Treasurer.

- A. The Chair 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/her term of office as Chair will terminate at the close of the annual meeting over which he/she presides, or when his/her successor shall have been appointed. He/she will then serve for a period of three years as a member of the Board of Directors.
- B. The Secretary shall be elected at the annual meeting. His/her term of office shall be four

years, or until his/her successor shall have been appointed.

C. The Treasurer shall be elected at the annual meeting. His/her term of office shall be four years, or until his/her successor shall have been appointed.

The terms of the Secretary and Treasurer shall be staggered so that there will always be a two year overlap between the two.

Article VIII - Amendments

This constitution may be amended by a majority vote (majority of those voting) of the membership of the organization.

By-Laws of the Institute on Lake Superior Geology

(Last amended by the Board—May 6, 2004)

The by-laws of the Institute on Lake Superior Geology are in revision and will be posted on the ILSG website when completed and approved. Please visit www.lakesuperiorgeology.org

Membership Criteria for the Institute on Lake Superior Geology

Approved May 8, 1997. Amended by the Board—May 6, 2004

A. Membership in the Institute on Lake Superior Geology requires either participation in Institute activities, or an indication on a regular basis of interest in the Institute. Those individuals registering for an annual meeting will remain as members for 4 years unless: 1) they indicate no further interest in the Institute by responding negatively to the statement on meeting circulars “Remove my name from the mailing list”; or 2) two successive mailings in different years are returned by the postal service as address unknown.

B. Those individuals who have not registered for an annual meeting in the past 4 years must indicate an interest in the Institute by postal, electronic, or verbal correspondence with the Secretary at least once every two years. Such individuals will be removed from the membership if they indicate no further interest in the Institute or two successive mailing in different years are returned by the postal service as address unknown.

C. The Secretary will maintain a list of current members. The list will include the date of the beginning of continuous membership, dates of returned mail, dates of last contact (expression of interest), and the date membership expires, barring a change of status initiated by the member. Those individuals who have become members of ILSG by Section B will have an expiration date listed at 2 years from the upcoming meeting. For example, a member who expresses interest in September of 1997 (the next annual meeting is May, 1998) will have an expiration date of May, 2000, unless the member contacts the Secretary or attends an annual meeting.

D. “Member for Life” status is granted to individuals who have been (nearly) continuous participants of the ILSG meetings for 15 years, Goldich Medal recipients, or those who have served as meeting chairs. This status will be further maintained unless the individuals indicate no further interest in the Institute, or 4 mailings in different years are returned by the postal service as address unknown, or they are deceased.

E. All members will be mailed the First Circular for the Annual Meeting and the ILSG Newsletter. The Chair of the annual meeting may opt to send the first circular to additional individuals. All returned mail should be reported to the Secretary.

F. The Secretary can designate any individual who is on the ILSG membership list (mailing list) as of January 1, 1997 as a member for life based on participation in ILSG activities.

G. Members are strongly encouraged to send address corrections to the Secretary to avoid unintentional lapse of membership.

Goldich Medal Guidelines

(Adopted by the Board of Directors, 1981; amended 1999)

Preamble

The Institute on Lake Superior Geology was born in 1955, as documented by the fact that the 27th annual meeting was held in 1981. The Institute's continuing objectives are to deal with those aspects of geology that are related geographically to Lake Superior; to encourage the discussion of subjects and sponsoring field trips that will bring together geologists from academia, government surveys, and industry; and to maintain an 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 ILSG by attending) has become aware of the fact that certain of their colleagues have made particularly noteworthy and meritorious contributions to the understanding of Lake Superior geology and mineral deposits.

The first award was made by ILSG to Sam Goldich in 1979 for his many contributions to the geology of the region extending over about 50 years. Subsequent medallists and this year's recipient are listed in the table below.

Award Guidelines

1) The medal shall be awarded annually by the ILSG Board of Directors to a geologist whose name is associated with a substantial interest in, and contribution to, the geology of the Lake Superior region.

2) The Board of Directors shall appoint the Goldich Medal Committee. The initial appointment will be of three members, one to serve for three years, one for two years, and one for one year. The member with the briefest incumbency shall be chair of the Nominating Committee. After the first year, the Board of Directors shall appoint at each spring meeting one new member who will serve for three years. In his/her third year this member shall be the chair. The Committee membership should reflect the main fields of interest and geographic distribution of ILSG membership.

3) By the end of November, the Goldich Medal Committee shall make its recommendation to the Chair of the Board of Directors, who will then inform the Board of the nominee.

4) The Board of Directors normally will accept the nominee of the Committee, inform the medallist, and have one medal engraved appropriately for presentation at the next meeting of the Institute.

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.

Nominating Procedures

1) The deadline for nominations is November 1. Nominations shall be taken at any time by the Goldich Medal Committee. Committee members may themselves nominate candidates; however, Board members may not solicit for or support individual nominees.

2) Nominations must be in writing and supported by appropriate documentation such as letters of recommendation, lists of publications, curriculum vita's, and evidence of contributions to Lake Superior geology and to the Institute.

3) Nominations are not restricted to Institute attendees, but are open to anyone who has

worked on and contributed to the understanding of Lake Superior geology.

Selection Guidelines

1) Nominees are to be evaluated on the basis of their contributions to Lake Superior geology (sensu lato) including:

- a) importance of relevant publications;
- b) promotion of discovery and utilization of natural resources;
- c) contributions to understanding of the natural history and environment of the region;
- d) generation of new ideas and concepts; and
- e) contributions to the training and education of geoscientists and the public.

2) Nominees are to be evaluated on their contributions to the Institute as demonstrated by attendance at Institute meetings, presentation of talks and posters, and service on Institute boards, committees, and field trips.

3) The relative weights given to each of the foregoing criteria must remain flexible and at the discretion of the Committee members.

4) There are several points to be considered by the Goldich Medal Committee:

- a) An attempt should be made to maintain a balance of medal recipients from each of the three estates—industry, academia, and government.
- b) It must be noted that industry geoscientists are at a disadvantage in that much of their work is not published.

5) Lake Superior has two sides, one the U.S., and the other Canada. This is undoubtedly one of the Institute's great strengths and should be nurtured by equitable recognition of excellence in both countries.

Goldich Medallists

1979	Samuel S. Goldich	1993	Donald W. Davis
1980	not awarded	1994	Cedric Iverson
1981	Carl E. Dutton, Jr.	1995	Gene LaBerge
1982	Ralph W. Marsden	1996	David L. Southwick
1983	Burton Boyum	1997	Ronald P. Sage
1984	Richard W. Ojakangas	1998	Zell Peterman
1985	Paul K. Sims	1999	Tsu-Ming Han
1986	G.B. Morey	2000	John C. Green
1987	Henry H. Halls	2001	John S. Klasner
1988	Walter S. White	2002	Ernest K. Lehmann
1989	Jorma Kalliokoski	2003	Klaus J. Schulz
1990	Kenneth C. Card	2004	Paul Wieblen
1991	William Hinze	2005	Mark Smyk
1992	William F. Cannon		

2006 Goldich Medal Recipient

Michael G. Mudrey Jr

Mount Horeb, Wisconsin

Goldich Medal Committee

Serving through the meeting year shown in parentheses.

George Hudak (2006)	University of Wisconsin, Oshkosh
Tom Hart (2007)	Ontario Geological Survey
Doug Duskin (2008)	Member from Industry

Citation for Goldich Medal Recipient

Michael G. Mudrey, Jr. 2006 Goldich Medal Recipient

It is my pleasure to acknowledge the many contributions of Mike Mudrey on the occasion of his being awarded the 27th Goldich Medal for “Outstanding Contributions to the Geology of the Lake Superior Region”. Over the past 30 years, Mike has produced an extensive list of papers, maps, and abstracts that have significantly contributed to our understanding of regional geology. He has also compiled an outstanding record of service to the Institute on Lake Superior Geology.

Mike Mudrey began his education at South Dakota School of Mines in 1963. In 1964 he transferred to Princeton, where he graduated with an A.B. degree in Geology and Geochemistry in 1967. At Princeton he had the opportunity to study with some of the pioneers of modern geology, and received a strong background in geology and chemistry. He began his association with economic geology working at Homestake in the summer of 1965. After working briefly with vertebrate paleontology in the summer of 1966, he began his long career in the Lake Superior Precambrian working as an assistant to Sam Goldich in the summer of 1967.

Mike was a graduate student at SUNY Stony Brook in 1968, then moved to Northern Illinois University, where he completed his M.S. in 1969. His thesis topic was the petrology of the Northern Light Gneiss, completed under Sam Goldich's supervision. During the summers he assisted Sam at the Bureau of Standards and in the field in Minnesota and Ontario. In 1969 Mike moved on to the University of Minnesota, where he graduated with a Ph.D. in geology and analytical chemistry in 1973. His thesis research was a petrologic study of the Pigeon Point Sill, with Paul Weiblen as his advisor. While at Minnesota, Mike worked as a geologist for the Minnesota Geological Survey where he gained additional experience in field mapping and geochemical studies. After graduation, Mike returned to Northern Illinois University to work two years as a Scientist and Project Manager for the Dry Valley Drilling Project of the NSF Antarctic Program. In 1976 Mike joined the Wisconsin Geological and Natural History Survey, where he worked until retirement in 2005.

At the WGNHS Mike's first job was to start up a Precambrian mapping program, necessitated by the discovery of volcanogenic massive sulfide deposits in the north. This work led to the first state bedrock map to subdivide the Precambrian, published in 1984. Mike was the driving force behind the long effort to complete gravity and aeromagnetic surveys of the state. Those who have been regulars at the ILSG are familiar with Mike's many contributions to the Precambrian geology of Wisconsin, but working at a small state survey requires one to wear more than one hat. Over his career at WGNHS, Mike ably served as expert on such diverse topics as earthquakes and seismicity, radioactive waste management, mineral and water resources, oil exploration, regional stratigraphy, and radon in the environment. Mike has always had a strong commitment to public service and education as well as scientific research. He was never too busy to answer a question on Wisconsin geology, whether from a legislator or a K-12 science student. In retirement he remains active, continuing to collaborate with his Survey and agency colleagues, and serving as consultant on radon to the Wisconsin Department of Health.

Mike has been an active contributor to the Institute on Lake Superior Geology since the early 1970s, when he first met Sam Goldich. He has served as co-chair, field trip chair, board member, member of the Goldich medal committee, Secretary-Treasurer (1990 to 1994), and field trip leader and session chair numerous times. Mike has nearly always contributed an abstract or two, and in the true spirit of Sam, he has never been at a loss for some good critical discussion.

It is my pleasure to present the 2006 Goldich Medal to my friend and colleague of many years Mike Mudrey, in recognition of his many contributions to regional geology and service to the Institute.

Submitted by B. A. Brown

ILSG Student Research Fund

The 2005 Board of Directors established the ILSG Student Research Fund with US\$10,000 from the Institute's general fund to encourage student research on the geology of the Lake Superior region. A minimum of two awards of US\$500 each for research expenses (but not travel expenses) will be made each year. Students are expected to present their research orally or during a poster session at an ILSG meeting. The award winners will also be automatically eligible for the Eisenbrey Travel Awards. To allow the fund to grow, the Fund will receive one-half of any additional proceeds from each annual meeting, after all other commitments and expenses are covered.

- The Board of Directors will be responsible for selecting a minimum of two awards. The ILSG Treasurer will issue the awards.
- The ILSG Student Research Fund is available for undergraduate or graduate students working on geology in the Lake Superior region.
- The applications are due to the ILSG Secretary by August 31st each year. Awards will be made by October 1st of each year.
- Names of the award recipients will be announced at the next annual meeting and posted on the ILSG website.
- The proposal application should be at least 500 words, and should have a statement of the research project, background information, a map of the research area, research steps necessary to complete the research, figures (if needed), references, and a list of research expenses. The proposal should also include a proposed end date for the research.
- The proposal will need to be signed by the researcher's supervisor.

Eisenbrey Student Travel Awards

The 1986 Board of Directors established the ILSG Student Travel Awards to support student participation at the annual meeting of the Institute. The name “Eisenbrey” was added to the award in 1998 to honor Edward H. Eisenbrey (1926-1985) and utilize substantial contributions made to the 1996 Institute meeting in his name. “Ned” Eisenbrey is credited with discovery of significant volcanogenic massive sulfide deposits in Wisconsin, but his scope was much broader—he has been described as having unique talents as an ore finder, geologist, and teacher. These awards are intended to help defray some of the direct travel costs of attending Institute meetings, and include a waiver of registration fees, but exclude expenses for meals, lodging, and field trip registration. The number of awards and value are determined by the annual Chair in consultation with the Secretary and Treasurer. Recipients will be announced at the annual banquet.

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

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

Successful applicants will receive their awards during the meeting.



Eisenbrey Student Travel Award Application

Student Name : _____ Date: _____

Address: _____

email: _____

Educational status: _____

Are you the senior author of an oral presentation or poster? Yes ____ No ____

Will any other students be traveling with you? Yes ____ No ____

If yes, then who? _____

Statement of need (use additional page if necessary): _____

Signature: _____

Department Head: _____

Student Paper and Poster Awards

Each year, the Institute selects the best of the student presentations and honors presenters with a monetary award. Funding for the award is generated from registrations of the annual meeting. The Student Paper and Poster Committee is appointed by the annual meeting Chair in such a manner as to represent a broad range of professional and geologic expertise. Criteria for best student paper—last modified by the Board in 2001—follow:

- 1) The contribution must be demonstrably the work of the student.
- 2) The student must present the contribution in person.
- 3) The Student Paper and Poster Committee shall decide how many awards to grant, and whether or not to give separate awards for poster vs. oral presentations.
- 4) In cases of multiple student authors, the award will be made to the senior author, or the award will be shared equally by all authors of the contribution.
- 5) The total amount of the awards is left to the discretion of the meeting Chair in conjunction with the Secretary, but typically is in the amount of about \$500 US (increase approved by Board, 10/01).
- 6) The Secretary maintains, and will supply to the Committee, a form for the numerical ranking of presentations. This form was created and modified by Student Paper and Poster Committees over several years in an effort to reduce the difficulties that may arise from selection by raters of diverse background. The use of the form is not required, but is left to the discretion of the Committee.
- 7) The names of award recipients shall be included as part of the annual Chair's report that appears in the next volume of the Institute.

Student papers and posters will be noted on the Program.

Student Paper and Poster Awards Committee

Dan England - Eveleth Fee Office Inc.

John Klasner - Western Illinois University (Retired)

Norm Trowell - Ontario Geological Survey

Report of the Chairs of the 51st Annual Meeting

REPORT OF THE 51st ANNUAL MEETING OF THE INSTITUTE ON LAKE SUPERIOR GEOLOGY Nipigon, Ontario

The Ontario Geological Survey and Lakehead University co-hosted the 51st Annual Institute on Lake Superior Geology meeting on May 24-28 in Nipigon, Ontario. The meeting consisted of two days of technical sessions with three pre-meeting and three post-meeting field trips. Ryan Tuomi provided excellent on-site AV assistance that kept the sessions running on schedule and also designed the Meeting web site. Bill Addison, Peter Hinz, Bernie Schnieders, John Scott, Mary Louise Hill and Mike Easton provided invaluable assistance with the field trips. Levina Collins of the Nipigon Economic Development Office acted as a liaison with the Town of Nipigon. Total registration for the meeting was 127 students and professionals.

Proceedings Volume 51 was published in two parts: Part 1 – Program and Abstracts, edited by Mike Easton and Pete Hollings, with published abstracts for 26 oral and 14 poster presentations; and Part 2 – Field Trip Guidebook, edited by Pete Hollings.

The 51st meeting marked the first time the ILSG Annual Meeting was held in Nipigon, enabling the organization of excellent field trips. On Tuesday, May 24, Tom Hart, Phil Fralick and Mark Smyk co-led a two-day trip to examine the geology and gold mineralization of the Beardmore-Geraldton greenstone belt. The following day, Peter Barnett led a small but dedicated group to view the Quaternary geology of the Beardmore-Nipigon area and, in a first for the Institute; Pete Hollings led a flotilla of small boats out on to Lake Superior to examine the Mesoproterozoic Midcontinent Rift (MCR) stratigraphy near Rossport. On May 28, three trips set out from Nipigon: Pete Hollings and Phil Fralick reprised the Rossport Trip; Tom Hart led a group to examine the geology of the Black Sturgeon area, focusing mainly on the diabase sills and ultramafic intrusions associated with the MCR; and Mark Smyk led a trip to look at the pegmatites and high-grade metamorphic rocks of the Quetico subprovince.

One hundred and ten participants attended the Annual Banquet. Dr. Jim Franklin provided the after-dinner presentation, entitled “*Mineral Resources for the Future: The Resource Potential of Northern Lake Superior*”. Peter Hinz had the privilege of presenting the 2005 Goldich Medal to Co-Chair Mark Smyk of the Ontario Geological Survey. Mark has worked tirelessly for the Institute over the last 17 years and has also made significant contributions to the understanding of Lake Superior geology.

The student paper committee (Penelope Morton, Greg Stott and Wally Rayner) were faced with the usual dilemma when it came to picking a winner from the eight talks and two posters. The winners were:

2005 Best Student Paper Awards

- 1) Daniela Vallini – University of Western Australia
(\$300, Winner, best oral presentation)
- 2) Noah Planavsky and Jennifer Murphy – Lawrence University
(\$200, Winners, best poster presentation)
- 3) Angelique Magee, OGS/Lakehead University
(\$100, Honourable mention, oral presentation)

In addition, Eisenbrey travel awards in varying amounts were presented to students from:

- Lawrence University (Noah Planavsky and Jennifer Murphy);

- North Dakota State University (Damion Knudsen);
- Lakehead University (Adam Richardson, Riku Metsaranta, Dawn-Ann Trebilcock, Chris Lane, Mike Maric, Jordan Laarman, and Bjarne Almqvist).

The Institute's Board of Directors met on May 26, 2005, and brief summary of the meeting follows:

1. Accepted report of the Chairs for the 50th ILSG, Duluth, Minnesota
2. Received, discussed, and accepted 2004-2005 ILSG Financial Summary from ILSG Treasurer Mark Jirsa.
3. Approved Mark Smyk as on-going ILSG Board member
4. Approved 2006 (52nd annual) meeting location—Sault Ste Marie, Ontario, and co-chairs Ron Sage (OGS - retired) and Ann Wilson (OGS).
5. Replaced David Meineke as the “member from industry” on Goldich Committee with Doug Duskin.
6. Amended the Institute's by-laws in order to qualify for 501c3 status with the IRS.
7. Established the ILSG Student Research Fund with US\$10,000 from the Institute's general fund to encourage student research on the geology of the Lake Superior region.

The 51st ILSG meeting was a great success and we would like to thank all the individuals who contributed to this success, including the people and businesses of Nipigon. The following organizations are thanked for their sponsorship of the meeting: Ontario Geological Survey, Lakehead University, Lake Nipigon Region Geoscience Initiative, Ontario Prospectors Association, Canadian Institute of Mining and Metallurgy (Thunder Bay Branch), Northwestern Ontario Prospectors Association, and Chaltrek Geological Supplies Inc. The field trips were well-attended and we would like to extend our thanks to the trip leaders and all those who found themselves with keys to rental cars thrust into their hands at short notice. The Municipality of Greenstone and Roxmark Mines Limited provided generous in-kind support for the Beardmore-Geraldton trip. We would also like to thank all those attendees who pitched in to help move poster boards, chairs and dining tables without having to be asked. The members of the Institute never cease to impress.

Both of us were very pleased with the 51st meeting and thankful that it was not marred by accident, injury or inclement weather. We appreciated all the positive feedback from delegates, who enjoyed the small-town setting, meeting venues and varied field trips. Logistical arrangements, although much more daunting in a small community, did not prove to be insurmountable. It bodes well for those considering hosting the Annual Meeting in a smaller town. It was a thoroughly enjoyable and rewarding experience.

Respectfully submitted

Pete Hollings and Mark Smyk
Co-Chairs, 51st ILSG Meeting

Board of Directors

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Dr. Ed Walker, Petrologic Ltd.

Exploring for Diamonds in Unconventional Rocks

Acknowledgements

Thank you to the following individuals, groups and organizations who contributed to making the 52nd Annual Meeting of the Institute on Lake Superior Geology a success.

Ontario Prospectors Association

Ministry of Northern Development and Mines – Ontario Geological Survey

Minuteman Press - Timmins

Volunteer Field Trip Leaders

Volunteer Van Drivers

Program

Monday May 8

8:00 a.m. **Field Trip 1:** Classic Stratigraphy of the Huronian Supergroup – Elliot Lake Transect

Leaders: Gerry Bennett (OGS-retired) and Mike Hailstone (OGS)

6:00 p.m. Return to Sault Ste Marie

Tuesday May 9

8:00 a.m. **Field Trip 1:** Classic Stratigraphy of the Huronian Supergroup – Searchmount Transect

Leaders: Gerry Bennett (OGS-retired) and Mike Hailstone (OGS)

8:00 a.m. **Field Trip 2:** Unusual Archean Diamond-bearing rocks of the Wawa Area

Leader: Ann Wilson (OGS)

6:00 p.m. **Conclusion of Trips 1 and 2**

6:00 p.m. - 8:00 p.m. **Registration** (Sault College)

6:30 p.m. - 9:00 p.m. **Ice Breaker Social** (Sault College Cafeteria) **and Poster Setup** (Sault College)

Wednesday May 10

8:00 a.m. - 4:00 p.m. **Registration** (Sault College)

9:00 a.m. - 9:10 a.m. **Introductory Remarks** – Ron Sage and Ann Wilson, Co-Chairs

Technical Session I

Session Chairs: Peter Hinz (Ontario Geological Survey), Helene Lukey (Cleveland Cliffs Inc.)

9:10 a.m. **Hailstone, Mike**

An overview of geology of the Sault Ste Marie area

9:35 a.m. **Rainbird, Robert H. and Davis, William J.**

Detrital zircon geochronology of the western Huronian Basin

10:00 a.m. **Bennett, Gerry**

The “Kona Dolomite” of Ontario

10:25 a.m. – 10:45 a.m. **Coffee Break and Poster Session**

10:45 a.m. **Moran, Patrick*, Fralick, Philip and Hollings, Pete**

Geochemical constraints on the deposition of Mesoarchean banded iron formation at the Musselwhite Mine, North Caribou greenstone belt, Superior Province.

11:10 a.m. **Fralick, Philip**

Iron formation in Neoarchean deltaic successions; Layering styles developed during siliciclastic and chemical sediment deposition, Superior Province, Canada.

11:35 a.m. **Jirsa, Mark. A. and Chandler, Val W.**

Structure of the Biwabik Iron Formation, Mesabi Iron Range, Minnesota

12:00 p.m. – 1:30 p.m. **Lunch Break and Poster Session (ILSG Board Meeting by invitation)**

Technical Session II

Session Chairs: Joseph Mancuso (*Bowling Green University*), Jim Miller (*Minnesota Geological Survey – Duluth*)

- 1:30 p.m. **Grabowski, Gary**
Sampling lamprophyre dikes for diamonds – Discover Abitibi Initiative
- 1:55 p.m. **Shute, Amy* and Hollings, Pete**
Geology and alteration associated with VMS mineralization in the Hamlin Lake area, Northwestern Ontario

2:20 p.m. – 2:45 p.m. **Coffee Break and Poster Session**

- 2:45 p.m. **Cannon, William F., Horton, J. Wright Jr., and Kring, David A.**
The Sudbury impact layer in the Marquette Range Supergroup of Michigan
- 3:10 p.m. **Hollings, Pete and Wyman, Derek**
Geochemistry of the ~2.7 Ga Blake River Group and Confederation Assemblages: Implications for supra-subduction zone volcanism in the Superior Province
- 3:35 p.m. **Holm, Daniel K., Anderson, R., Boerboom, Terrence J., Cannon, William F., Chandler, Val, Jirsa, Mark, Miller, James, Schneider, D. A., Schultz, Klaus and Van Schmus, W. Randy**
Continental growth and evolution of the northern interior of the conterminous U. S.
- 3:55 p.m. **Announcements**

6:00 p.m. – 7:00 p.m. **Cash Bar** (*Sault College Cafeteria*)

7:00 p.m. **Annual Banquet and Award Presentation** (*Sault College Cafeteria*)

Announcement of 53rd Annual Meeting Location

2006 Goldich Award Presentation to M.G. Mudrey Jr.

2006 Banquet Address - Dr. E. C. Walker

Meeting participants not registered for the banquet are welcome to attend the address.

Thursday May 11

9:00 a.m. – 10:30 a.m. **Registration**

Technical Session III

9:00 a.m. - 9:05 a.m. **Announcements**

Session Chairs: George Hudak (*University of Wisconsin-Oshkosh*), Laurel Woodruff (*United States Geological Survey*)

- 9:05 a.m. **Planavsky, Noah*, Knudsen, Andrew and Shapiro, Russell**
Evidence for widespread distribution of iron dependent metabolisms in Precambrian oceans
- 9:30 a.m. **Waggoner, Thomas D.**
Sulphur Isotopes from pyrite in the Negaunee Iron Formation

9:55 a.m. **Mudrey, Michael G. Jr.**
Statistical analysis of indoor radon data and relationships to geology in Wisconsin

10:20 a.m. – 10:45 a.m. **Coffee Break and Poster Session**

10:45 a.m. **Magee, M. Angelique*, Hollings, Pete and Fralick, Philip W.**
Geology and geochemistry of the Chimney Lake volcanoclastic breccia near Armstrong, Ontario

11:10 a.m. **Miller, James D. Jr. and Peterson, Dean M.**
The Precambrian Research Center – A new initiative to promote Precambrian field studies at the University of Minnesota Duluth

11:35 a.m. - 1:30 p.m. **Lunch Break and Poster Session** (Posters removed after lunch)

Technical Session IV

Session Chairs: Theodore Bornhorst (Michigan Technological University), Richard Ojakangas (University of Minnesota - Duluth)

1:30 p.m. **Smyk, Mark C., Hollings, Pete and Heaman, Larry M.**
Preliminary investigations of the petrology, geochemistry and geochronology of the St. Ignace Island Complex, Midcontinent Rift, northern Lake Superior, Ontario

1:55 p.m. **Halls, Henry C., Stott, Greg M., Ernst, R. E., and Davis, Donald W.**
A Paleoproterozoic mantle plume beneath the Lake Superior region

2:20 p.m. **Vallini, Daniela A., Cannon, William F., Schultz, Klaus J., and McNaughton, Neal J.**
The thermal history of low metamorphic grade Paleoproterozoic metasedimentary rocks of the Penokean orogen, Lake Superior Region: Recognizing a widespread 1786 Ma overprint using xenotime geochronology

2:45 p.m. **Presentation of Best Student Paper and Poster Awards and Eisenbrey Awards**

3:10 p.m. - 3:35 p.m. **Coffee Break**

NOTE: Asterisk * denotes a student eligible for a Best Student Paper Award

3:30 p.m. **Field Trip 6** – Geology of the Paleoproterozoic East Bull Lake Intrusion departs Sault College, Sault Ste Marie for East Bull Lake; overnight at East Bull Lake Lodge

4:00 p. m. **Field Trip 4** – Unusual Archean Diamond-bearing rocks of the Wawa Area, participants make their own way to Wawa; overnight in Wawa

Poster Presentations

Bartingale, R. J.* and Shaw, C. A.

Defining flow patterns: Paleomagnetic characteristics of the Wissota Dike

Boerboom, T. J.

Bedrock geological maps of the Split Rock Point and Two Harbors Northeast 7.5' quadrangles, north shore of Lake Superior, Minnesota

Brown, B. A., Czechanski, M. L., Reid, D. D. and Mudrey, M. G. Jr.

New evidence for syn-depositional subsidence in the Middle Ordovician rocks of southwest Wisconsin

Buchholz, T.W., Falster, A. U. and Simmons, Wm. B.

Some accessory minerals of the Cary Mound granite/granophyre complex, Wood County, Wisconsin

Cote, V.

The Sault and District Prospectors Association

Craddock, J. P., Patel, D., Porter, R., and Wirth, K.

Anisotropy of magnetic susceptibility (AMS) analysis of Keweenaw Rift rhyolites, Minnesota

Easton, R. M.

Complex folding and faulting history in Huronian Supergroup rocks located north of the Murray fault zone, Southern Province, Ontario

Gross, A.* and Holm, D. K.

Kinematic analysis and monazite geochronology of the Eau Pleine and Niagara shear zones, Wisconsin

Hudak, G. J., Hocker-Finamore, S. M. and Heine, J.

Field distribution, petrography and lithogeochemistry of epidiosites in the vicinities of Fivemile, Needleboy and Sixmile Lakes, Vermilion District, NE Minnesota

Jirsa, M. A.

New geological mapping of the Mesabi Iron Range

Juda, N.*, Wirth, K., Craddock, J., Vervoort, J. and Andring, M.

Petrogenesis of a granite xenolith in the 1.1 Ga Midcontinent Rift at Silver Bay, MN

Kissin, S. A., Heggie, G. J., Franklin, J. M., Karimzadeh Somarin A.

Sulphide saturation mechanisms in gabbroic intrusions in the Nipigon Embayment

MacTavish, A.

MetalCORP Ltd. Big Lake Cu-Zn-Ag-Au-Co, Ni-Cu-PGE and Mo Property

Magee, A.

Mining and exploration activity in northwestern Ontario

Miller, J. D., Jr. and Severson, M. J.

Geology of the Duluth Complex in the four Babbitt 7.5' quadrangles, northeast Minnesota

Mudrey, M. G., Jr.

Statistical analysis of indoor radon data and relationships to geology in Wisconsin

Peterson, D. M.

3D visualization of mafic intrusions in the Duluth Complex, northeastern Minnesota

Rousell, D. H.

Unresolved problems and the evolution of Sudbury geology

Stonier, P.*, Holm, D. K., Medaris, L. G., Jr. and Schneider, D.

Characterizing the monazite fingerprint of Paleoproterozoic (Statherian) metasedimentary sequences in central Wisconsin

Wirth, K. R., Vervoort, J., Craddock, J. P., Davison, C., Finley-Blasi, L., Kerber, L., Lundquist, R., Vorhies, S. and Walker, E.

Source rock ages and patterns of sedimentation in the Lake Superior region: Results of preliminary U-Pb detrital zircon studies

NOTE: Asterisk * denotes a student eligible for a Best Student Poster Award

Friday May 12

8:00 a.m. **Field Trip 3:** Keweenaw Rocks of the Point Mamainse Area

Leaders: Tom Hart and Anthony Pace (OGS)

8:00 a.m. **Field Trip 4:** Unusual Archean Diamond-bearing rocks of the Wawa Area

Leader: Ann Wilson (OGS)

8:00 a.m. **Field Trip 5:** Glacial Lakes Algonquin and Nipissing Shoreline Bedrock Features – Mackinac Island, Michigan

Leader: Ron Sage (retired-OGS)

We will be meeting at the Arnold Transit Co. boat dock in St. Ignace MI no later than 9:15 a.m. to catch the 9:30 a.m. ferry

8:00 a. m. **Field Trip 6:** Geology of the Paleoproterozoic East Bull Lake Intrusion

Leaders: Mike Easton (OGS) and R. S. James (Laurentian University)

6.00 p.m. **Return of Trips 3 and 6 to Sault Ste Marie, Ontario**

Field Trip 4 concludes in Wawa

Field Trip 5 concludes at ferry dock on Mackinac Island, Michigan

DEFINING FLOW PATTERNS: PALEOMAGNETIC CHARACTERISTICS OF THE WISSOTA DIKE.

BARTINGALE, R.J. and **SHAW, C.A.**, Department of Geology, University of Wisconsin – Eau Claire, Eau Claire, WI 54702-4004

We analyzed a gabbro dike intruding Precambrian granite below the Lake Wissota Dam in western Wisconsin. Data consisted of alternating field demagnetization and anisotropy of magnetic susceptibility measurements (AMS). Chan (1991) interpreted previous results as consistent with a Keeweenawan age (1.1 Ga) for the dike. However, research done by Macouin et. al. (2003) show similar dikes in the upper midwest and above Lake Superior have been reinterpreted to be related to the 2.07 Ga Kenora-Kabetogama Dike swarm based on moderately SE-plunging paleomagnetic directions. This study was designed to test the age interpretation of the Wissota dike and magma flow patterns.

AMS data taken with respect to the major mineral axis indicates a north-east trending, horizontal flow pattern within 4 meters of the north contact and vertical flow in the center. This suggests the concentrations of feldspar phenocrysts on the northern contact were formed near the present level, possibly being fed by the vertical flowing magma. The poles have strong correlation in the center, but weaken within 4 meters of the contact. When fit to a girdle, many samples show a strong foliation. Paleomagnetic poles in several gabbro sites have a characteristic remnant magnetization plunging between 28° and 289° in a WNW direction. Samples have an N-directed overprint we interpret as recent, and record one episode of magnetism. Plotted on an apparent polar wander path for North America, the poles plot near 24° north and 176° west, which is consistent with ages of approximately 1.1 Ga. We conclude that the Wissota dike is probably Keeweenawan in age (Figure 1).

References

- Chan, Lung, 1991, Paleomagnetism of central Wisconsin dike swarm; constraints on thermomechanical model of Midcontinent Rift: Institute on Lake Superior Geology Proceedings and Abstracts, v.37, Part1, p.23.
- Macouin, M., Valet, J.P., Besse, J., Buchan, K., Ernst, R., LeGoff, M., and Scharer, U., 2003, Low paleointensities recorded in 1 to 2.4 Ga Proterozoic dykes, Superior Province, Canada: Earth and Planetary Science Letters, v. 213, p. 79-95.

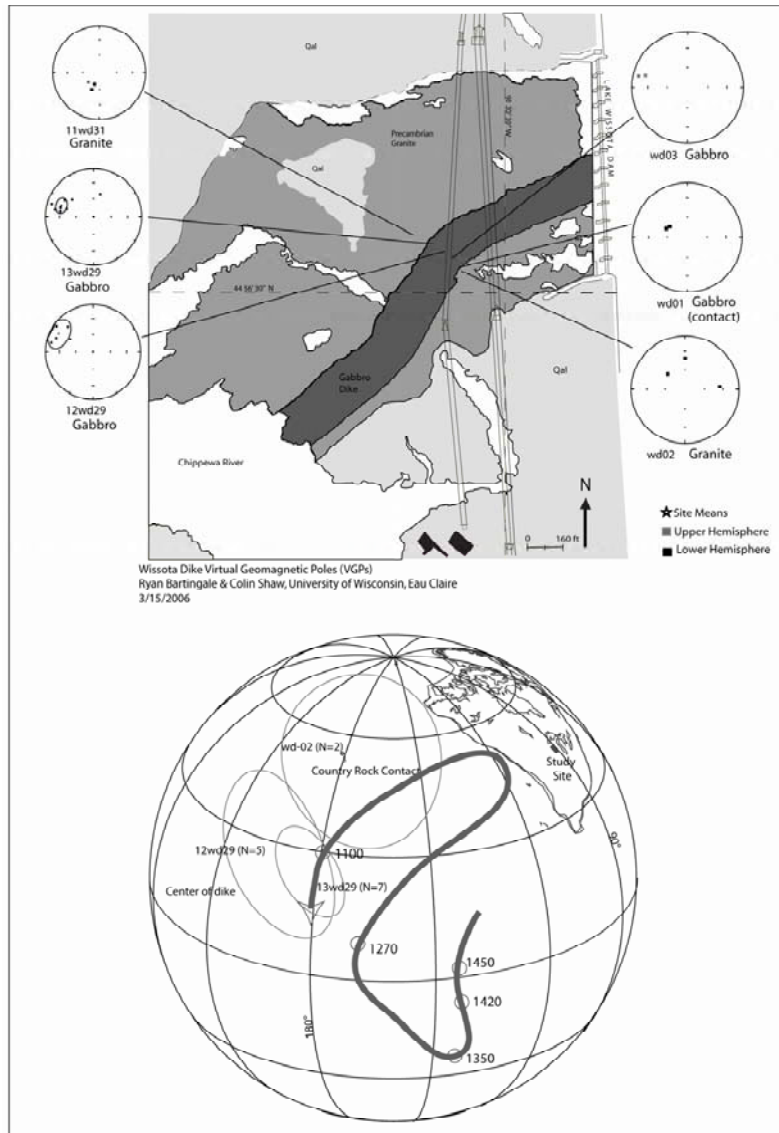


Figure 1. Wissota dike virtual geomagnetic poles (VGPs).

THE "KONA DOLOMITE" OF ONTARIO

BENNETT, GERALD, 123 LaSalle Court, Sault Ste Marie, ON

The stratigraphic similarity between the Chocoday Group of the Marquette Range Supergroup of Michigan and the lower part of the Cobalt Group of the Huronian Supergroup of Ontario has been recognized for some time. Young (1983) and others accepted the correlation but at that time there were also doubters. Both Chocoday Group and the Cobalt Group lie (at least in part) on Archean basement rocks. The lowermost formations of both groups contain rocks generally considered to be glaciogenic, which are overlain by formations dominated by quartz-arenite. But there the lithologic similarity seemed to end. The Mesnard Formation of the Chocoday Group is overlain by the Kona Formation which contains a thick sequence of dolostone, whereas the (proposed equivalent) Gordon Lake Formation is predominantly a siltstone/sandstone sequence. There have however been reports of thin beds and nodules of dolostone within the Gordon Lake formation by Hoffman et al. (1980) and Jackson (1994).

In 1986 Peter Born of the Ontario Geological Survey called the writers attention to a previously unmapped dolostone unit apparently overlying the Lorrain Formation in Fenwick Township, northwest of Sault Ste Marie, Ontario. Subsequent more detailed mapping by the writer revealed that the unit is comprised of at least 10 m of laminated dolostone and chert with clastic dolostone and oolitic dolostone. The writer correlated the dolostone of Fenwick Township with the Gordon Lake Formation of the Huronian Supergroup. Mr. Ken Hatfield, then of Lake Superior State University, pointed out the similarity to the Kona Formation of the Marquette area (Bennett et al., 1989, Born, 1988). No stromatolitic structures comparable to the "big cusp" dolomite of the Kona Formation were noted, but that some thinly laminated units are probably stromatolitic structures or algal mats (Personal communication, Dr. Hans Hoffman, 1990).

The occurrence in Fenwick Township is strikingly similar to the dolostone of the Kona Formation of Michigan. Given the recent geochronological studies of Vallini et al. (2005), there is now little doubt that the Cobalt Group of Huronian Supergroup may be correlated with the Chocoday Group of the Marquette Range Supergroup.

References

Bennett, G., Leahy, E.J, Melisek, J. Born, P. and Hatfield, K. 1989. Sault Ste. Marie Resident Geologists District–1988; in Report of Activities 1988, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 142, p. 207-217.

Born, Peter, 1987. Geology of the Havilland Bay – Goulais Bay Area District of Algoma; Ontario Geological Survey, Open File Report 5602, 114 p with map at a scale of 1:15 840 (1 inch to ¼ mile)

Hoffman, H. J., Pearson, D.A.B. and Wilson, B.H., 1980. Stromatolites and fenestral fabric in Early Proterozoic Huronian Supergroup, Ontario; Canadian Journal of Earth Sciences, v.17, p.1351-1357.

Jackson, S. L., 1994. Geology of the Aberdeen area; Ontario Geological Survey, Open File Report, 5903, 69p

Vallini, Daniela, A., Cannon, William, F, and Schulz, Klaus J., 2005. New age data for the Chocoday Group, Marquette Range Supergroup: Implications for the Paleoproterozoic Evolution the Lake Superior and Lake Huron regions. Institute on Lake Superior Geology Proceedings, 51st Annual Meeting, Nipigon, Ontario, Part I – Proceeding and Abstracts, v.51 part 1

Young, G.M. 1983. Tectono-sedimentary history of early Proterozoic rocks of the northern Great Lakes; in Early Proterozoic Geology of the Great Lakes Region, Geological Society of America Memoir, v.160, p.15-32.

**BEDROCK GEOLOGIC MAPS OF THE SPLIT ROCK POINT AND TWO
HARBORS NORTHEAST 7.5-MINUTE QUADRANGLES, NORTH SHORE OF
LAKE SUPERIOR, MINNESOTA**

BOERBOOM, TERRENCE J., Minnesota Geological Survey, boerb001@umn.edu

The Minnesota Geological Survey is continuing quadrangle-scale geologic mapping of 7.5' quadrangles adjacent to Lake Superior as part of the U.S. Geological Survey STATEMAP program. This mapping effort has resulted in seven published geologic maps in an area from Duluth to Split Rock Point (Fig. 1A). Work is currently in progress on the Little Marais, Schroeder, and Tofte quadrangles, and Lutsen will be mapped in the coming year. Field mapping is at scale 1:12,000, and map compilations are at 1:24,000.

The North Shore is experiencing burgeoning development, creating a growing need for understanding bedrock aquifers and for identifying construction resources. Nearly all water wells near Lake Superior are finished in bedrock aquifers, and saline brines are commonly encountered. Refining the volcanic stratigraphy is the first step in understanding where these brines originate. Identification of intrusive rocks is the first step in locating sources for crushed-rock aggregate. Also, mapping has identified potential sources of paving stone, for which new sources are being pursued by landscaping companies. Thus, the goal of this mapping is to refine the knowledge of the volcanic and intrusive rocks for societal needs, as well as to provide a geologic framework for ongoing studies of the geochemical evolution of the Keweenaw Midcontinent rift system, through collaborative studies with staff from Macalester College.

TWO HARBORS NE

Prior to this study, no mapping had been done in this quadrangle. Although parts of the quadrangle contain few bedrock outcrops, areas underlain by intrusive rocks are generally well exposed. The newly recognized, informally named, London intrusion is a crudely layered or composite intrusion with a basal laminated ferrogabbro, an intermediate granophyric ophitic gabbro, and a cap of ophitic diabase. Coarse-grained felsic-intermediate granophyric rocks form an irregular layer between the ophitic gabbro and the upper ophitic diabase, and also lenses within the other units. Fine-grained ferromonzodiorite occurs locally at the base of the intrusion, likely as a hybridized partial melt of adjacent andesite. Other intrusions include the northward extension of the Silver Creek diabase and Lafayette Bluff diabase, and other poorly exposed units whose distributions are based largely on geophysical data. Sporadically exposed volcanic rocks include the southwestern portion of the Gooseberry River lavas (Green, 2002), here composed of olivine tholeiite in the upper part and transitional basalt to andesite in the lower part, and a newly recognized sequence termed the Gustafson Hill lavas composed of variably porphyritic ferroandesitic to basaltic rocks, separated from the Gooseberry River lavas by the Silver Creek diabase.

SPLIT ROCK POINT

The Split Rock Point quadrangle is dominated by volcanic rocks of the Gooseberry River lavas, with subordinate mafic to felsic intrusions that include the Silver Creek and Beaver River diabase, the Split Rock intrusion, and a narrow multilithic breccia dike (Boerboom, 2004; Boerboom and others, 2004).

The upper Gooseberry River lavas include a thick porphyritic basalt flow and a fault-sliced sequence of andesite sandwiched between ophitic olivine tholeiite flows. The lower Gooseberry River lavas are poorly exposed, but available outcrops indicate they are composed dominantly of andesitic rocks continuous with those mapped in the Two Harbors Northeast quadrangle.

The Split Rock intrusion is a hypabyssal, north–south elongate body with the form of a south-plunging syncline that has a thin, lower mafic phase coeval with the dominant phase of pink, flow-banded, weakly porphyritic felsite that contains scattered but ubiquitous small mafic enclaves.

References

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- 2003b, Bedrock geologic map of the Two Harbors quadrangle, Lake County Minnesota: Minnesota Geological Survey Miscellaneous Map M-139, scale 1:24,000.
- Boerboom, T.J., Miller, J.D., Jr., and Green, J.C., 2004, Geologic highlights of new mapping in the southwestern sequence of the North Shore Volcanic Group and Beaver Bay Complex: Institute on Lake Superior Geology, 50th Annual Meeting, Duluth, Minn., Proceedings, v. 50, pt. 2, Field trip guidebook, p. 46-85.
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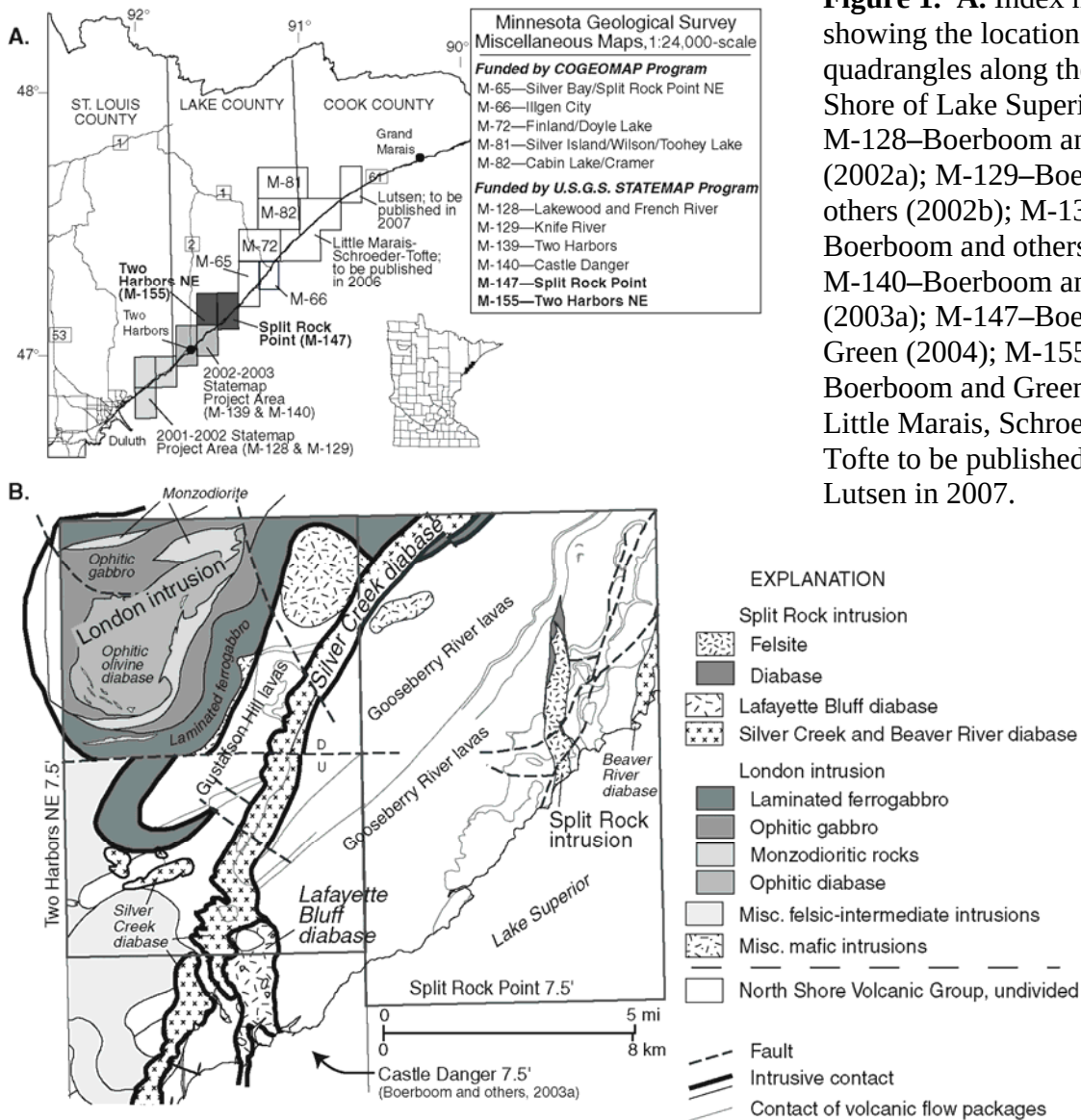


Figure 1. A. Index map showing the location of mapped quadrangles along the North Shore of Lake Superior. M-128—Boerboom and others (2002a); M-129—Boerboom and others (2002b); M-139—Boerboom and others (2003b); M-140—Boerboom and others (2003a); M-147—Boerboom and Green (2004); M-155—Boerboom and Green (2005). Little Marais, Schroeder, and Tofte to be published in 2006; Lutsen in 2007.

NEW EVIDENCE FOR SYN-DEPOSITIONAL SUBSIDENCE IN THE MIDDLE ORDOVICIAN ROCKS OF SOUTHWEST WISCONSIN

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Extensive new rock cuts and exposures were created during the rebuilding of U.S. Highway 151 into a modern 4-lane highway through the Driftless Area of southwest Wisconsin. These cuts, some exceeding 100 feet high, provide a unique cross section of the Middle Ordovician rock of the historic Upper Mississippi Valley Base Metal District of zinc and lead. The new cuts provide a detailed view of the stratigraphy, and expose some structures not previously described in the region. Examples of collapse structures and local block faulting have been recognized throughout the mining district for many years. These structures could be seen in older road cuts, and they were described in many early reports on the mining district. Structures of this type have traditionally been interpreted as pitch-and- flat structures, which resulted from solution and collapse related to the formation of the zinc-lead deposits.

The oldest collapse features observed in the new cuts formed in Early Middle Ordovician time, during deposition of the St. Peter Sandstone. The youngest known at this time formed in Late Middle Ordovician time, during deposition of the carbonate of the Galena Formation. These features formed as much as 200 million years earlier than the zinc-lead mineralization, which has been dated as Early Permian in age. The early syn-depositional collapse structures are interpreted to be the result of local collapse of paleokarst features developed in the underlying carbonate of the Early Ordovician Prairie du Chien Group. Extensive karst is known to have formed during the interval of aerial exposure following lithification of the Prairie du Chien rock and prior to deposition of the St. Peter Sandstone. This interval contains a major regional unconformity which marks the Sauk-Tippecanoe sequence boundary throughout the region. Collapse occurred as overlying sediment accumulated and compacted, prior to complete lithification.

The role of these syn-depositional features in controlling the path of mineralizing fluids is unknown. The few examples known at this time contain no significant mineralization, although mineralized pitch and flat structures and gash vein lead deposits are known to occur nearby. It is possible that the paleokarst features were small and localized, and were not important as conduits for mineralizing fluids, which migrated along regional tectonic features. In contrast, areas of sulfide mineralization were typically associated with extensive rock alteration and deep weathering, which required modifications to the design of cuts and structures, and use of alternative slope stabilization methods during construction.

**SOME ACCESSORY MINERALS OF THE CARY MOUND
GRANITE/GRANOPHYRE COMPLEX, WOOD COUNTY, WISCONSIN.**

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¹1140 12th Street North, Wisconsin Rapids, Wisconsin 54494,

²Department of Geology and Geophysics, University of New Orleans, New Orleans,
Louisiana 70148.

Early Proterozoic ($1,833 \pm 4$ Ma) granite, granophyre and comagmatic rhyolite outcrop on Cary Mound in western Wood County, WI, and are exploited in several quarries. All phases of the complex are cut by numerous faults and fractures that served as avenues for fluid transport, resulting in widespread chloritization of the granite and granophyre and development of thin hydrothermal veins. Several studies (Sims, 1990; Bruesewitz and Cordua, 2003) postulate that the complex may be a collapsed caldera and indicate that the complex may be of anorogenic or late orogenic origin.

Granophyric phases are locally miarolitic, particularly in the Haske quarry, and host a complex mineralogy ranging from simple magmatic through pegmatitic to hydrothermal mineralization, even though no pegmatites *sensu stricto* have yet been found on Cary Mound. Miaroles may be either simple vugs lined with crystals of quartz, microcline + biotite, probably formed as a result of local volatile saturation, or may have marginal pegmatitic facies marking the transition from granophyre to miarole, the latter primarily noted in the Haske quarry. In areas where such miaroles are in close proximity, pegmatitic margins may merge and form larger areas of pegmatitic texture. These pegmatitic facies may represent pods of pegmatitic melt generated by fractionation of the crystallizing granophyre; if so, the melt was probably enriched in volatiles and incompatible elements.

Typical NYF (niobium-yttrium-fluorine = typical A-type granitic association as opposed to LCT (lithium-cesium-tantalum = typical S/I-type granitic association) pegmatite mineralization is present in these pegmatitic phases; quartz, microcline, fluorite, allanite-(Ce) and zircon. Locally ferrocolumbite, samarskite-(Y) and thorite have been identified; a Ti-rich Y-Nb oxide mineral has been noted as well and may be polycrase-(Y), but confirmation is required, and a number of additional phases await further study. Pegmatite-bordered miaroles may be quartz cored or filled with quartz + late chlorite, sulfides, fluorite, siderite and calcite; these are interpreted as products of a pervasive late hydrothermal phase introduced along networks of thin fractures. The most abundant sulfides are pyrite, chalcopyrite and pyrrhotite, though sphalerite, galena, marcasite, arsenopyrite and rarely molybdenite may be present. Unusual acicular sulfide crystal morphologies are sometimes present (Buchholz et al, 1997). Small silvery-colored grains of Cu-Co-Ni sulfides have been noted; no further identification work has been done due to paucity of material. Barite is common in small amounts but is usually inconspicuous. Gypsum of secondary, weathering origin may be locally common in small amounts.

Cassiterite is uncommon but has been identified from thin fissures in several sites (Cepress and County quarries), and appears to have formed early, probably as a higher-temperature hydrothermal phase perhaps transitional from magmatic/pegmatitic to

hydrothermal/pneumatolytic. Xenotime-(Y) from a thin fissure in the Haske quarry may be of similar origin.

Hydrothermal alteration and chloritization is widespread throughout the complex, and associated mineralized veins and fissures in general reflect the late hydrothermal mineralization noted in miaroles. Although most are rich in chlorite, one vein system in the Cary-Rock Road quarry is mineralized with fine-grained lithian muscovite (1.1 wt. % Li₂O) associated with pyrite, chalcopyrite, siderite, apatite and barite. Pyrrhotite is generally absent from vein mineralization, whereas the Fe-S paramorphs pyrite and/or marcasite are usually common. Tiny grains of molybdenite are often common in metasomatized granite/granophyre in the Haske quarry. Sparse millerite (NiS) has recently been identified from a hydrothermal vein in the Haske quarry. Rutile is uncommon but has been noted from the Cephress and Haske quarries. Small late-formed crystals and grains of a LREE-phosphate (probably either monazite-(Ce) or rhabdophane-(Ce) have been found on chlorite and pyrite from the Haske and Cephress quarries.

The mineralization present in pegmatitic miarole margins may indicate the parent magma had locally evolved to a Nb, Y and F-enriched phase. Abundant fluorite and the existence of lithium-bearing muscovite veins suggest the possibility of pneumatolytic or greisen-type mineralization within the complex. The pervasive chloritic hydrothermal alteration and sulfide mineralization suggest that small vein-type sulfide deposits may be present. However locating these, if they exist, may be challenging due to extensive forests and remnant Cambrian sandstone cover.

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THE SUDBURY IMPACT LAYER IN THE MARQUETTE RANGE SUPERGROUP OF MICHIGAN

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The 1850 Ma meteorite impact at Sudbury, Ontario created a crater estimated to be 180 km in diameter (Abramov and Kring, 2004). A layer of material formed by the Sudbury impact has been well documented in northwestern Ontario and northern Minnesota (Fig. 1) (Addison and others, 2005). In Michigan, only about 500 km from the center of impact, marine sediments of the Marquette Range Supergroup were being deposited and should record the impact. One possible record of an impact is addition to local sediments of material excavated from the crater. This material may vary from coarse fragments of the target rock from the ejecta curtain to finer particles from the impact-generated dust cloud, including accretionary lapilli and mineral grains bearing shock metamorphic features. At the time of impact at least parts of the Michigan sedimentary basin were in shallow-water suggesting the likelihood of major tsunami-related deposits. We are investigating possible impact generated rocks at five sites in northern Michigan (fig.1), which are at a comparable stratigraphic horizon to the Ontario ejecta and are similar petrographically. All localities are at or within a few hundred meters above the base of the Baraga Group and may record both airborne and tsunami deposition.

Baraga Basin- layer 1-15 m thick in lower part of Michigamme Formation. Well developed accretionary lapilli (fig. 2) and planar deformation features (fig. 3).

West Dead River- isolated outcrop of bedded to massive lapilli-rich material (fig. 4). Contains angular chert fragments to about 1 m diameter. Strong carbonate replacement. At least 2 m thick and probably at least 100 m above base of Michigamme Formation.

East Dead River- bed of breccia about 30 m thick (fig. 5, 6). Sparse lapilli. Crudely graded with coarsest clasts at base. Underlain by banded iron-formation and overlain by black pyritic slate. Contains numerous clasts of chert. About 300 m above base of Michigamme Formation.

Marenisco- bed about 2 m thick near base of Copps Formation. Coarse sand to conglomerate containing many clasts of underlying Archean granite. Also contains slabs of chert to about 2 m diameter and quartz grains with possible relict planar deformation features. Strong carbonate replacement.

Republic- numerous boulders of lapilli-rich breccia in gravel pit, possibly locally derived. Our study of these localities and the search for additional sites is in its early stages. We hope that calling attention to these likely impact-related rocks will encourage additional searches and discoveries. We suspect that most new “discoveries” will result from recognizing tell-tale signs of impact processes within already known “unusual” breccias or “volcanic” units within this narrow stratigraphic interval.

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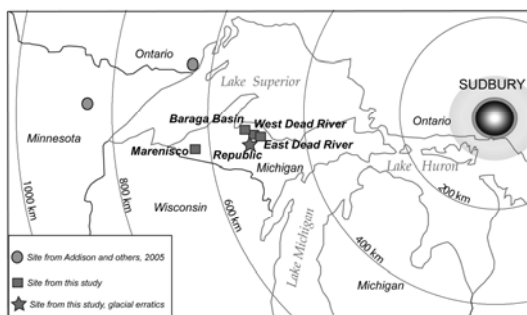


Figure 1 Location of impact layer sites

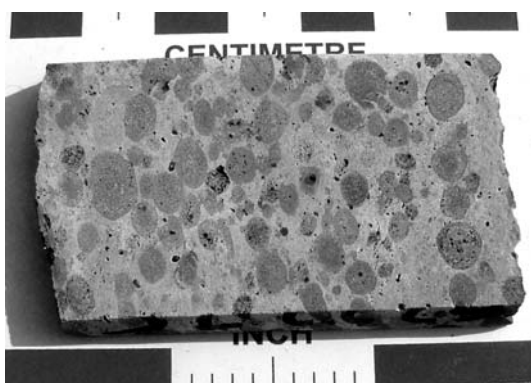


Figure 2. Baraga Basin. Accretionary lapilli in drill core.

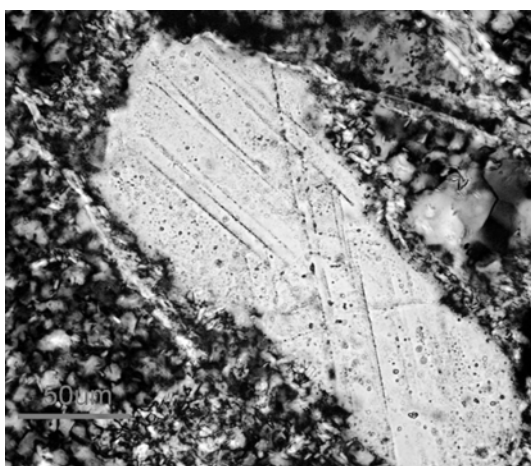


Figure 3. Baraga Basin. Quartz grain with two sets of relict planar deformation features.

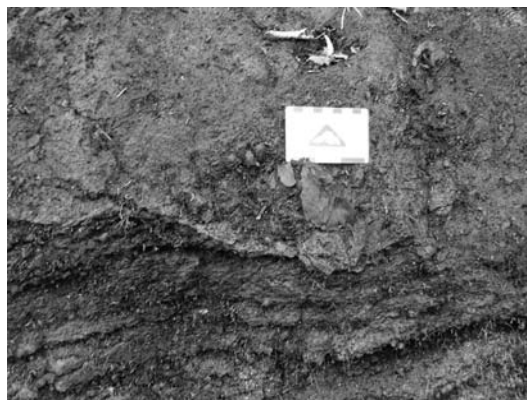


Figure 4. West Dead River. Bedded accretionary lapilli unit unconformably overlain by massive breccia with angular chert. Card 8 cm long.

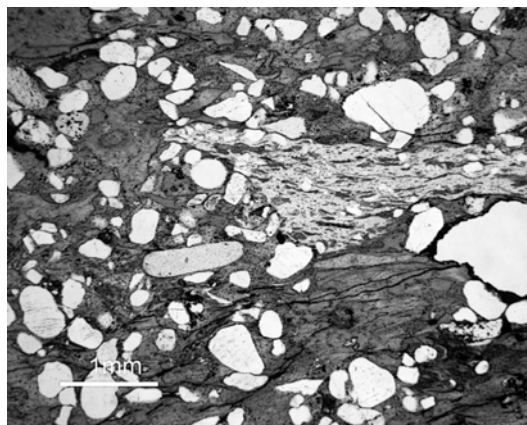


Figure 5. East Dead River. Photomicrograph of breccia with "volcanic" shards and rounded quartz grains.

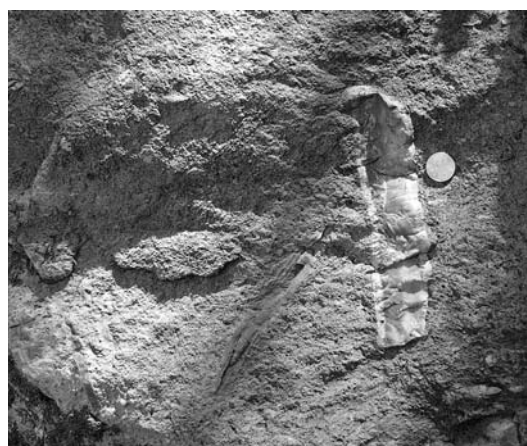


Figure 6 East Dead River. Multi-lithic breccia of chert and a variety of "volcanic" fragments in finer breccia groundmass.

THE SAULT AND DISTRICT PROSPECTORS ASSOCIATION

COTE, VIVIENNE, President, Sault and District Prospectors' Association, Sault Ste Marie, Ontario

The Sault and District Prospectors Association (SDPA) has been in existence since the early 1970's. The purpose of the association is to promote mineral exploration in the area and raise awareness of the role mineral development plays in the economy of the region and the north in general. Although the group is relatively small it is quite active with speakers from various backgrounds and interests presenting a diverse array of topics at the monthly meetings.

The highlight of the year is the SDPA annual field trip. The trips proved so popular that in 2005 a fall field trip was added. The latest trips have included the Archean diamond bearing rocks in the Wawa area, the Keweenawan rocks of the Mamainse Point area, Huronian stratigraphy of the Elliott Lake area as well as the Eagle River Mine in the Wawa district.

The poster is a visual overview of the various fieldtrips undertaken by the group against a backdrop of the general geology of the area. A wide variety of participants have attended including prospectors, geologists, students, rock hounds and of course, our mascot, the dog "Chloe".

The SDPA is an associate member of the Ontario Prospectors Association.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS) ANALYSIS OF KEWEENAW RIFT RHYOLITES, MINNESOTA

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The North Shore Volcanic Group (NSVG) of the 1.1 Ga Midcontinent Rift System (MRS) in Minnesota is dominated by basalt, with approximately 10–25% of the bi-modal igneous suite being composed of felsic flows (rhyolites and icelandites). Several of the rhyolite flows may be rheomorphic ignimbrites due to their vast expanse and presence of tridymite paramorphs and local exposures of flow banding, laminations and lineations (Green and Fitz, 1993).

In this study we identified four well-exposed rhyolite flows between Grand Portage and Duluth where the over and underlying mafic flows clearly distinguish the rhyolite flow thickness and outcrop character. Oriented samples were collected from the bottom, middle and top of each of the four flows and oriented cores (or equant cubes) were analyzed at the Institute for Rock Magnetism, University of Minnesota using the “Roly-Poly”, which is an alternating current (AC) susceptibility bridge for determining anisotropy of low-field magnetic susceptibility. An alternating current in the external “drive” coils produces an alternating magnetic field in the sample space with a frequency of 680 Hz and amplitude of up to 1 mT. The induced magnetization of a sample is detected by a pair of “pickup” coils, with a sensitivity of 1.2×10^{-6} SI volume units. For anisotropy determination, a sample is rotated about three orthogonal axes, and susceptibility is measured at 1.8° intervals in each of the three measurement planes. The susceptibility tensor is computed by least squares from the resulting 600 directional measurements. The output is a trend and plunge for each of the principal susceptibility tensors (i.e. $K_{\max}$, K_{int} , $K_{\min}$), mean susceptibility, and three axial ratios $L=K_{\max}/K_{\text{int}}$, $F=K_{\text{int}}/K_{\min}$, and $P=K_{\max}/K_{\min}$ (lineation, foliation, and degree of anisotropy respectively). Principal tensors are plotted on lower hemisphere stereonet projections. AMS is, thus, a magnetic proxy for interpreting magmatic flow in the rhyolites.

From north to south, we sampled the Kimball Creek (near Hovland, $n=56$, 366 m thick), Devil Track (near Grand Marais, $n=61$; 250 m thick), Palisade Head (near Silver Bay, $n=62$, 100 m thick), and Lakewood (north of Duluth, $n=58$, 78 m thick) rhyolites. Despite an average anisotropy for the sample suite ($n=237$) of 7.5%, only the Devils Track (base and top) and Palisade rhyolites preserve a layer-parallel $K_{\max}$ grouping that is interpretable as rift-normal, suggesting northwestward eruption from the rift axis (Fig. 1).

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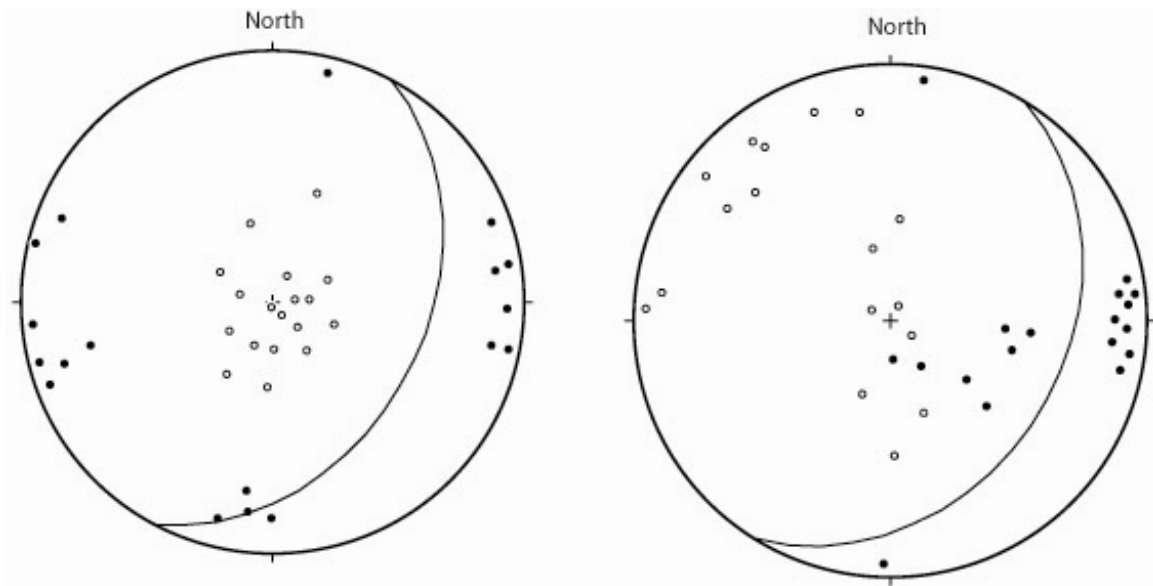


Figure 1: Lower hemisphere projections of AMS data for Palisade (left) and Devils Track (right; combined flow bottom and top samples). Solid circles are Kmax and open circles are Kmin axes. In both samples, Kmax intersects rhyolite layering and is parallel to measured field lineations and Kmin is layer-normal. The Kmax orientation is in the plane of bedding and normal to the Keweenawan rift, suggesting rift-normal eruption.

**COMPLEX FOLDING AND FAULTING HISTORY IN HURONIAN
SUPERGROUP ROCKS LOCATED NORTH OF THE MURRAY FAULT ZONE,
SOUTHERN PROVINCE, ONTARIO**

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Huronian Supergroup strata located north of the Murray fault zone are generally thought to record a relatively simple structural history of broad folding and faulting, related primarily to distal effects of the ~1835 Ma Penokean orogeny. Detailed mapping by the Ontario Geological Survey in Porter and Vernon townships (Easton 2005, 2006), northeast of Agnew Lake indicates that, at least in the area immediately west of Sudbury, this view is incorrect.

At least 2 periods of folding are present, roughly orthogonal to one another - the resulting interference forms a dome and basin pattern (Figure 1). F_1 folds Nipissing gabbro intrusions present in the lowermost part of the stratigraphy, whereas Nipissing gabbro appears to be emplaced along fractures related to F_2 axial planes. This suggests either multiple periods of gabbro emplacement, or that gabbro emplacement occurred syn-folding. In either case, folding cannot be significantly younger than 2210 Ma.

The map pattern is also affected by at least 5 major fault sets, 4 of which are post-folding. The earliest faults are north-trending, and juxtapose Archean granitic basement against Huronian Supergroup strata. These faults appear to have been fluid conduits, as indicated by the presence of large quartz vein systems and microbrecciation in Archean basement, and hydrothermal annealing of quartz in sedimentary rocks, adjacent to the faults. East-northeast faults also juxtapose Huronian strata against basement rocks, but are post- F_1 folding, with both vertical and lateral movement. They may be associated with a set of north to northeast, dominantly normal faults, which may have an older thrust component.

Most significant in terms of map pattern, at least in the southern part of the map area closest to the Murray fault system, are east to east-northeast normal faults, across which major changes in stratigraphic level occur. There may be a thrust component to these faults, but if so, it has been obscured by subsequent vertical movement, and the fact that the east to east-northeast faults are the loci for the development of extensive zones of Sudbury breccia. The localization of Sudbury breccia along this fault set suggests that it may have developed at ~1850 Ma, due to the Sudbury impact or the peak of the Penokean orogeny, or both.

Finally, significant vertical displacement, occurs along a major set of closely spaced northwest-trending faults. Some of these faults are the loci of Sudbury swarm diabase dikes (~1240 Ma). The dikes are undeformed, which suggest that this fault set formed between 1850 and 1240 Ma. The complex history of the area provides new evidence for an earlier orogenic event in the region (“Bleazardian?”), and has major implications for detailed stratigraphic correlation of Huronian Supergroup strata and mineralized Nipissing gabbro intrusions.

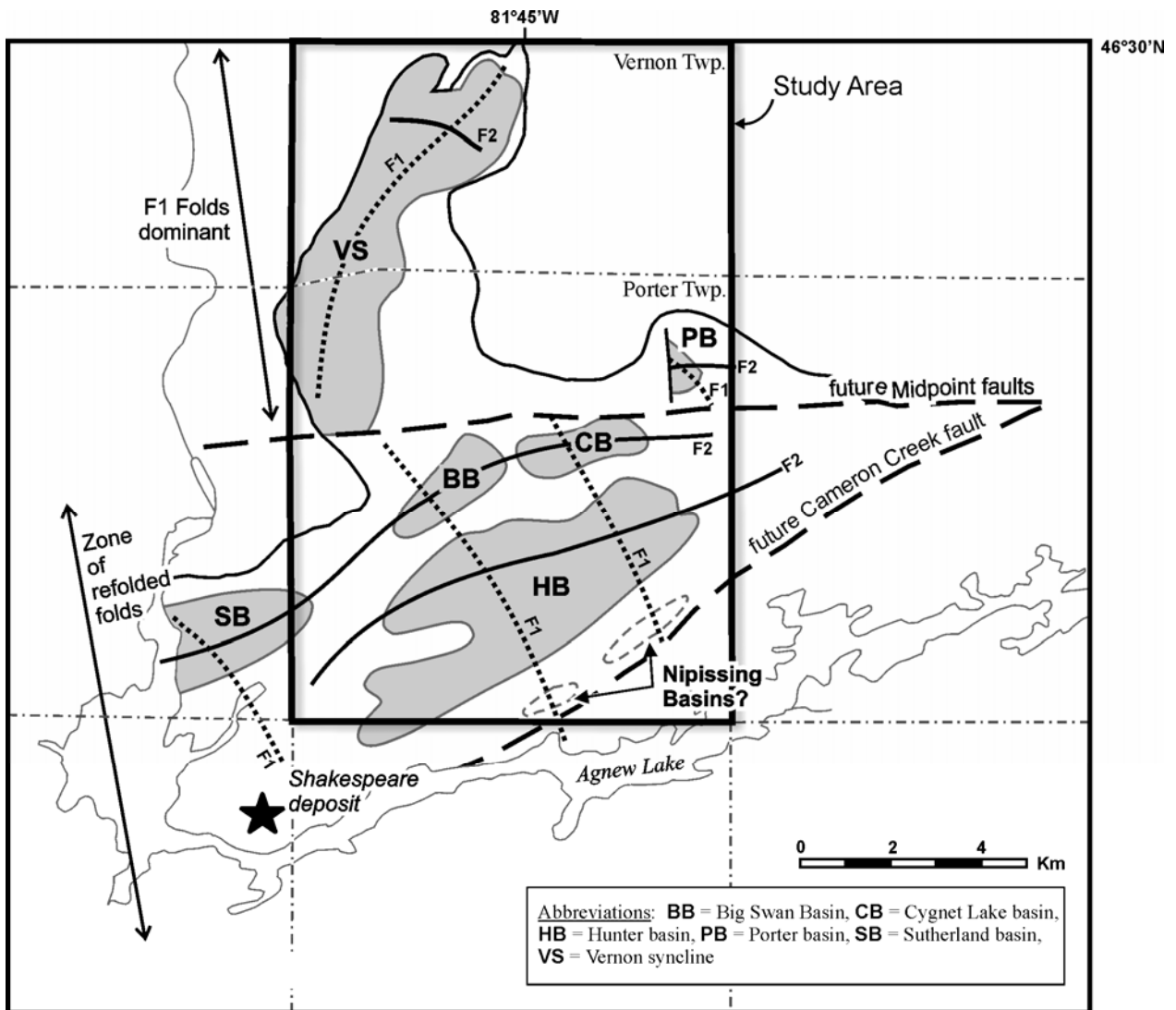


Figure 1. Simplified geological map of the northeast shore of Agnew Lake, showing the distribution of fold styles within Porter and southern Vernon townships. The contact between the Mississagi and Bruce formations has been highlighted to illustrate the fold pattern, and units stratigraphically above the Bruce Formation are shown by a pattern. Between the Cameron Creek and Midport faults, the area is dominated by a dome and basin geometry, indicating the presence of two fold generations, with approximately perpendicular axial planes. North of the Midport fault, the early, north-oriented fold style (F₁) dominates. Abbreviations: BB = Big Swan basin, CB = Cygnet Lake basin, HB = Hunter basin, PB = Porter basin, SB = Sutherland basin, VS = Vernon syncline.

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**IRON FORMATION IN NEOARCHEAN DELTAIC SUCCESSIONS:
LAYERING STYLES DEVELOPED DURING SILICICLASTIC AND
CHEMICAL SEDIMENT DEPOSITION, SUPERIOR PROVINCE, CANADA**

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Neoproterozoic iron formations (IFs) developed in volcanically quiescent, shallow marine settings consist of magnetite- and/or hematite-rich chemical sediments interbedded with siltstones and slates. The mechanism responsible for depositing such successions contrasts with the two principal models for iron hydroxide or oxyhydroxide precipitation from early Precambrian seawater. The deposition of large Paleoproterozoic iron formations through the mixing of Fe^{+2} enriched, deep ocean waters with the oxygenated waters on shelves is generally accepted (Cloud 1973, Holland 1973, Pufahl and Fralick 2004). In contrast, many Archean IFs appear to have formed through the venting of hydrothermal fluids associated with volcanically active terrains (Fralick and Barrett 1995). The latter model is not applicable to rocks formed in shallow, volcanically inactive areas and the former has only been applied to Paleoproterozoic shelves where precipitation was occurring during the oxygenation of the Earth's atmosphere. The shallow water, Neoproterozoic iron formations form a unique class of IFs where precipitation was driven by factors other than upwelling or hydrothermal venting. This IF type was examined in the Beardmore-Geraldton area of Wabigoon Subprovince and in the Eagle Island Group of Uchi Subprovince.

The shallow water Neoproterozoic iron formations described here were primarily deposited on flooding surfaces overlying fluvial channel and shore-proximal braid delta deposits. Magnetite and/or hematite laminae are also interbedded with some distributary mouth sediments draping reactivation surfaces on barforms to ripples. Additionally, the iron oxides are present as: disseminated detritus in the upper portion of thin graded siliciclastic layers; intervals of finely parallel laminated hematite and jasper, or magnetite and magnetite+chert, separating clastic layers; and, micro-ripple laminated jasper with hematite drapes. The chemical sediments precipitated in the water column of the near-shore deltaic environment and accumulated during periods of lower current activity and siliciclastic supply. The ferric compounds were redistributed during intervals of river plume outflow, especially accumulating in association with fine-grained detritus in event layers formed where the plume lost contact with the bottom (Fig. 1). Offshore equivalents of these assemblages do not contain IF. The model presented for IF deposition relies on an elevated nutrient flux (N, P) in the near-shore that stimulated microbially induced oxidation of Fe^{+2} . This implies the existence of thriving microbial communities in Neoproterozoic, near-shore settings; communities of organisms that were able to produce their energy by photosynthesis, oxidize iron either intra- or extra-cellularly, and generate thick successions of IF (Fralick and Pufahl in press).

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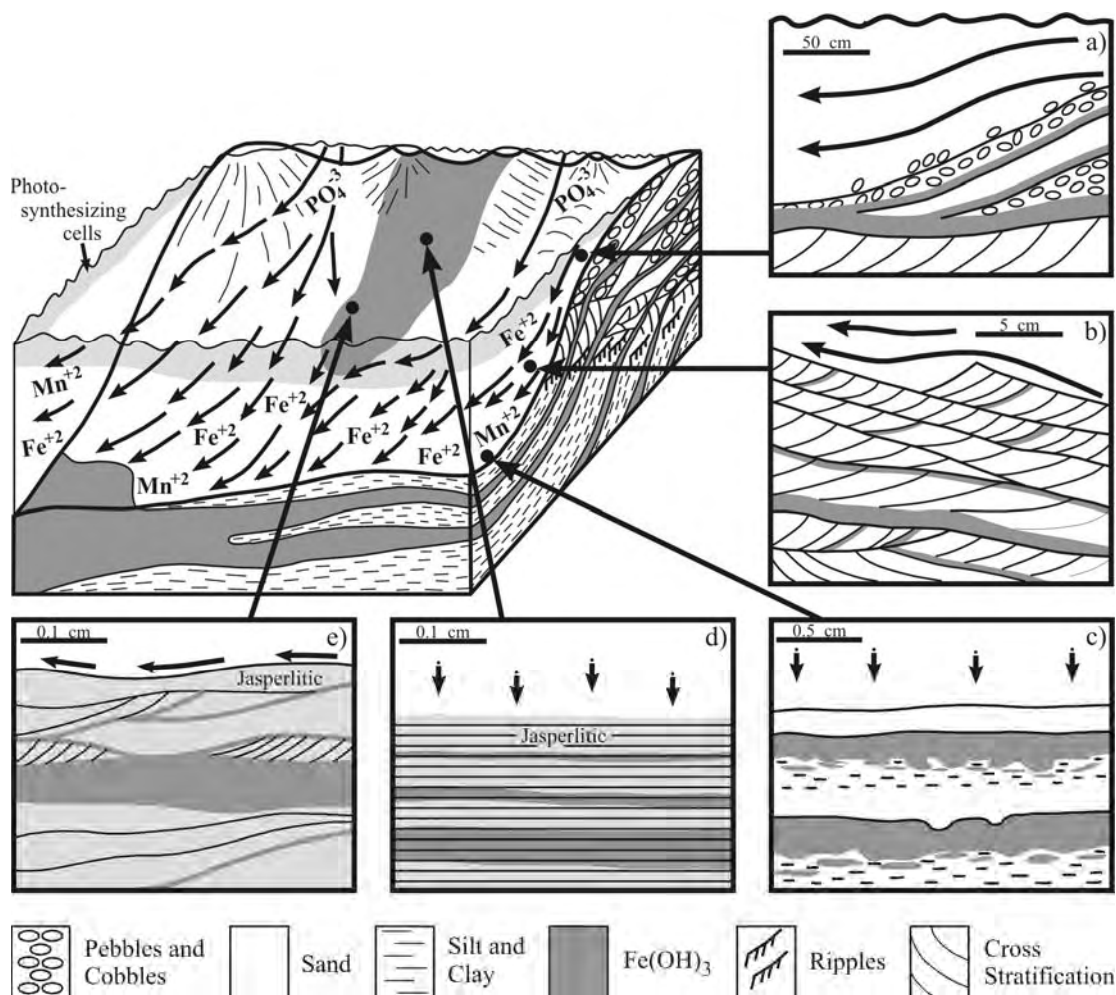


Fig. 1. Schematic representation of the processes responsible for depositing iron formation in shallow Neoproterozoic settings.

**SAMPLING LAMPROPHYRE DIKES FOR DIAMONDS;
DISCOVER ABITIBI INITIATIVE**

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The Discover Abitibi Initiative is funded by the private sector and, the federal and provincial governments (respectively Industry Canada through FedNor and the Ontario Ministry of Northern Development and Mines through the Northern Ontario Heritage Fund). The program is designed to stimulate mineral exploration in the Ontario portion of the Abitibi greenstone belt. A project to sample lamprophyre dikes, in the Kirkland Lake – Cobalt area, was approved by the Discover Abitibi program in July, 2004.

Forty-five samples, each weighing 24 kg, were submitted to SGS Lakefield Research Ltd. in Lakefield, Ontario for litho-geochemical analysis and diamond extraction, selection and description.

Six of the forty-five samples submitted returned diamonds. Samples GGDA0402 and GGDA0432 each returned one microdiamond. Samples GGDA0433, GGDA0435 and GGDA0441 returned 5, 3 and 23 microdiamonds respectively. Sample GGDA0410 contained one 0.011 carat (2.214 mg) macrodiamond.

The results of this project demonstrate that diamonds occur in the lamprophyric rock from the Kirkland Lake – Cobalt area.

- A 25 kg sample represents about one cubic foot of rock. Although every attempt was made to collect as representative a sample as possible from each exposure, the relatively small volume sampled may have easily missed a diamond. Therefore, sample locations that did not return a diamond should not be considered to barren.
- Further study is needed to determine where the diamonds are located within the dikes. Most dikes sampled that returned diamonds contained xenoliths. Spider Resources Ltd. has recently postulated that the diamonds are found in the xenoliths on their Wawa property.
- A variety of rock types host lamprophyre dikes and breccia, including all types of metavolcanic and metasedimentary rocks, as well as felsic intrusive rocks including granodiorite, granite and syenite. No preference is apparent for those that contain diamonds.
- There are numerous lamprophyre locations that were not sampled in this project. Published Ontario Geological Survey (and its predecessors) can be used to locate these exposures.
- The Kirkland Lake – Cobalt area hosts more than 30 kimberlite pipes, over half of which are diamondiferous. There are many targets being tested for potential kimberlite. In May 2005, Tres-Or Resources Ltd. discovered a kimberlite pipe on its Temagami North property, Lapointe 1 target, located 16 km northwest of sample GGDA0402.

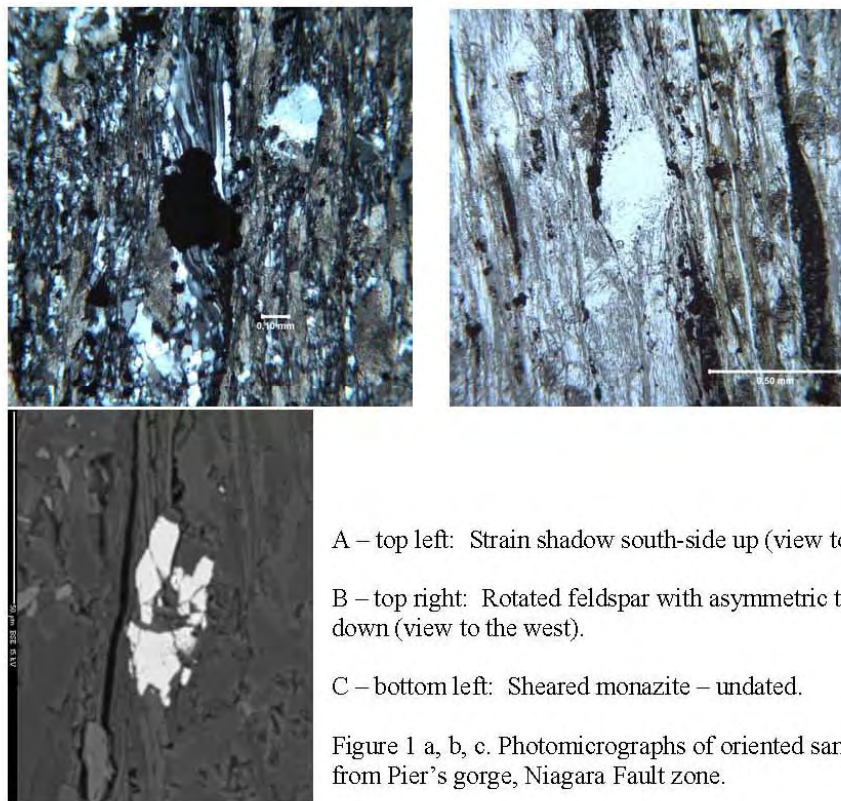
KINEMATIC ANALYSIS AND MONAZITE GEOCHRONOLOGY OF THE EAU PLEINE AND NIAGARA SHEAR ZONES, WISCONSIN

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Introduction. The southern margin of Laurentia experienced several episodes of arc accretion that account for the growth of new continental crust during the late Paleoproterozoic, 1900-1600 Ma. The Niagara fault zone and the Eau Pleine shear zone are structural remnants of an ancient arc-continent collision that occurred during the Penokean orogeny (1870-1830 Ma). As Laurentia continued to grow, these sutures likely persisted as zones of weakness; recent studies have proposed that the Niagara Fault zone may have been reactivated during gneiss dome exhumation (Schneider et al., 2004). Other structural discontinuities in the area show evidence of long-lived reactivation including the Great Lakes tectonic zone to the north. Our purpose is to evaluate the importance of tectonic heredity on the geologic history of the central Penokean orogen.

Kinematic analysis. Tectonites from both shear zones contain steep penetrative foliations and dominantly down-dip stretching lineations. Oriented samples of these tectonites exhibit kinematic indicators suggestive of a multi-stage displacement history. Samples of the Niagara Fault zone from Pier's gorge show spectacular quartz-filled strain shadows (Fig. 1a) that show south-side up relative motion, along with asymmetrical tails on feldspar grains (Fig. 1b) that show south-side down movement. Mesoscopic field indicators from a large outcrop on the north side of Highway 101 preserve definitive south-side down movement as seen in sigma structures and near isoclinal folding of late veins. Oriented samples of the Eau Pleine shear zone at March Rapids display south-side down movement in rotated feldspar grains. Sheared quartzofeldspathic gneiss at the south end of Dancy Quarry exhibits variable grain-size reduction – from coarse gneissic fabric to strongly sheared ultramylonitic fabric all of which are subparallel. The coarse gneiss samples show south-side up movement seen in rotated feldspars. In contrast, the finer-grained mylonites contain bent mica and fish structures which show south-side down relative motion. Multiple episodes of movement are evident from the kinematic work described here.

Monazite geochronology. U-Pb dating of monazite has proved useful for determining the timing of formation and reactivation of large shear zones in the western U.S. (McCoy et al. 2005). Initial monazite microprobe work on a single coarse-grained sample of the Eau Pleine shear zone produced a tight cluster of monazite total-Pb ages at ~1846 Ma (Loofboro et al., 2004). This age is consistent with the timing of formation of the shear zone based on cross-cutting relations (Sims et al., 1989). Dating of monazite from the finer-grained ultramylonites is currently in progress. Medium-grained monazite spot dating on two samples of the Niagara fault zone yielded two age populations: the older age of ~1628 Ma is about the same age as the Mazatzal orogeny, whereas the younger ca. 1496 Ma date is about the time that the Wolf River batholith intruded the area (Rose, 2004). Both of these dates, although preliminary, suggest that the Niagara fault zone was influenced by younger tectonic stresses and fluid channelization events. Textural work shows that some monazite grains at the Pier's gorge site are sheared (Fig. 1c), providing opportunity for constraining maximum age of deformation. Meso- and microscopic kinematic studies combined with total-Pb ages of metamorphic monazite hold great potential for constraining the timing and sense of relative motion along these shear zones.



A – top left: Strain shadow south-side up (view to the west).

B – top right: Rotated feldspar with asymmetric tails. South-side down (view to the west).

C – bottom left: Sheared monazite – undated.

Figure 1 a, b, c. Photomicrographs of oriented samples collected from Pier's gorge, Niagara Fault zone.

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AN OVERVIEW OF GEOLOGY OF THE SAULT STE MARIE AREA

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This presentation will provide an overview of the geology of the Sault Ste. Marie area. The variety of lithologies in the area span the ages from Archean to Paleo- and Mesoproterozoic. The Archean Batchawana Greenstone Belt is part of the Abitibi sub-province and is typical of many Archean Greenstone Belts within the Superior province dominated by metabasalts with intercalated calc alkaline to felsic metavolcanics and metasediments. This belt has been divided into an older Eastern Domain and a Western domain by Grunsky (1991) along a plate-plate collision boundary. The Batchawana Greenstone belt is surrounded on three sides by younger Archean gneisses of the Chapleau, Algoma and Ramsey Lake Gneiss domains.

The belt of Paleoproterozoic Huronian rocks between Sudbury and Sault Ste. Marie are part of the Southern structural province. Standard nomenclature for the division of the sedimentary groups within the Huronian utilize a model of four glacial cycles from conglomeratic diamictite base formations through deep marine formations to deltaic shallow marine formations. Although these environments of deposition work for the sedimentary groups, they mask the genesis of the Huronian basin which is now thought to be an early Proterozoic, active then passive rift system. (Bennett, G. 2006.) Recent studies into the earth's early atmosphere have revealed that at approximately 2.35 Ga, oxygen made its appearance in the earth's atmosphere. Huronian sedimentary rocks in the Elliot Lake area preserve that event.

Lake Superior is the one of the longest and deepest continental rift systems on the face of the planet and is approximately 1 Ga years old. The rift is also known as the Mid Continental Rift (MCR). In the Mamainse Point Formation Keweenawan subaerial, alkaline basaltic flows, intercalated with conglomerates and intruded by felsic potassic keratophyres of the MCR are exposed on the west side of the Batchawana Greenstone Belt approximately 60 kilometers north of Sault Ste. Marie. Studies of these alkaline basalts demonstrate a geomagnetic reversal separated by a conglomerate unit with the older eastern alkaline basalt flows being reversely polarized. (Hart, T., R. and Pace, A. 2006)

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A PALEOPROTEROZOIC MANTLE PLUME BENEATH THE LAKE SUPERIOR REGION

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New paleomagnetic and radiometric U-Pb age data on baddeleyite¹ show that the 2101 to 2126 Ma Marathon dyke swarm radiates from a region, approximately in east-central Wisconsin (after closure of the 1.0 Ga Mid-Continent Rift), suggesting that these dykes are associated with a possible plume centre that lies off the southern margin of the Superior Province rather than on the northern side within the Hudson bay embayment. The period of magmatic activity includes a reversal of the magnetic field from moderately steep negatively inclined remanences (R polarity) with southeasterly declination to approximately antipodal ones (N polarity)^{1,2}. The Marathon swarm was originally defined on the basis of a set of north-trending dykes in the general area of Marathon, but the new age data show that NE-trending dykes east of Wawa also belong to this swarm. These NE-trending dykes occur within a swarm of NE to ENE-trending “Kapuskaing” dykes that give similar paleomagnetic directions to the Marathon dykes, but with steeper positive and negative inclinations. Outside the Kapuskaing Zone (KZ) both polarities are observed for which positive baked contact tests exist¹. Inside the KZ, only Kapuskaing dykes of R polarity occur. Since feldspar clouding and negative baked contact tests are associated with Kapuskaing dykes lying in the high grade eastern part of the Chapleau Block, thereby demonstrating a secondary, magnetization³, it is possible that all Kapuskaing dykes within the southern KZ have been remagnetized, either during the uplift or as a consequence of slow cooling at depth.. By analogy with the 2.45 Ga Matachewan dykes which show the same phenomenon⁴, the R magnetization in Kapuskaing dykes is younger than N, which is the same age relation deduced on the basis of U-Pb ages for the Marathon swarm¹. The remanence inclination of Kapuskaing dykes, whether R or N, is steeper than the average value for Marathon dykes. A few dykes with comparably steep inclinations *are* present in the Marathon swarm as originally defined, and one of these dykes (of N polarity) gives a U-Pb age of 2125.7 ± 1.2 Ma¹. Another, with a relatively shallow N inclination compared to the mean, gives an age of 2121 ± 14/-7 Ma², so steep inclinations may be a reflection of secular variation rather than apparent polar wander. Geochemically, Kapuskaing dykes cannot be distinguished from Marathon ones, so we provisionally place the Kapuskaing dykes with the Marathon swarm, thus defining a radiating swarm with a fan angle of about 70°, with N to ENE trends.

The Fort Frances dyke swarm has R polarity⁵ and an age of 2076 Ma² and trends NW, and together with the recently dated 2067 ± 1 Ma R polarity Franklin dyke^{6,7} that trends WNW in the Minnesota River valley, forms a broadly radiating swarm that converges to a focal region approximately in central-southern Wisconsin. Taken as a whole, the Marathon and Fort Frances dykes define a radiating swarm with a fan angle of about 140° and a plume centre approximately in Wisconsin. The plume had a life span of about 60 My (from 2126 to 2067 Ma), comparable to that of the older 2.45 Ga Matachewan plume to the east, which had a longevity of at least 50 million years.

Geochemical data from dyke chilled margins show that the Fort Frances dykes have flatter REE patterns compared to Marathon dykes but that one or two dykes within the Marathon and Fort Frances swarms may belong to the other one, which would indicate a radial stress pattern. Alternatively, the noticeable dyke-free gap between the Marathon and Fort Frances swarms may arise if intrusion of the N-NE trending Marathon dykes changed the orientation of the maximum principal stress to favour NW-WNW intrusion of the later Fort Frances dykes.

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**GEOCHEMISTRY OF THE ~2.7 GA BLAKE RIVER GROUP AND
CONFEDERATION ASSEMBLAGES: IMPLICATIONS FOR SUPRA-
SUBDUCTION ZONE VOLCANISM IN THE SUPERIOR PROVINCE**

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The broadly coeval Blake River Group (BRG) of the southern Abitibi Belt and the Confederation Assemblage of the Birch-Uchi greenstone belt, have been interpreted as subduction-related volcanic assemblages generated in oceanic and continental margins respectively (Hollings and Kerrich, 2000; Pélouin et al., 1996). Both greenstone terranes contain a range of mafic rocks types (i.e., variably tholeiitic to calc alkaline) and host volcanogenic massive sulfide (VMS) deposits. The Blake River Group is host to numerous VMS deposits, ranging from the Horne Mine (55 Mt massive sulphide ore mined, total tonnage ~144 Mt), to the Quemont Mine along the southern margin of the Sequence (16 Mt), and relatively small ore bodies common in the Noranda Mine Sequence (e.g., 1-5 Mt; Gibson and Watkinson, 1990). The Confederation assemblage is host to the past-producing South Bay VMS mine which produced 1.6 million tons of ore with an average grade of 11% Zn, 2% Cu and 2.12 ounces Ag per ton (Atkinson et al., 1990).

Differences in the proportions and types of rocks in the two areas suggest they represent end-members in a range of subduction settings present during the late Archean. The BRG was erupted over a short period between about 2703 - 2698 Ma and is one of the youngest pre-orogenic volcanic suites in the southern Abitibi belt. Plume-associated komatiites are inter-layered with arc-type rocks in the south-central part of the Abitibi Subprovince that contains the BRG. The ~2725-2745 Ma Confederation assemblage was not associated with plume volcanism and was situated at the margin of a proto-continent containing rocks that date back to ~3 Ga. Despite the important differences in their settings, the major element trends of tholeiitic rocks from the two areas resemble each other, and Phanerozoic arcs, more than tholeiites from continental rift settings that may be analogues for some Archean greenstone belts.

Rhyolites in both areas are interpreted to be the fractionation products of mantle-derived melts. In addition to documenting variable crustal contamination, the trace elements systematics of the rhyolites provide evidence of zircon fractionation events that occurred without significant changes in major element compositions. These results are probably attributable to extraction of rhyolitic liquids from crystal mush zones that was accompanied by preferential entrainment of zircon crystals, leading to Zr fractionation.

The BRG suite includes magmas generated in relict plume asthenosphere but the chemical trends also provide evidence of slab melt metasomatism (Wyman and Hollings, 2005). Primitive rocks in the Confederation assemblage define trace element trends that are analogous to typical modern arcs with no indication that melt-mobilized elements such as Zr and Nb have been introduced in significant amounts. Adakite-like rocks were formed as a result of local events such as arc rifting in the South Bay area, or as an indirect consequence of larger events such as global-scale mantle-plume episodes that

strongly influenced the southern Abitibi subprovince and the BRG (Wyman and Hollings, 2005). Niobium enriched basalts associated with crustally contaminated rhyolites in the southwest of the South Bay study area are most plausibly linked to rifting of the Uchi Subprovince proto-continent margin. The lack of evidence for HFSE metasomatism in the sources of tholeiitic and calc alkaline mafic rocks, indicates that metasomatism of the sub-arc mantle was dominated by hydrous fluids. Therefore, slab melting occurred not in response to a pervasive steep geotherm but to specific geodynamic events, which in this case were probably linked to the early phases of arc rifting along the continental margin.

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**CONTINENTAL GROWTH AND EVOLUTION OF THE NORTHERN
INTERIOR OF THE CONTERMINOUS U.S. *NICE (Northern Interior Continental
Evolution) Working Group***

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The Penokean orogeny, long considered the dominant Paleoproterozoic event in the Lake Superior region, has been extrapolated to much of the buried basement of WI, IA, NE, and MI. In contrast, geon 17 crust (Yavapai orogen) is dominant south of the Archean Wyoming craton requiring a 100 m.y. age difference of juvenile crust along strike of the Transcontinental Proterozoic Province. We reconcile this problem with a revised history of the growth and evolution of continental crust in the northern mid-continent based on integration of modern geochronology and regional aeromagnetic data.

A new aeromagnetic compilation of the region documents a complex terrane of 3.5-1.0 Ga rocks. In MN, the Archean craton is subdivided by the Great Lakes tectonic zone, a late Neoproterozoic suture. Paleoproterozoic rifting of the craton created an irregular continental margin consisting of the Becker embayment and the MRV promontory. Bordering the embayment and onlapping the craton are a Paleoproterozoic fold-thrust belt and foreland basin. Within the Becker embayment are calc-alkaline volcanic and granitoid arc rocks formed by Penokean subduction and suturing of the arc with the craton.

A sharp post-Penokean aeromagnetic discontinuity, the Spirit Lake tectonic zone (SLtz), extends eastward from NW Iowa, where it is defined by an abrupt southeastward decrease in the magnetic anomaly, through NC Wisconsin, where it is expressed by a sharp truncation of linear patterns in the Archean gneisses of the Marshfield terrane. The SLtz marks the northern extent of juvenile Yavapai age crust and the southern extent of Archean and Penokean crust. The nature of the SLtz is enigmatic and as yet poorly imaged in the third dimension by geophysical data. However, the preservation of Penokean juvenile crust only in an embayment along the southern rifted margin of the Superior craton suggests the SLtz formed initially as a major strike-slip fault zone responsible for margin truncation. South of the SLtz, the structural grain is subparallel to the SLtz and to axial traces of Mazatzal-age folds (Baraboo syncline). Gneisses and mafic volcanic rocks, probably basement rocks from which 1750 Ma rhyolites formed, are inferred from gravity-magnetic highs to be at subcrop in several areas. The Yavapai terrane is marked by abundant geon 14 granites identifiable by a generally smooth aeromagnetic pattern and low gravitational attraction. Additional high-relief, high-intensity circular magnetic anomalies within the Yavapai terrane of Iowa delineate related granites.

In southern WI and NE Iowa the aeromagnetic pattern reveals an extensive area of folded basement and Baraboo Interval quartzites beneath thin Paleozoic cover. The Yavapai-Mazatzal terrane boundary must be southeast of these deformed rocks. This area is bordered to the SE by large irregular shaped magnetic highs making up the Green Island

plutonic belt (GIPB) along the north edge of the Eastern Granite-Rhyolite province. We interpret the GIPB as having intruded into dominantly Mazatzal age crust.

Geochronologic and thermochronologic data corroborate the new tectonic province map and provide important time constraints on the evolution of southern Laurentia during the late Paleoproterozoic.

Basement crystallization ages. U-Pb zircon crystallization ages for juvenile crust exposed in WI definitively bracket the Penokean orogeny between 1880 & 1830 Ma. In contrast, U-Pb zircon ages from basement drill hole samples in NE are dominantly 1800 Ma or younger and probably represent eastward extension of the Yavapai age basement of CO. However, very few samples were available from the basement of Iowa, southern MN, SE South Dakota, and southern WI, with the result that many late-20th century interpretations for the buried basement in this region consisted of south-westward extension of the Penokean terrane. For example, the Precambrian basement of NW Iowa was commonly shown as Penokean crust abutting Archean crust, similar to the situation in northern WI along the Niagara Fault Zone. New basement ages appear representative of a growing U-Pb database for the region south of the SLtz. Key points relevant to this summary are as follows: (a) single-crystal TIMS U-Pb zircon data yield Yavapai-interval crystallization ages (1740 & 1760 Ma); (b) ion-probe analysis of zircons confirm these data; (c) zircons separated from gneissic xenoliths from the Manson impact structure in Iowa confirm the existence of igneous activity ca. 1760 Ma. These data yield no Penokean interval ages. Thus, all presently available U-Pb data support our interpretation that Yavapai orogenic crust extends eastward from NE into Iowa and southern WI, and that Penokean crust may be entirely absent from Iowa and SE Minnesota.

Metamorphic & igneous ages. Metamorphism along the southern margin of the Superior province has been historically attributed to Penokean orogenesis. Indeed, a narrow window of amphibolite-facies rocks north of the Niagara Fault zone does record 1.83-1.80 Ga monazite U-Pb metamorphic ages. Peak metamorphic conditions with attendant magmatism likely mark the culmination of arc accretion. However, the dominant metamorphic and igneous imprint on the Precambrian basement is a regional Yavapai age tectonothermal event dated at ca. 1.76 Ga. Yavapai convergence led to weakening of the mid-crust and generation of the classic gneiss domes now exposed in northern MI and WI. Geon 17 metamorphism extends eastward into the Lake Huron region, where geon 18 metamorphic or magmatic activity is largely absent.

Cooling/resetting ages. The results of over 100 modern Ar/Ar mineral ages from basement rocks of the NC midcontinent have allowed detailed characterization of its Proterozoic thermal history. Penokean biotite cooling ages are preserved only in low-grade arc rocks in EC Minnesota; a few hornblende ages also record Penokean cooling in the metasedimentary rocks of the orogen. Elsewhere throughout the Superior and Huron region, hornblende and mica Ar/Ar ages are predominantly 1.76-1.75 Ga or somewhat younger, reflecting rapid, widespread cooling and orogenic collapse following the aforementioned Yavapai amphibolite-facies metamorphism and magmatism. Geon 17 rapid cooling of Archean and Paleoproterozoic metamorphic rocks of the gneiss dome corridor was caused by their exhumation and regionally was followed by a period of

tectonic quiescence, crustal stabilization, and deposition of the supermature Baraboo Interval (1730-1630 Ma) quartzites.

Across much of the WI bedrock, low-temperature reheating was responsible for resetting mica cooling ages caused by geon 16 Mazatzal collision and foreland deformation. Interestingly, the northern limit of Mazatzal deformation and reheating is approximately located along the Niagara Fault zone in northern WI and upper MI. However, in MN the deformational front must bend south of the MRV promontory as those rocks are not thermally/isotopically reset and are overlain by flat-lying Baraboo Interval quartzites (Sioux quartzite). In the Huron region, Mazatzal heating is recorded only locally along the north shore of Lake Huron. Intrusion of the Wolf River batholith and associated geon 14 A-type plutons across the continental margin had a limited thermal effect on the country rock, in part reflecting their rapid emplacement at shallow levels. However, hydrothermal alteration along the Paleoproterozoic basement/cover contact occurred at considerable distances from the batholith.

In summary, the continental interior straddles several terrane boundaries, including the transition from Archean tectosphere to Paleoproterozoic lithosphere. The SLtz is a fundamental Yavapai-age Proterozoic boundary, equivalent to, and possibly a direct extension of the Cheyenne belt suture zone, which also juxtaposes Yavapai orogen crust on the south against the Archean craton, and transects geon 18 (Trans-Hudson) structures in southern South Dakota. The Cheyenne-Spirit Lake structure is a fundamental feature in the evolution of the southern margin of Laurentia, the North American craton. Our new interpretation of the Paleoproterozoic continental growth and evolution of the northern interior of the North American craton suggests greater correspondence to that of the Rocky Mountains than previously thought. Although that region has structurally and magmatically modified during Cenozoic and older tectonism, relatively little tectonism has occurred in the cratonic interior in the last one billion years, providing us a uniquely unaltered perspective into Precambrian evolution of the North American continental lithosphere.

**FIELD DISTRIBUTION, PETROGRAPHY, AND LITHOGEOCHEMISTRY
OF EPIDOSITES IN THE VICINITIES OF FIVEMILE, NEEDLEBOY AND
SIXMILE LAKES, VERMILION DISTRICT, NE MINNESOTA**

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The Lower Member of the Ely Greenstone Formation (LMEG) contains a well-studied, more or less east-west striking, steeply north-dipping and north-facing sequence of Neoproterozoic submarine volcanic, volcanoclastic, chemical sedimentary, and intrusive strata in the vicinity of Fivemile Lake, Needleboy Lake, and Sixmile Lake in the Vermilion District of northeastern Minnesota. Primary volcanological features of these rocks are generally well-preserved despite syn- to post-volcanic hydrothermal alteration (quartz, epidote, chlorite, sericite, actinolite, albite, iron carbonate, dolomite and calcite) and subsequent greenschist facies metamorphism. Based on field characteristics, the LMEG has been subdivided into an older Fivemile Lake Sequence (FLS) and a younger Central Basalt Sequence (CBS; Peterson and Patelke, 2003). Volcanogenic massive sulfide prospects have been identified in near Fivemile Lake, Skeleton Lake, Needleboy Lake and Eagles Nest Lake #4 (Giagrande, 1981; Peterson and Jirsa, 1999; Hudak and Morton, 1999; Peterson, 2001; Hovis, 2001; Hudak et al., 2002; Hudak et al., 2003).

Epidosites (granular to granoblastic, high variance mineral assemblages comprising epidote + quartz $\pm$ chlorite $\pm$ actinolite) have been identified in several locations within the LMEG. South of Fivemile Lake, epidosites occurs as discrete 0.1-2m diameter round- to lens-shaped pale yellow green masses within a 400m by 500m discordant alteration zone located in an actinolite-epidote-quartz altered diabase dike – sill complex that intrudes the FLS. Petrographic and electron microprobe studies (Hocker et al., 2003) indicate the presence of both pistacite and zoisite within this alteration zone. Epidosites also occur within a 300m by 200m, northeast-trending disconformable alteration zone approximately 500-700m east- southeast of Sixmile Lake. At this location, CBS pillow lavas and lobes are intensely altered to a mineral assemblage composed of pistacite, zoisite, quartz, actinolite, Fe-chlorite, Mg-chlorite, magnetite, chalco-pyrite (locally altered to malachite) and minor sphalerite within approximately 200m of a synvolcanic gabbro sill-dike complex.

Isocon analysis (Grant, 1986) has been used to evaluate metasomatism during the genesis of the epidosite alteration zones. Least-altered compositions were selected based on box-plot analysis (Large et al., 2001) and petrographic observations. The LMEG epidosites have specific gravities 5-10% greater than least-altered samples, consistent with observations from epidosites in the Josephine Ophiolite (Harper, 1999). Variation diagrams indicate that Zr and Hf are the least mobile elements during metasomatism in both the diabase intrusion and the CBS lava flows; the best-fit line for these two elements on an isocon diagram defines the isocon. Relative to least-altered diabase, epidosite masses are enriched in Ca, Al, Si, and Sr, and depleted in Fe, K, Na, Mn, Mg, Cu, Zn and Eu. These geochemical variations are consistent with alteration in a high temperature (>350°C), high water:rock ratio reaction zone deep within a synvolcanic submarine

hydrothermal system (e.g. Harper, 1999) capable of producing volcanogenic massive sulfide mineralization up-section. Variations in chemical behavior within the CBS pillowed flows with increasing distance from the gabbro sill-dike complex suggest that epidosite zones at this locality formed within localized high temperature hydrothermal zones driven by heat derived from the gabbro. Further work is needed to evaluate the extent of epidosites in the CBS, and potential VMS mineralization up-section in the Upper Member of the Ely Greenstone Formation.

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STRUCTURE OF THE BIWABIK IRON FORMATION, MESABI IRON RANGE, MINNESOTA

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Six years of mapping by the Minnesota Geological Survey along the Mesabi Iron Range generated a variety of new maps, and considerable data regarding the structure of the Paleoproterozoic Biwabik Iron Formation and adjacent units (Fig. 1). Bedrock mapping utilized GIS to integrate data sources that included archived geologic and structure contour maps created by industry and government organizations, test pit and drill hole records, digital bedrock topography, and several iterations of aeromagnetic data. The aeromagnetic data delineate oxidation zones along faults, folds, and fractures in otherwise strongly magnetic iron-formation. These data and field work in more than 400 mines created a mass of structural observations that provide a context for understanding the deformation history of the range.

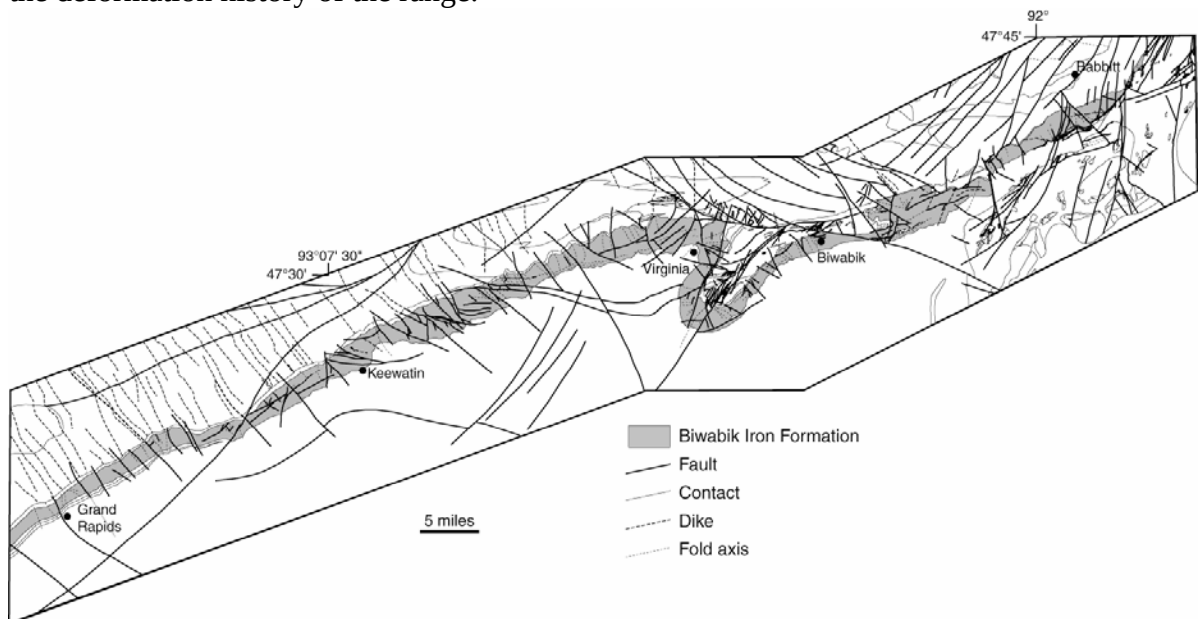


Figure 1. Generalized geologic map of the Mesabi Iron Range showing structures in and along the subcrop of Paleoproterozoic Biwabik Iron Formation (gray). Bedrock north of the Biwabik Iron Formation is largely Archean in age; south of the Biwabik Iron Formation is Paleoproterozoic Virginia Formation bedrock; and to the southeast is the Mesoproterozoic Duluth Complex.

The Biwabik Iron Formation is part of the Paleoproterozoic Animikie Group—a sequence of quartzose sandstone, iron-formation, and mudstone—that was deposited unconformably on a relatively stable shelf composed of Archean granite and greenstone. Depositional ages of the Animikie Group vary from 1,878 to 1,777 Ma (Fralick and others, 2002; Addison and others, 2005; Heaman and Easton, 2005). This broad temporal span indicates a protracted history of deposition, and probably also deformation. Much of the Biwabik Iron Formation forms a south-dipping homocline that contains little evidence of disruption, with the exception of locally well developed deformation structures. Although the precise ages of various structural elements on the Mesabi range are nearly impossible to ascertain, a relative chronology has been established from cross-cutting relationships. Assigning deformation events to specific structures is probably premature; however, "D₀, D₁, D₂..." nomenclature is applied here to refer to suites of

apparently related structures. The oldest are those presumably related to soft-sediment deformation (D_0), including slumps, sedimentary breccias, and structures that appear to be the result of differential compaction. The earliest "regional" deformation (D_1) is manifest in localized, small-scale rotational structures, bedding-parallel slickensides, and larger nappe and sheath folds. The structures commonly lie along boundaries between units having strong rheologic contrast, such as the contacts between thick sequences dominated by mudstone and siliceous grainstone. Nearly all of these structures display asymmetry that indicates south-over-north tectonism. This northward vergence, and the apparent timing relative to later structures, is consistent with compressional deformation—potentially related to the Penokean orogen.

One of the long-standing controversies in iron-ore genesis is the question of whether the oxidation and leaching of iron-formation that formed the high-grade hematite ores occurred by supergene or hypogene processes. Although not conclusive, the observation of several early-formed, south-dipping thrust faults with folded, mineralized wall rocks, and bedding-parallel slickensides that host abundant secondary iron and silica implies that at least some of the mineralization was coincident with compressional deformation, perhaps during Penokean orogenesis. This is consistent with the hypogene model proposed by Morey (1999) that attributes oxidation and leaching to ground-water flow driven northward from uplift in the Penokean fold and thrust belt.

A second regional suite of structures (D_2) is largely extensional. These are monoclines and normal faults that are mutually transgressive; that is, faults that have sympathetically folded wall rocks, and folds that pass laterally to faults. These are some of the major structures along which oxidation and leaching has occurred, and the focus of most hematite ore mining. Veins, vugs, and other secondary mineralization features are abundant. D_2 structures likely formed as localized responses to regional tilting.

The most recent deformation effects (D_3) are trough-like collapse structures, presumably related to post-leaching subsidence. The collapse, and associated oxidation and weathering, are best developed in the uppermost subcrop of iron-formation, implying supergene alteration played a significant role. Thus, the answer to the supergene vs. hypogene debate appears to be that both processes were significant, perhaps at different times. The Virginia horn—where the subcrop extent of iron-formation makes a hook-shaped bend—is a complex horst, bounded by faults in the subjacent Archean rocks along which vertical movements have occurred during the entire temporal spectrum from early deposition to latest crustal accommodation. Lacking finite ages, the structures may record Penokean (Geon 18), Yavapai (Geon 17), Mazatzal (Geon 16), and/or Keweenawan (Geon 11) deformation events. The presence of diabase dikes cutting iron-formation as far west as Keewatin raises the possibility that at least some of the later phases of deformation on the Mesabi range are related to development of the 1,100 Ma Midcontinent Rift.

Funding for Minnesota Geological Survey mapping on the Mesabi range was provided by the Minnesota Legislature on recommendation of the Minerals Coordinating Committee, the Environmental Trust Fund administered by the Legislative Commission on Minnesota Resources, the EDMAP program of the U.S. Geological Survey, and the State Special appropriation to the Minnesota Geological Survey. Products can be digitally downloaded or

ordered on paper through the Minnesota Geological Survey website (www.geo.umn.edu/mgs). Available products include maps of bedrock topography and depth to bedrock (Miscellaneous maps M-126, M-158), historic 1899 land-surface topography, hydrology, and infrastructure (M-118, M-157), bedrock geology (M-163), and Quaternary geology (M-164).

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PETROGENESIS OF A GRANITE XENOLITH IN THE 1.1 GA MIDCONTINENT RIFT AT SILVER BAY, MN

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This study examined a well-known granitic xenolith locality within the hypabyssal Beaver Bay Complex of the Midcontinent Rift System (MRS). The xenolith is exposed along the shore of Lake Superior at Silver Bay, MN. Our goal was to constrain the origin of the granite using U-Pb zircon geochronology, whole-rock and trace element geochemistry, and anisotropy of magnetic susceptibility. Previous researchers have interpreted the origin of granite xenoliths contained within MRS rocks as either Archean crustal fragments or MRS felsic plutons.

The granite xenolith (~ 50 meters in diameter) occurs within Beaver River diabase, and is cross-cut by a mafic dike. The rock consists primarily of quartz, albite, and orthoclase. Granophyric intergrowths of quartz and feldspar are common. In addition, accessory minerals including sphene, apatite, and zircon are present. At the macroscopic level, the xenolith exhibits no indications of magmatic flow or foliation, and our study of anisotropy of magnetic susceptibility (AMS) as a proxy for magmatic flow confirms this (Figure 1).

U-Pb analyses of zircons from the xenolith yield an age of 1094 ± 11 Ma on a concordia diagram. This is within error of the age of the youngest dated MRS granophyres. The geochemistry of the granite is similar to other MRS granophyres (e.g., Eagle Mountain, Finland Granite), except that the granite xenolith has higher concentrations of silica and sodium and very low potassium and other alkali elements (e.g., Rb, Ba; Figure 2). The apparent alkali mobility may have resulted from fluid infiltration during late-stage cooling. The compositions of several granitic dikes at Beaver Bay are similar to the Silver Bay xenolith. The Silver Bay xenolith and Beaver Bay dikes share “within plate” and A-type granite major and trace element compositions with MRS granophyres. Geochemical data from granite xenoliths at Split Rock are significantly different from those at Silver Bay and from other MRS granophyres by having volcanic arc characteristics. This suggests that the Split Rock xenoliths might have a different origin from those at Silver Bay.

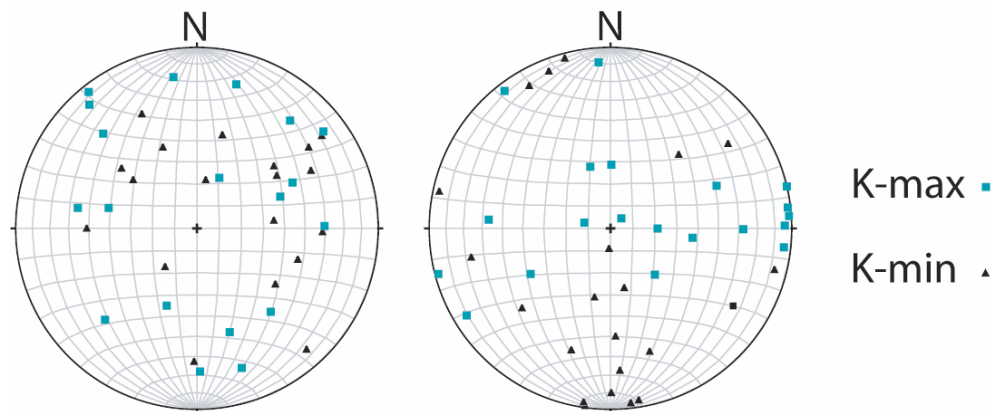


Figure 1. Equal area lower hemisphere projections of AMS results for samples granite xenolith (KP05-45B) and a cross-cutting mafic dike (KP05-45I).

The Keweenaw age and A-type granite characteristics of the granite xenolith at Silver Bay suggest a greater distribution of MRS granophyres than previously thought. These granophyre bodies may also underlie volcanic flows in the more central portions of the rift. Further isotopic analysis of the granite xenoliths, such as with the Sm-Nd system, would help constrain the petrogenesis of the MRS granophyres.

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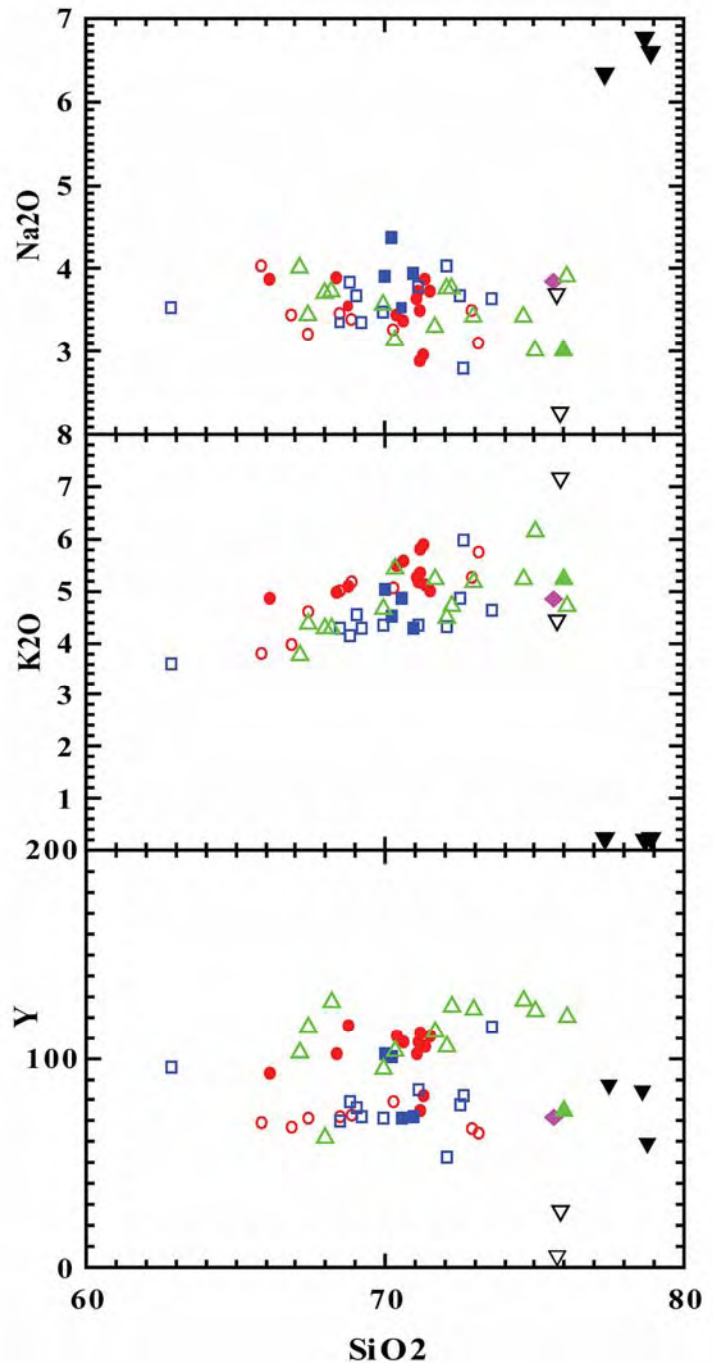


Figure 2. Harker diagrams showing the concentrations of Na₂O, K₂O, and Al₂O₃ in the granite xenolith compared to data from other MRS granophyres (Wirth and Vervoort, in prep.). Symbols: filled inverted triangles = Silver Bay granite xenolith; open inverted triangles = Split Rock granite xenoliths; other symbols are MRS granophyre bodies.

SULPHIDE SATURATION MECHANISMS IN GABBROIC INTRUSIONS IN THE NIPIGON EMBAYMENT

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Interest in the Nipigon Embayment as favourable exploration target for platinum-group element (PGE) deposits was stimulated by the suggestion by Naldrett (1992) that the area is a likely geological setting for the development of nickel-copper-PGE deposits based on criteria established in studies of the Noril'sk deposit in Siberia.

Proterozoic gabbroic intrusions in the Nipigon Embayment of northwestern Ontario were studied with the aim of discerning the mechanism of sulphide saturation leading to (PGE) concentrations recently discovered. Two intrusions, the Seagull intrusion (1116.2±9.2 Ma), south of Lake Nipigon, and the Kitto intrusion (1117±1.8 Ma), on the eastern shore of Lake Nipigon, were the subject of the study, as they contain potentially economically significant PGE concentrations. Most of the study was carried out on the Seagull intrusion, as only limited samples were available from the Kitto intrusion. Neither intrusion is well exposed, and most samples were taken from drill-core.

Profiles of sulfur, copper, nickel, gold, palladium and platinum as a function of depth in drill-holes reveal that sulphur saturation occurred at the base of the Seagull intrusion, where a zone of sulfide mineralisation is developed. However, sulphur saturation was noted at higher levels in the intrusion, notably in the high-grade RGB zone. These observations suggest the operation of different processes in formations of the mineral occurrences – a Noril'sk-type process involving assimilation of sulphur for the basal zone and a reef-type process for the higher zones (Naldrett 1993).

Olivine compositions were determined in both intrusions, and in both cases, the compositions indicate that the parental magmas were undersaturated with respect to sulphur. Thus, according to theories of PGE deposit formation, both intrusions have potential for PGE concentration.

Contamination of the parental magma, either through assimilation of country rock or magma mixing, has been ascribed a crucial role in the formation of an immiscible melt (Irvine 1975; Naldrett 1989). Neodymium (Nd)-samarium(Sm) isotopes provide a means of testing for contamination. Heggie (2005) reported data on Nd/Sm isotopic studies on Seagull intrusion samples for a range of depths in several drill-holes, as well results from underlying Quetico Subprovince metasedimentary rocks and Sibley Group sedimentary rocks. The calculation of ϵ_{Nd} for these samples yielded values of -0.2 to -4.0 (±0.5) for the Seagull intrusion, but -16 to -23 for the Quetico metasediments and a mean of -5 for Sibley Group sediments.

Rb/Sr isotopic studies on the same samples were used in a comparison of $^{143}\text{Nd}/^{144}\text{Nd}$ vs. $^{87}\text{Sr}/^{86}\text{Sr}$. Sibley Group sediments differ markedly from the Seagull intrusion in both factors, whereas the Quetico metasediments have lower $^{143}\text{Nd}/^{144}\text{Nd}$ ratios and similar $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. As the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the Seagull samples trend to somewhat higher values than those found in the Quetico metasediments, some assimilation of the high $^{87}\text{Sr}/^{86}\text{Sr}$ from Sibley material must have occurred. However, since $^{143}\text{Nd}/^{144}\text{Nd}$ in the Seagull samples decreases with depth, trending toward lower Quetico metasediment values, assimilation of Quetico material is also likely.

The source of sulfur in the Seagull intrusion was investigated through the study of sulphur isotopes and selenium/sulfur ratios. Sulphur isotopic compositions of samples from the base of the Seagull intrusion were compared with those from Quetico metapelites and evaporites from the Sibley Group. Sulphides from the Seagull intrusion had $\delta^{34}\text{S}$ ranging from -2.3 per mil (‰) to $+2.6$ ‰ with a mean value of -0.9 ‰. Sulphides in Quetico Subprovince metapelites has $\delta^{34}\text{S}$ ranging from -2.3 ‰ to $+1.1$ ‰ with a mean value -0.8 ‰. Finally, Sibley Group evaporites had $\delta^{34}\text{S}$ ranging from $+7.7$ ‰ to $+9.0$ ‰. According to Franklin and Mitchell (1977), these correspond to a mean H_2S composition of -4.2 ‰, based on prior knowledge of temperatures of formation of the sulphate minerals (barite, anhydrite and gypsum) in the Sibley Group. These data provide plausible evidence for incorporation of Quetico sulphide in the sulphide zone at the base of the Seagull intrusion. The source of sulphur in higher zones remains to be determined.

Comparison of $\delta^{34}\text{S}$ with $\text{Se/S} \times 10^6$ in Seagull sulphides and Quetico metapelites revealed that the Quetico samples lie well outside the region for mantle sulphur, whereas the Seagull samples show considerable scatter in $\text{Se/S} \times 10^6$. Together with their negative $\delta^{34}\text{S}$ values, it is evident that assimilation of Quetico sulphide is the explanation for these data.

Although the Nipigon Embayment has a number of features that seem to provide for a Noril'sk model setting, continental rifting, evaporites in the section, voluminous basaltic eruption among others, there are problems in its application to the two cases studied here. The Seagull and Kitto intrusions are among the earliest igneous events associated with the Mid-Continent Rift (Davis and Green 1997). Although some contribution from Quetico metapelite sulphide seems likely, the Sibley Group evaporites do not seem to be likely sulphur sources. Rather a reef-type of process seems to be responsible for zones of PGE enrichment at higher levels in both intrusions.

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MetalCORP LTD. BIG LAKE Cu-Zn-Ag-Au-Co, Ni-Cu-PGE, AND Mo PROPERTY

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The Big Lake Property of MetalCORP Ltd. of Thunder Bay, Ontario comprises 33 claims (365 units totalling 5840 hectares) and is located approximately 230 km east-northeast of the city of Thunder Bay and 18 km southeast of the town of Marathon in Northern Ontario, Canada.

Work completed by MetalCORP since early 2004 includes a MegaTEM airborne time-domain EM and magnetometer survey (2004), a detailed helicopter-borne ATEM III time-domain EM and magnetometer survey, detailed and reconnaissance prospecting (918 samples), linecutting, surface and down-hole pulse-EM surveys, geological mapping, and 3 phases of diamond drilling, totaling 31 diamond holes (8300 m). This work resulted in the discovery of 4 previously unknown mineralized zones that represent 3 separate and distinct mineralization styles. The mineralized zones include: the **J4 and J5 Pt-Pd reefs** within the Big Lake Ultramafic Complex; the **A2 Ni-Cu Zone** within the Gus Creek Mafic Intrusion; and the **BL14 Cu-Zn-Ag-Au-Co Zone** within strongly altered ultramafic metavolcanic flows and associated metasedimentary rocks. The A2 and BL14 zones are not exposed on surface and are buried beneath 10 to 75 m of glacial drift. The property is also host to the historic **Playter Mo-Cu-Pb-Ag Prospect** which has yet to be fully evaluated by MetalCORP.

The Big Lake Property is located near the southern margins of the eastern portion of the Archean-age Schreiber-Hemlo greenstone belt of the eastern Wawa Subprovince of the Canadian Shield. The greenstone belt is split into distinct eastern and western segments by the 1108 Ma Mesoproterozoic Coldwell Alkalic Complex. The eastern part of the belt is subdivided into the Hemlo-Black River assemblage (2.77 Ma) to the north and the Heron Bay (2.70 Ma) assemblage to the south, both of which are primarily affected by amphibolite-facies regional metamorphism. The western portions of both assemblages are lower in grade and exhibit upper greenschist facies regional metamorphism. The Big Lake Property occurs within the Heron Bay Assemblage which is intruded by the granitic to granodioritic Heron Bay Batholith, the recently recognized mafic Gus Creek Intrusion, the Bell's Lake Ultramafic Intrusion, and the >30 km long Big Lake Ultramafic Complex.

The **BL14 Cu-Zn-Ag Zone** is located stratigraphically below the eastern end of the sill-like Big Lake Ultramafic Complex, approximately 800 metres south of the A2 zone (*see below*). The south-facing, high temperature, mafic dominated Cu-rich VMS zone is overturned, dips at ~25° to the north, and consists of:

1. A stringer zone of intensely biotitized and strongly chloritized and talcose breccia containing up to 30% bands, veins, stringers and pods of chalcopyrite and pyrite with up to 5% disseminated to streaked sphalerite and minor galena;
2. A semi-massive to near-massive zone of chalcopyrite, pyrrhotite, sphalerite, and minor galena underlain by a strongly to intensely biotitic, chloritic, and talcose footwall alteration zone that locally contains anthophyllite and sillimanite.

Trace element lithogeochemistry shows that the footwall metavolcanic rocks contain unusually high amounts of Ni, Cr, TiO₂, and Pd that suggests that the host-rocks were originally komatiitic basalts or possibly ferro-picrites. The mineralized zone is capped by relatively unaltered clastic and chemical metasedimentary rocks. The thickest BL14 Zone intersection (DDH BL06-24) to date (April 6, 2006) contained **5.57% Cu, 103.9 grams/tonne (gpt) Ag, 6.74 gpt Au, 1.66% Zn,**

689 ppm Co, and 0.15% Pb over 5.38 m (17.65 ft). This interval included **7.45% Cu, 137.8 gpt Ag, 9.18 gpt Au, 2.24% Zn, 891 ppm Co, and 0.21% Pb over 3.95 m (12.96 ft).** Stringer zone mineralization intersected to date contained up to **2.56% Cu, 1.00% Zn, 46.0 gpt Ag, 1.60 gpt Au, and 0.10% Pb over 0.93 m (3.05 ft).**

The **J4 and J5 Pt-Pd Reefs** consist of narrow, apparently stratabound intervals hosted within thick peridotite units contained within the upper and central intrusive cycles of the eastern portion of the north-facing, well-differentiated, unlayered, sill-like Big Lake Ultramafic Complex. The ultramafic complex is presently undated; however, it is thought to be younger than most of the supracrustal rocks observed within this portion of the Schreiber-Hemlo Greenstone Belts. Diamond drilling shows that the central portions of the complex dip to the north at ~45°, whereas the eastern portions of the complex dip to the north at ~25°. Geological mapping suggests that the western portions of the complex exhibit a steeper northerly dip. The two host intrusive cycles and are very similar in appearance, progression of rock units, and apparent thickness. The observed mineralization consists of trace amounts of very finely disseminated pyrrhotite and chalcopyrite within serpentinized to locally talcose, fine-grained, pyroxene-oikocryptic peridotite. The J4 Reef varies between 0.58 and 2.11 m in thickness, occurs within the basal peridotite unit of the uppermost (J4) intrusive cycle of the Big Lake Complex and is usually directly adjacent to the contact with an overlying olivine-bearing pyroxenite unit. The J5 Reef is identical in appearance to the J4 Reef, varies between 0.75 and 3.00 m in thickness, and occurs within the basal peridotite of the central (J5) intrusive cycle of the complex near, but not adjacent to, the upper contact of the host unit with an overlying olivine-bearing pyroxenite. The **J4 Reef** has been traced for 2.20 km (1.37 mi) and contains up to **0.70 gpt Pt and 0.79 gpt Pd (1.49 gpt 2PGE)/1.67 m.** The **J5 Reef** has been traced for a similar distance and contains up to **0.81 gpt Pt, 0.85 gpt Pd (1.86 gpt 2PGE)/0.75 m.** It is interesting to note that both reefs were intersected while drill testing the BL14 Zone described above.

The **A2 Ni-Cu Zone** occurs near the base of the discordant Gus Creek Mafic Intrusion (2669.3 ± 1.8 Ma., Jack Satterly Geochronology Laboratory, University of Toronto, 2005) and consists of disseminated, blebby, and stringered, locally semi-massive pyrrhotite, chalcopyrite, and pentlandite hosted within the 2 to 20 m thick, conduit-like, A2 host intrusion breccia sequence. The A2 intrusion breccia is a complex interval of variably mineralized (1 to 30% sulphides), varitextured, inclusion-rich, gabbroic to melagabbroic intrusive rocks overlain by unmineralized, medium- to coarse-grained gabbro and quartz leucogabbro and underlain by occasionally mineralized, pyroxene-phyric melagabbro and feldspathic pyroxenite. Inclusion/fragment types include a variety of gabbros, ultramafic intrusive rocks, and clastic and chemical metasediments. The strongest mineralization occurs near the base of the intrusion breccia, comprises the A2 Ni-Cu Zone, and includes **1.66% Ni and 0.20% Cu/0.30 m, 1.00% Cu and 0.80% Ni/0.40 m, 1.40% Cu and 0.27% Ni/0.77 m, and 0.98% Cu and 0.29% Ni/1.40 m.** The geometry of the A2 mineralized zone remains uncertain and may be more complex than initially thought, but within the area drilled appears to strike ~140° and dip southwest between 40 and 60°. It is presently thought that much of the observed sulphide mineralization within the A2 Zone consists of fragments from a high R-factor, massive, Ni-Cu sulphide body located somewhere at depth.

MINING AND EXPLORATION ACTIVITY IN NORTHWESTERN ONTARIO

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Northwestern Ontario continued to see a significant increase in mining and mineral exploration in 2005. Six mines produced a total of 1.5 million ounces of gold in 2005, approximately 70% of Ontario's total.

Gold producers included:

Campbell Mine (*Placer Dome Inc.*);

David Bell Mine (*Teck Cominco Limited and Barrick Gold Corporation*);

Golden Giant Mine (*Newmont Canada Limited*);

Musselwhite Mine (*Placer Dome Inc./Kinross Gold Corporation*);

Red Lake Mine (*Goldcorp Inc.*); and

Williams Mine (*Teck Cominco Limited and Barrick Gold Corporation*).

North American Palladium Ltd. produced 177 167 ounces of palladium and 18 833 ounces of platinum at its Lac des Iles Mine and development of the underground operation below its open pit mine continues.

The Golden Giant Mine closed its mining operation in December of 2005 and will be decommissioning the mine site in the first half of 2006.

There are approximately 400 active exploration projects in the northwest, the vast majority of which are focused on gold. Areas receiving the most interest from exploration companies were the Red Lake greenstone belt, Shoal Lake area, Dogpaw Lake area, Shebandowan greenstone belt, Fort Hope greenstone belt, Onaman-Tashota belt and the Pickle Lake greenstone belt. Elevated mineral commodity prices are contributing to levels of exploration activity in northwestern Ontario not seen since the mid-1980's.

Exploration in northwestern Ontario continues for the following mineral deposit types: diamonds, uranium, copper-nickel-platinum group elements, volcanic hosted massive sulphides, rare earth elements in pegmatites, iron-oxide-copper-gold, copper-molybdenum-gold porphyry, and lode gold.

GEOLOGY AND GEOCHEMISTRY OF THE CHIMNEY LAKE VOLCANICLASTIC BRECCIA NEAR ARMSTRONG, ONTARIO

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The Chimney Lake volcanoclastic breccia (CLVB) is part of a group of Mesoproterozoic rocks that unconformably overlie the Archean basement of the central Wabigoon Subprovince near the northwestern end of Lake Nipigon. Mapping in 2003 resulted in the discovery of a number of previously unmapped, Mesoproterozoic units, including the Badwater layered gabbro intrusion (Middleton 2005), the Pillar Lake volcanic assemblage (PLV), and an undeformed volcanoclastic breccia located on the north shore of Chimney Lake (MacDonald 2004). The Badwater layered gabbro (1599 Ma; Heaman and Easton 2006) intrusion has anorthositic to gabbroic layers. The PLV are a series of flat-lying, greenschist-facies, undeformed, massive and pillowed basalt flows. A robust age date of the PLV has not yet been obtained, but dates obtained by geochronological methods indicate that the PLV were erupted between 1514 Ma and 1120 Ma (Heaman and Easton 2006). The CLVB was originally mapped as a conglomerate within the Pass Lake Formation of the Sibley Group and has not been dated by geochronological methods (MacDonald 2004).

Field relationships between the CLVB and surrounding lithologic units, such as the PLV, are not discernible due to poor outcrop control. CLVB contains fragments of gabbro, basalt, amygdaloidal basalt, and fragments tentatively described as granitoid and sedimentary rocks. Fragments range in size from 0.2 cm to 30 cm in diameter. Gabbroic fragments are angular with sharp edges, displaying no evidence of assimilation. Basalt fragments sometimes exhibit assimilation features and have angular to subrounded and ameboidal shapes. Amygdules within basalt fragments are infilled with chlorite and locally clay minerals. Alteration envelopes of chlorite, hematite and clay minerals surround the amygdules. The breccia matrix consists of very fine- to coarse-grained, angular to sub-rounded, hematite- and actinolite-altered volcanic and igneous fragments.

Preliminary geochemical results indicate that the CLVB contains fragments of basalt that are similar in composition to the alkaline PLV basalt. The gabbroic clasts vary in composition but it appears that they are similar to the Badwater layered gabbroic intrusion. The Badwater layered gabbroic intrusion and the PLV are geochemically dissimilar. The similarity between the fragment composition in the CLVB and nearby lithologic units suggests a local source. The CLVB could be a reworked autoclastic breccia related to Pillar Lake volcanism, or alternately it may represent a diatreme breccia dike that was emplaced after Pillar Lake volcanism.

Ongoing detailed mapping of the volcanoclastic breccia in conjunction with additional geochemical analyses will determine the source and cause of the volcanism that resulted in this breccia unit, as well as other local volcanic rocks.

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THE PRECAMBRIAN RESEARCH CENTER—A NEW INITIATIVE TO PROMOTE PRECAMBRIAN FIELD STUDIES AT THE UNIVERSITY OF MINNESOTA DULUTH

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As the minerals industry enters an anticipated period of protracted expansion, a major impediment to this growth is a scarcity of new geoscientists adequately trained in basic field methods. This is especially true in field studies of Precambrian terrains, which host much of the world's ore deposits. The Precambrian Research Center (PRC) is being created at the University of Minnesota Duluth (UMD) with the primary goal of satisfying this new demand for field geologists by providing training and support to upper-level undergraduate students, graduate students, and professional geologists in modern methods of geologic mapping in glaciated Precambrian terrains. A secondary goal of this center is to attract exceptional students, who have an interest in conducting field-oriented thesis research, to the University of Minnesota Duluth's graduate program. Ultimately, it is our hope that the PRC will sustain and enhance the reputation the geology department at UMD has developed over the past 50 years for producing well-trained field geologists.

The PRC will have five programmatic components:

1. Summer geology field camp in northeastern Minnesota

Beginning in 2007, the PRC will offer a summer field camp focused on the unique aspects of field mapping in Precambrian terrains of the southern Canadian Shield. The field camp will be a course accredited through the College of Science and Engineering at UMD. It will be open to undergraduate and graduate students from throughout the U.S., Canada, and abroad. It will be staffed by 4 to 6 professional field geologists contracted with the PRC.

Field camp highlights

- Introduction to basic field methods in glaciated Precambrian shield terrains.
- Overview of the Precambrian geology of the southern Canadian Shield.
- Week-long capstone field mapping projects with small field excursions supervised by professional field geologists; Boundary Waters Canoe Area Wilderness option.
- GIS compilation of field data and digital geologic map-making.
- Integrating structure, drill core, and geophysics into 3-D geologic interpretations.

2. Graduate assistantships and grants

The PRC will offer several yearly research assistantships for students accepted into the UMD graduate program who wish to pursue field-based research projects focused on the Precambrian geology of the Lake Superior region. Small research grants will also be available to undergraduate and graduate students to assist in various aspects of field-based studies of Precambrian geology. Undergraduate or graduate students may apply for these grants, but preference will be given to students from UMD and those who have attended the PRC field camp.

3. Professional workshops/field experiences

The PRC's goal of providing advanced training to professional geologists, as well as students, will be achieved by sponsoring a regular series of workshops and field

experiences (at least two per year) on various topics related to field mapping of Precambrian shield geology. In addition, customized geologic mapping experiences for groups of industry geologists and/or the geologic staff of individual companies can be arranged. The PRC will work with UMD to ensure that these programs meet the continuing professional development requirements of geologic licensing boards. Industry members of the PRC will receive registration waivers to these advanced training sessions depending on their level of support.

4. Advanced geology courses at UMD

Three new field-based courses will be offered for upper level undergraduates and graduate students within the Department of Geological Sciences. These courses include Advanced Field Methods and Geological Maps; Geology in Three-Dimensions; and Geologic Problem Solving Using Digital Methods.

5. Outreach, field trip offerings, and career planning for students

The PRC will offer outreach education to K-12 students and the general public on the geology and mineral resources of the Lake Superior region. It will also offer to lead field trips on the Precambrian geology of the area for UMD students and students visiting the area from other colleges and universities. Finally, the PRC will serve as a clearinghouse for students to find job opportunities in the public or private sector that require field mapping skills.

PRC activities and finances will be overseen by the heads/directors of three principal organizing institutions within the University of Minnesota: the Natural Resources Research Institute (NRRI) at UMD, the Department of Geological Sciences at UMD, and the Minnesota Geological Survey (MGS) at the University of Minnesota Twin Cities campus. The NRRI will oversee the business activities of the PRC; the geology department will oversee the PRC's educational programs; and MGS will provide guidance on geologic mapping projects. The PRC will employ 3 to 4 permanent staff and will contract with many field-experienced academic and professional geologists from throughout the Lake Superior region for its various programs and activities. A Board of Advisors consisting of preeminent geologists from industry and academia will be established to provide advice and oversight of PRC activities and programs.

Funding for the PRC will come from many sources. Base funding will be sought from the State of Minnesota to support administrative expenses, from the University of Minnesota in the form of tuition deferments, and from students and professional geologists by tuition and fees paid for summer field camp, academic courses, and workshops/field experiences. Funding for particular research projects will be sought from the U.S. Geological Survey through their EDMAP program and from the minerals industry for sponsorship of industry-generated thesis projects. The minerals industry, which stands to be a major beneficiary of the PRC by its professional workshops and by having access to well-trained students, will also be requested to serve as a key benefactor of the PRC.

GEOLOGY OF THE DULUTH COMPLEX IN THE FOUR BABBITT 7.5' QUADRANGLES, NORTHEAST MINNESOTA

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The Minnesota Geological Survey published 1:24,000-scale digital geologic maps of the Babbitt, Babbitt Northeast, Babbitt Southwest, and Babbitt Southeast 7.5' quadrangles in 2005 (Severson and Miller, 2005; Miller and others, 2005; Miller and Severson, 2005; and Miller, 2005, respectively). The area was originally reconnaissance mapped by Bonnicksen (1970a-d). The Precambrian rocks in the four Babbitt quadrangles are best known for hosting the easternmost Mesabi Iron Range taconite mines and some of the Cu-Ni-PGE deposits that occur along the northwestern margin of the Duluth Complex. The maps, which include three cross sections, will be on display as a poster presentation.

Trending northeasterly through the map area, the Duluth Complex is in intrusive contact with Paleoproterozoic rocks of the Animikie Group and Archean granitic rocks of the Giants Range batholith. The Animikie Group units include the basal Pokegama Quartzite, the overlying Biwabik Iron Formation, and the Virginia Formation. The Peter Mitchell (Northshore Mining) and Dunka Pit (closed) taconite mines occur in the map area.

The northwestern margin of the Duluth Complex is exposed in the Babbitt quadrangles. The Duluth Complex is the largest exposed intrusive component of the Mesoproterozoic (1.1 Ga) Midcontinent Rift. It was emplaced as multiple intrusions into the lower section of comagmatic volcanic rocks of the North Shore Volcanic Group, which is evident from field relationships in the map area.

The oldest Mesoproterozoic rock units in the Babbitt quadrangles are several types of mafic hornfels inclusions, which represent thermally metamorphosed remnants of the North Shore Volcanic Group. The most common type is basaltic hornfels, which by the common occurrence of meta-amygdaloidal textures, are clearly thermally metamorphosed mafic volcanic lava flows. Magnetic, nonmagnetic, and plagioclase porphyritic varieties of basalt hornfels are recognized, with the magnetic types usually occupying a stratigraphically lower position. An interesting hornfels type is a well cross-bedded mafic hornfels that is interpreted to be a strongly metamorphosed volcanogenic interflow sandstone unit (Patelke, 1996). An enigmatic hornfels type is a medium- to fine-grained, equigranular oxide olivine gabbro that displays a domainal distribution of granular mafic phases possibly representing granoblastic recrystallization of an originally ophitic texture. The thickness, homogeneity, and average medium grain size imply that the unit may be a metamorphosed subvolcanic sill or a large lava flow.

The oldest intrusive rocks of the Duluth Complex in the map area are gabbroic to anorthositic rocks of the early anorthositic series. The anorthositic series consists of a structurally complex suite of plagioclase-rich gabbroic rocks that cover large expanses of the upper reaches of the Duluth Complex (Miller and others, 2002). Over most of the map area, anorthositic rock types, with plagioclase ranging from 75 to 95 percent, typically occur as meter- to decameter-sized inclusions in troctolitic rocks. However, in

the Babbitt Southwest quadrangle, several varieties of anorthositic-series rocks occur over large areas. In addition to standard plagioclase-rich anorthositic-series lithologies, typically with poikilitic to intergranular olivine, these large areas of anorthositic-series rocks also contain a distinct olivine oxide gabbro lithology that only locally is leucocratic. This rock type was referred to as the Powerline gabbro by Bonnicksen (1972), who suggested it was an upper differentiate of the Partridge River intrusion. Paces and Miller (1993) acquired a U-Pb age of $1,098.6 \pm 0.5$ Ma for this unit, also considering it part of the Partridge River intrusion. However, this mapping has clearly shown this gabbro to be in gradational contact with other anorthositic-series rocks and to be crosscut by troctolitic rocks of the Partridge River intrusion.

The main Duluth Complex units in the Babbitt quadrangles are various types of troctolitic (Ol + Pl) cumulates of the layered series. The layered series is the youngest component of the Duluth Complex and is composed of a suite of discrete layered mafic intrusions that show variable degrees of internal differentiation (Miller and others, 2002). The Babbitt quadrangles include parts of four major layered series intrusions: the Partridge River intrusion, the South Kawishiwi intrusion, the Greenwood Lake intrusion, and the Bald Eagle intrusion. Only the Partridge River and the South Kawishiwi intrusions are sufficiently exposed to subdivide their igneous stratigraphies into map units; both intrusions are composed mostly of olivine-plagioclase cumulates, and different map units are distinguished on the basis of subtle differences in the amount of interstitial augite and Fe-Ti oxide, the occurrence of melatroctolitic intervals, and on variable concentrations of anorthositic-series inclusions. The igneous layering in the lower 500 meters of both intrusions is better known because of the high density of exploration drill core.

Several of the major Cu-Ni-PGE sulfide deposits that occur along the base of the Duluth Complex in this area were first discovered in the early 1960s. From southwest to northeast, these include the Northmet (formerly Dunka Road), the Mesaba (formerly Babbitt), the Serpentine, the Dunka Pit, and the Birch Lake deposits. Polymet is in the final stages of permitting the Northmet deposit, and if successful, is scheduled to begin development in 2008. Assessment activity on the other deposits has increased as well, particularly on the Birch Lake deposit.

The geologic picture portrayed in these maps and cross sections provide new insights and important constraints on models for the emplacement, crystallization, and mineralization histories of the Partridge River and South Kawishiwi intrusions. The potential development of Cu-Ni-PGE deposits will provide further insights into the detailed geology and mineralization of this economically important part of the Duluth Complex.

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GEOCHEMICAL CONSTRAINTS ON THE DEPOSITION OF MESOARCHEAN BANDED IRON FORMATION AT THE MUSSELWHITE MINE, NORTH CARIBOU GREENSTONE BELT, SUPERIOR PROVINCE

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Iron formations (IFs), chemical sedimentary rocks containing greater than 15% iron (James 1954), can be broadly divided into Superior- and Algoma-type. Superior-type IF are laterally extensive, associated with sedimentary rocks deposited in shallow water settings, and are generally Paleoproterozoic in age. They formed from the upwelling of oxygen-deficient, Fe⁺²-bearing ocean water onto shallow shelves where oxygen was present (Cloud 1973). In contrast, Algoma-type IFs are laterally and vertically limited, associated with volcanic and sedimentary rocks deposited in deep-water, and mostly Archean in age (Gross 1996). They are commonly considered to have formed by precipitation from venting hydrothermal fluids, although shallow-water deposits of Algoma-type are present and probably represent microbially induced precipitation (Fralick, this conference).

This study utilized banded chert-magnetite iron formation present in surface exposures at the Musselwhite Mine. The site sampled is an unmineralized area of the gold-bearing horizon. Sixteen samples were collected, from which monomineralic layers were separated and analyzed using XRF and ICP-MS. This is an amphibolite facies Algoma-type IF that overlies a thick mafic metavolcanic succession with apparent conformity. Millimeter to approximately one centimeter thick layers of chert and magnetite alternate in the lower half of the IF. These layers contain very small amounts of siliciclastic material. Higher in the IF there is a gradational increase in the amount of siliciclastic debris intercalated with the chemical sediment layers, until the succession is dominated by siliciclastics. All samples came from the lower, relatively siliciclastic free zone.

Concentrations of most major and trace elements are relatively low in the magnetite and chert samples. Exceptions to this are Si in the cherts and Fe, Mn and P in the magnetite layers. The Si, Fe and Mn are self-explanatory. The slightly elevated phosphorous values indicate possible scavenging of PO₄⁻² from seawater by iron hydroxides or oxyhydroxides during precipitation or microbial activity in the sediment. Trace element abundances normalized to chondrite (Fig.1a,b) indicate the fluid that precipitated the IF was depleted in Ni, Cr, Zn, Co, Cu, Ti and K; and enriched in Sc, Y, W and Cs, relative to chondrites. Figure 1C shows the chert layers have less admixed siliciclastic material and also less Ni, Cr, Zn, Co and Cu, possibly denoting the iron compounds precipitated from higher temperature fluids. Rare earth element plots portray similar patterns to REE plots of recent metalliferous sediment and vent water from the TAG field (Atlantic) and the Atlantis II Deep (Red Sea) (Peter 2003). The geochemical data indicate both the Si- and Fe-rich layers precipitated from vented fluids in an environment where there was sufficient oxygen to form iron hydroxides or oxyhydroxides.

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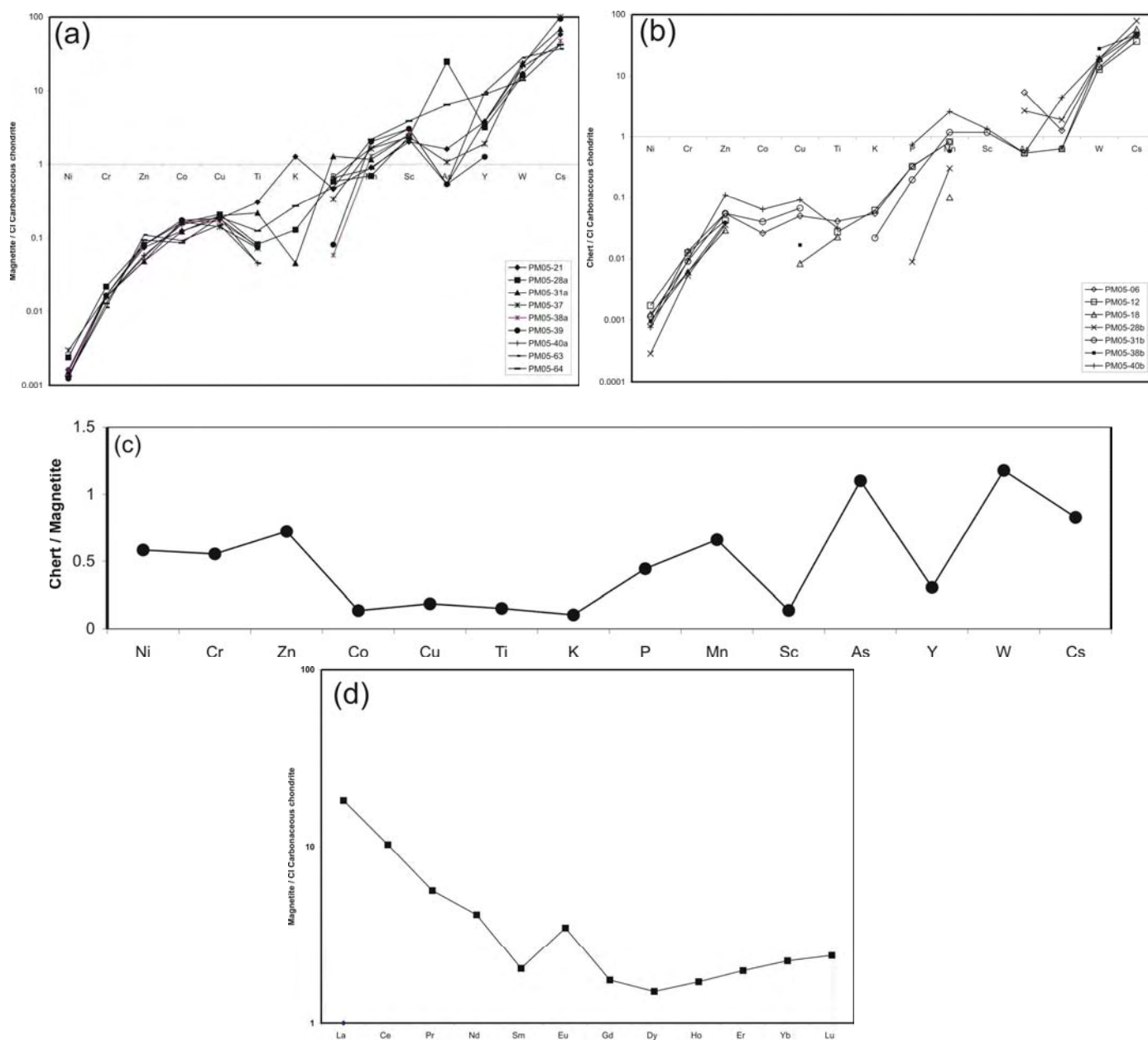
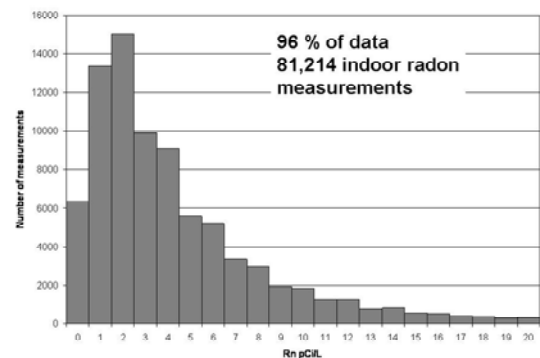


Figure 1. (a) Logarithmic plot of trace element values from magnetite layers taken from the BIF at Musselwhite mine. Trace element values normalized to CI Carbonaceous chondrite values of McDonough and Sun (1994). (b) Logarithmic plot of trace element values from chert layers taken from the BIF at Musselwhite mine. Trace element values normalized to CI Carbonaceous chondrite values of McDonough and Sun (1994). (c) Chert values normalized to magnetite values from the present study. (d) REE plot normalized against CI chondrite.

STATISTICAL ANALYSIS OF INDOOR RADON DATA AND RELATIONSHIPS TO GEOLOGY IN WISCONSIN

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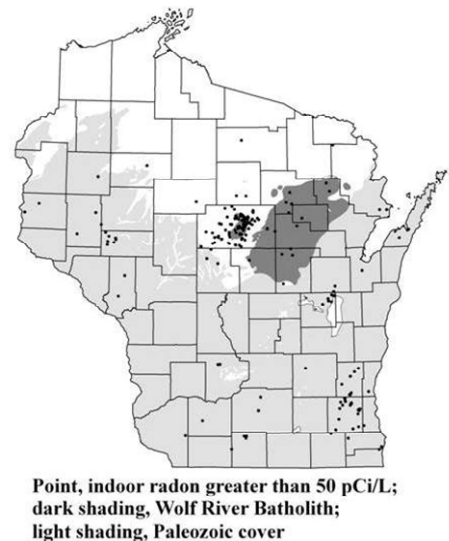
In the 1986 with the discovery of exceeding high radon values in Pennsylvania, the US Environmental Protection Agency initiated a nation-wide study to determine the population and geographical risk associated with radon. Because Wisconsin has a strong state radiation protection program, and known occurrences of uranium and other radionuclides, it was one of 10 initial states to be analyzed. Since then, 84,262 residential indoor radon in air covering all areas has been collected. These data are not randomly distributed and reflect collection by interested by home owners. Nearly 50% of the analyses have been accurately located and digitized permitting geologic analysis; the remainder has only zipcode locational information. This study compares the EPA radon survey with the more extensive Wisconsin data base and evaluates the data with respect to various geologic attributes in order to define those areas and geologic units in Wisconsin where radon may pose a higher risk. The original EPA survey of 1194 homes is considered the only statistically useful survey for evaluating average values of indoor radon in Wisconsin: the mean of 3.4, with a Q1 of 1.2 and a Q3 of 4.1. The data are highly skewed. The highest value found in Wisconsin is 938 near Hudson.



Elevated indoor radon is found in all areas of Wisconsin as is predicted by geological analysis. Soil derived from granite and carbonate rock that is the principal geological factor leading to elevated indoor radon in Wisconsin. Because radon can migrate only a few meters over the 3.8 day half-life, soil chemistry and soil texture principally influence elevated indoor radon. Because elevated radon is found in all areas of Wisconsin, and because do-it-yourself radon testing is inexpensive, it is highly recommended that all houses in Wisconsin should be tested for radon.

This study was funded by the U.S. Environmental Protection Agency to the Radiation Protection Section, Wisconsin Division of Public Health, Wisconsin Department of Health and Family Services, and to the Wisconsin Geological and

Natural History Survey, University of Wisconsin Extension, while Mudrey was with the WGNHS.



3D VISUALIZATIONS OF MAFIC INTRUSIONS IN THE DULUTH COMPLEX, NORTHEASTERN MINNESOTA

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One of the main hallmarks of science is that it allows one to imagine reality. In the geosciences, one of the main realities that geologists try to imagine is the geometry and structural juxtaposition of geological units and/or mineralized zones in the subsurface. This is especially true for geologists that work in the mineral exploration and mining industries, earthquake monitoring and hazard assessment agencies, and at contaminated groundwater sites.

The advent of 3D geological computer programs has brought about a revolution in the understanding of the Earth in three dimensions. This digital poster presentation using the computer program gOcad (by Earth Decision Science) will display geological features of numerous troctolitic intrusions within the Duluth Complex, and will highlight how such visualizations advance our understanding of geological processes that ultimately led to the formation of billions of tonnes of Cu-Ni-PGE mineralized rocks. An image of the basal surface of a portion of the Partridge River Intrusion is presented in Figure 1. The bowl-shaped depression hosts the Babbitt deposit, currently held by Teck-Cominco.

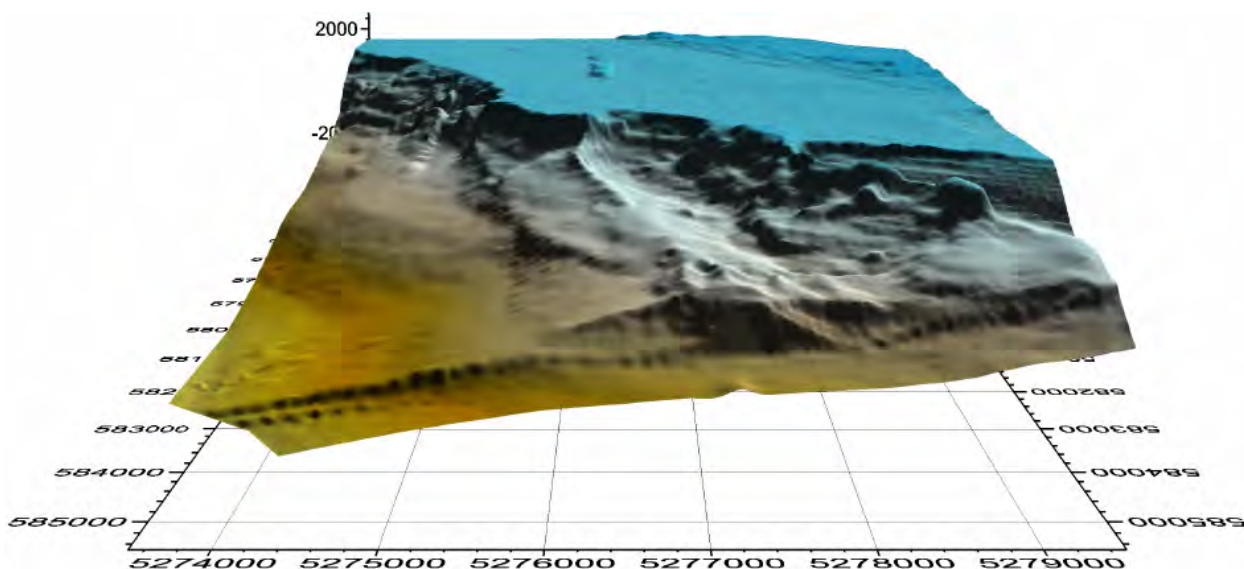


Figure 1. 3D view of the basal surface of a portion of the Partridge River Intrusion. View looking due west and down 10°. Grid lines are UTM coordinates, in meters.

EVIDENCE FOR WIDESPREAD DISTRIBUTION OF IRON DEPENDENT METABOLISMS IN PRECAMBRIAN OCEANS

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Starting with the first detailed descriptions of Precambrian microfossils (Barghorn and Tyler, 1965), the dominant view has been that cyanobacteria were the primary producers in Paleoproterozoic, and more generally in all early Precambrian, ecosystems (Awramik, 1992). An increased understanding about the chemical evolution of the ocean atmosphere system lead some to question the theoretical and observational foundation of this dogma (Blank, 2004). Currently, there are little constraints on many of the basic attributes of most pre1.8Ga ecosystems. For instance, the diversity of bacterial metabolism in early environments is still debated and distribution of bacterial metabolisms in early earth's history is poorly constrained. Although the atmosphere became oxygenated approximately 2.5Ga widespread marine anoxia and sulfate limitation resulted in pre1.8Ga oceans with significant quantities of dissolved iron. There is strong theoretical support from ecological modeling that these iron rich oceans supported an abundant iron dependent microbial community (Konhauser et al., 2002). In our analysis of the Paleoproterozoic Animikie basin we found empirical evidence for the widespread distribution of a microbial community with iron dependent metabolisms that thrived at a characterizeable oxygenic chemocline.

There are two distinct stromatolites Animikie Basin; large, hemispheroidal, calcitic, peritidal stromatolites, and iron rich, subtidal, digitate stromatolites. Based on the morphology of the stromatolites, the inferred primary silica composition (Barghoorn and Tyler, 1965), and the microstructure the iron rich stromatolites were proposed as having formed as either sinter deposits or in the hot spring apron (Walter, 1972). The stromatolites proposed to be sinter deposits are defined by the presence of thin laminations (thinner in width than the majority of Gunflint microfossils) with distinct boundaries between the laminations (Hoffman, 1969; Walter, 1972). The spring origin of the stromatolites has been widely accepted, (Sommers and Awramik, 2002; Siminson, 1987) and even popularized to general audiences (Knoll, 2003).

Field and microscopy work revealed that the 'abiogenic' stromatolites formed under a strong microbial influence. Field observation demonstrated that the stromatolites represent one facies in a well preserved sedimentary package. The iron rich stromatolites also display mesostructural features that cannot be readily explained by abiotic processes. For instance, the columnar sections of the stromatolites display crestal thickening, often with tuffs similar those seen in modern microbial mats and laminations that are far above angle of repose. The presence of alternating residual organic rich and residual organic poor lamination couplets and total organic carbon values of up to 2.5% also strongly suggests microbial mediation. In the least metamorphically altered stromatolites the thinner organic rich laminations are composed predominately of hematite in siliceous cement. The organic poor laminations and the surrounding siliceous material contain very low concentrations of iron. The iron distribution cannot be explained by secondary

oxidation and therefore necessitates a means for iron disproportionation within the organic rich laminae.

The rare earth element (REE) pattern and sedimentological characterization suggest that the iron rich stromatolites formed at an oxygenic chemocline. Ce is the only REE that can be oxidized in surface aqueous solutions, which results redox reactions controlling the element's cycling and abundance. The stromatolites display a negative cerium anomaly, which indicates stromatolite formation in aerobic conditions or at an oxygenic mixing zone. The stromatolites occur at a transition out a zone with regular authogenic iron deposition, which implies formation at an oxygenic chemocline.

In modern environments, iron oxidizing *β proteobacterium* dominate at oxygen mixing zones or in microaerophilic conditions where there are similar or even significantly lower ferric iron concentrations than the predicted (Holland, 1984,) values for the Paleoproterozoic oceans (Emerson and Revsesbach, 1994). Iron oxidizing *β proteobacterium* induce iron precipitation on average 60 times faster than abiotic reactions providing a means for the observed iron disproportionation in the organic rich stromatolite laminae.

The stromatolites also display a positive Gd anomaly, which serves as independent biogenicity proxy. Abiogenic iron precipitates, because of the lanthanide tetrad effect, display a negative Gd anomaly (Bau, 1999). Microbial communities slightly preferential or proportionately adsorb Gd compared to Tb, and Dy (Anderson and Pedersen, 2003). Modern ocean water has positive Gd anomalies that are mirrored by negative Gd anomalies in the largely abiogenic ferromanganese pavements. The stromatolites have similar or even more pronounced Gd anomalies than modern oceans. The stromatolites positive Gd anomaly necessitates biogenic precipitation of iron oxides within the stromatolites.

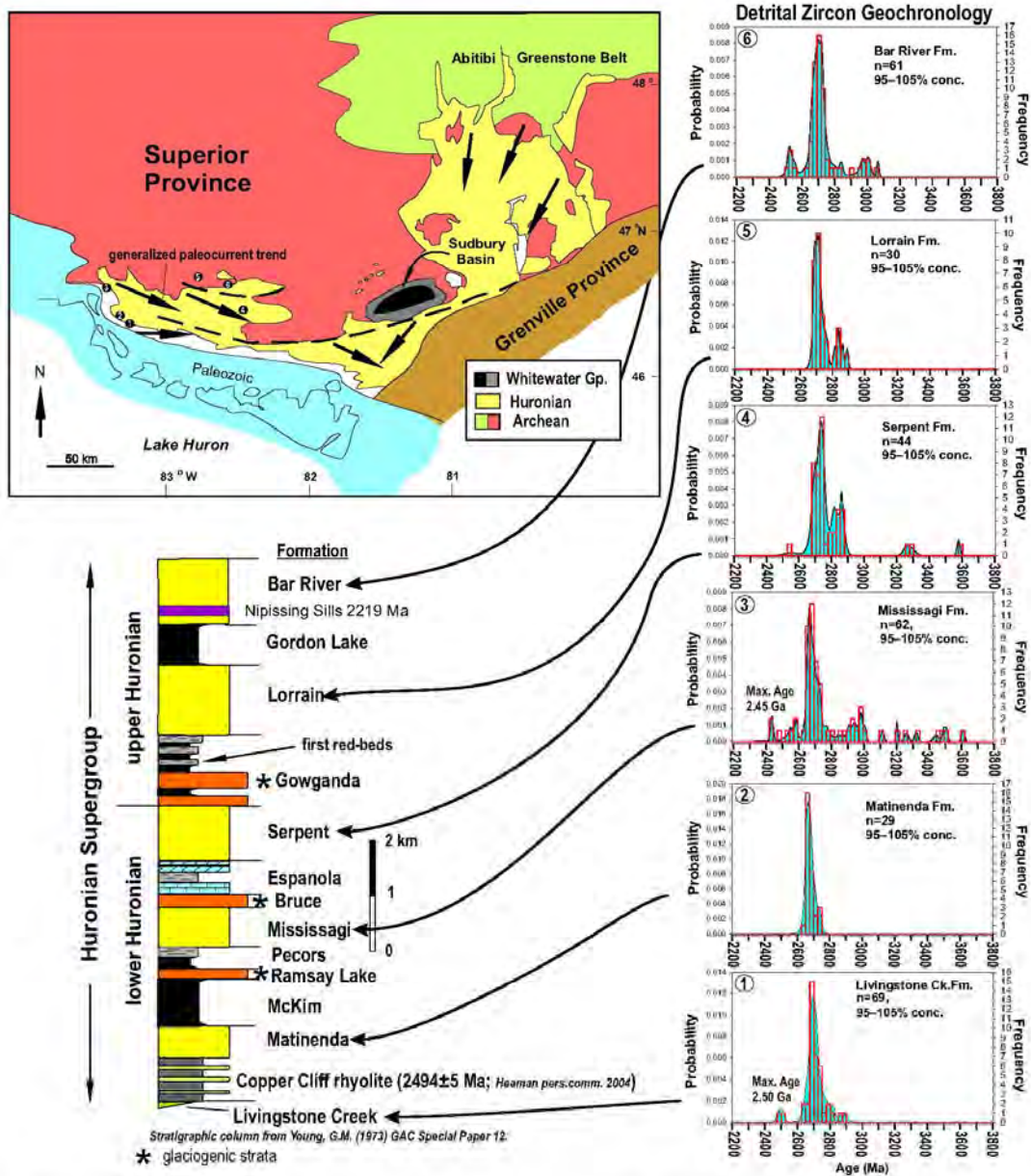
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DETRITAL ZIRCON GEOCHRONOLOGY OF THE WESTERN HURONIAN BASIN

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The Paleoproterozoic Huronian basin hosts an up to 12 km-thick succession of mainly siliciclastic sedimentary rocks deposited along the southern margin of the Superior Province (Huronian Supergroup). Paleocurrent data from crossbedding in fluvial sandstones throughout the succession suggest provenance from the west and northwest. U-Pb SHRIMP analysis of detrital zircon from six sandstone samples from the western part of the Huronian basin indicates provenance mainly from Neoarchean sources with prominent modes ca. 2.67 and 2.72 Ga. A sample from the stratigraphically lowest unit (Livingstone Creek Formation-Elliot Lake Group) contains zircon ranging in age from 2.90 - 2.65 Ga, with one ca. 2.50 Ga grain (weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2497 ± 10 Ma). This grain probably was derived from co-eval volcanic rocks erupted during rifting and initiation of the Huronian basin and provides a maximum age for deposition of the Huronian. A sample from the overlying Matinenda Formation has a unimodal zircon age population at ca. 2.67 Ga. The overlying Mississagi Formation (Hough Lake Group) has a polymodal zircon population varying in age from 3.62 - 2.45 Ga. Given the easterly paleocurrent indicators at the sampling locality, the pre-3.0 Ga grains could have derived from gneisses of the Minnesota River Valley terrane, southwest of the Huronian basin. The two youngest grains from the Mississagi Formation (weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ ages- 2445 ± 9 Ma and 2451 ± 6 Ma), likely were eroded from volcanic rocks (or their intrusive equivalents) in the unconformably underlying Elliot Lake Group. Samples from succeeding thick fluvial quartz arenites of the Serpent (Quirke Lake Group) and Lorrain (Cobalt Group) formations show similar detrital zircon age profiles with a range of ages from 2.88-2.68 Ga, and a significant ca. 2.72 Ga population. A marine quartzarenite from the uppermost unit of the Huronian (Bar River Formation-Cobalt Group) has a generally similar population to that of the Serpent and Lorrain formations but with a broader range of ages, including 3 grains at ca. 2.53 Ga of unknown provenance, and 4 grains at ca. 3.00 Ga. Overall, detrital zircon geochronology and sedimentology of the western Huronian basin is compatible with provenance from the Wawa Subprovince of the western Superior craton with contributions from adjacent older gneissic terranes.



Regional generalized geology showing sample locations, stratigraphy and cumulative probability/frequency diagram showing SHRIMP $^{207}\text{Pb}/^{235}\text{U}$ age distribution of single detrital zircons from sandstones of the Huronian Supergroup from the western part of the Huronian basin.

UNRESOLVED PROBLEMS AND THE EVOLUTION OF SUDBURY GEOLOGY

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Geological events, which shaped the area now occupied by the Sudbury Basin and surrounding footwall, span at least 1470 Ma from 2711 Ma, the minimum age of the Levack Gneiss Complex, to 1238 Ma, the age of olivine diabase dikes. The area has undergone several tectonic, magmatic, metamorphic and mineralization events which have been largely overshadowed by the Sudbury Event at 1850 Ma. Ascribing the Sudbury Event to meteorite impact is an entrenched paradigm; several unresolved problems are largely ignored. The aim of this abstract is to outline the geological evolution of the area and to identify certain outstanding problems. The events which have affected the area may be grouped as follows: doming, Sudbury Event and post Sudbury Event.

Early workers recognized that the Paleoproterozoic rocks of the Sudbury Basin were superimposed on an Archean dome, with the NW boundary extending to the Huronian outliers and the other boundaries obscured by later deformation. Evidence for the dome is as follows: 1) in the South and East Ranges the footwall rocks become progressively younger away from the dome; 2) rocks of the Levack Gneiss Complex, metamorphosed to the granulite facies at depths of up to 28 km and uplifted to depths of 5 to 11 km, possibly during emplacement of the Cartier batholith, suggests that the complex cored a paleodome; 3) mafic dikes in the footwall of the North and East Ranges, located between 10 and 15 km from the outer margin of the Sudbury Igneous Complex (SIC), are oriented normal to the adjacent margin of the SIC which is consistent with dike emplacement during local magmatic doming; 4) the Nipissing gabbro, which has an affinity for rocks of the Huronian Supergroup, is absent between the NW edge of the SIC and the Huronian outliers, which suggests little or no deposition of Huronian sediments or their complete erosion, implying that the site of the basin was a topographic high; and 5) three felsic plutons, viz., Murray, Creighton and Skead intrude the area of the inferred paleodome. Prior to the Sudbury Event, rocks of the Southern Province and the Huronian outliers were folded about EW- to NE-trending axes and locally about NNE-to NNW-trending axes.

The Sudbury Event is ascribed, without question, to meteorite impact by virtually all investigators. The bolide coincidentally struck a local dome which was presumably pregnant with sufficient Ni-Cu-PGE- Zn-Pb-Cu-Ag-Au mineralization to form one of the world's largest mining camps. The notion that the ores are of cosmic origin has received little support. Features formed by the event include: Footwall Breccia and Sudbury Breccia (SB); shatter cones; planar deformation features; Onaping Formation; and SIC. SB in the granitic rocks of the North Range footwall consists of pseudotachylite, a rock considered to have formed by frictional melting in dry rocks during high-speed slip along large faults concentric with the outer margin of the North Range SIC. Field work has led others to question the existence of the faults. In contrast to the North Range SB, clastic SB occurs in the footwall of the South and East Ranges. It apparently formed by explosive dilation, fluidization and flowage into extension fractures. Clastic SB occurs at Lake Temagami, 80 km NE of the outer margin of the SIC and the most distant locality reported to date. Clasts in breccias surrounding impact craters tend to increase in size with distance from impact. Clasts at Lake Temagami are smaller than those in some bodies near the SIC. Curved and striated fracture surfaces known as shatter cones are supposedly unique to impact craters. At Sudbury, they are scarce in the North Range footwall but are common in the South and East Range footwall where they tend to occur in clusters. Most fractures are in the shape of curved surfaces rather than cones. In attempts to define the size of the Sudbury crater, numerous authors have subscribed to the thesis, first proposed in 1970, that the Huronian outliers

were preserved in down-faulted blocks formed by the simultaneous collapse of the central uplift and the emplacement of the SIC. Despite convincing evidence that the sediments were deposited in a rim syncline around a domal structure long before the Sudbury Event, relating the preservation of the outliers to impact still persists

The origin of the Onaping Formation has been interpreted as follows: volcanic, fall-back breccia from meteorite impact, impact-induced volcanism or hyaloclastis. A discontinuous breccia at the base of the formation contains fragments as much as 79 x 23 km which reflect the lithology of the adjacent country rocks. The clasts were possibly emplaced by sliding down a submarine slope (crater wall?). Above the basal unit the formation consists of a series of breccias. Possibly melt, continuously fed from below, underwent passive to explosive fragmentation and rapid cooling on interaction with water. The “Onaping melt” may represent an impact melt, a hypabyssal intrusion or some combination. Diamonds in the Onaping Formation are referred to, by their discoverers, as “impact diamonds” without even considering alternatives such as a diatrema origin.

Based largely on geochemical data, most investigators interpret the SIC to be an impact melt sheet. However, the granophyre, the upper unit of the SIC, intrudes the Onaping Formation. This implies that the SIC crystallized from a magma, possibly impact-triggered. An alternate scenario is that the granophyre represents a later intrusion and that the bulk of the SIC was emplaced before the Onaping, perhaps as a melt sheet. This means that the Onaping “melt” was injected through the SIC before fragmenting into a hyaloclastite. Structural data suggests that the SIC was emplaced in approximately the present disposition of the North Range i.e., dipping inward at 42°. Evidence is as follows. Igneous layering in the norite dips less than the dip of the base of the SIC. Folding of a horizontal melt sheet would produce a foliation with a steeper dip than the basal contact and a strain in possible hinge zones such as the lobes located at both ends of the East Range. A plagioclase lineation in the north lobe is orthogonal to the base of the SIC. The lineation is attributed to crystal growth in a magma chamber. Apparently, even minor deformation will destroy the orthogonality. Thus the mineral fabric and the low overall strain in the North Lobe preclude a fold origin for the present shape of the SIC.

The Sudbury Event was followed by differentiation of the units of the SIC (1850 Ma), formation of the Ni-Cu-PGE deposits, deposition of the Vermilion, Onwatin and Chelmsford Formations, hydrothermal alteration and formation of Zn-Pb-Cu deposits inside the basin. NW-directed compression and a weaker SW-directed compression (Penokean Orogeny, 1900 to 1700 Ma) folded the rocks of the basin about NW-trending, doubly-plunging fold axes and developed a prominent cleavage in them. Deformation died out to the NW as the North Range Onaping Formation and SIC have undergone only local and mild ductile deformation. In the South Range, the Onaping Formation and the SIC are steepened to the NW and displaced by a SE-dipping zone of reverse shear. On the outcrop-scale, the SIC displays anastomosing conjugate shear zones.

A revised model is required which embraces all aspects of Sudbury Geology. Many features are either force-fitted into an impact model or ignored. Some, but not all, elements are better explained by endogenic models such as diatremes and plumes. Because of the time span of Sudbury geology, perhaps too many pieces of the puzzle have been lost, thus precluding an unequivocal history of Sudbury Geology.

GEOLOGY AND ALTERATION ASSOCIATED WITH VMS MINERALIZATION IN THE HAMLIN LAKE AREA, NORTHWESTERN ONTARIO

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The Shebandowan Greenstone Belt is located within the Wawa Subprovince of the Superior Province and has been the target of numerous exploration efforts over the last century. The belt is host to many different precious and base metal mineral deposits. Past producers include the Shebandowan Ni-Cu PGE mine, the North Coldstream Cu-Au-Ag mine, and the Ardeen Au mine, Northern Ontario's first gold producing mine. With a renewed interest in the belt by many exploration companies, the potential for new discoveries is growing. The Hamlin Lake area is within the Shebandowan Greenstone belt and located approximately 120 km west of Thunder Bay, Ontario. This project will be looking at the alteration and tectonic setting that is associated with the Hamlin Lake volcanogenic massive sulfide (VMS) system. The VMS system was first recognized when massive sulfides were found while surface sampling during the 2005 field season. The mineralization includes pyrite, chalcopyrite and pyrrhotite all at the surface with stringer mineralization found in some areas as well. Trenching and drilling followed during the fall and winter of 2005/06 and revealed significant additional mineralization. The copper values as high as 1.49% have been found in surface samples with 4.88g of gold, and the Ray Smith showing is part of the Hamlin Lake property with copper values as high as 6% and 6.0g of gold.

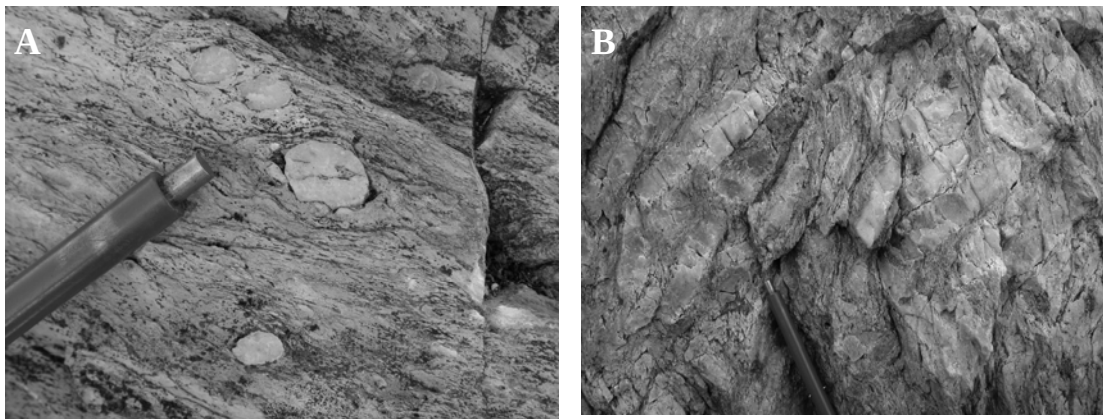


Figure 1. (a) Rhyolite showing round amygdules; (b) Felsic fragmental showing partial alignment of the clasts (magnet for scale is approximately 12.0cm long)

The Hamlin Lake area consists of four major units; felsic volcanic rocks; mafic volcanic rocks; pink brecciated rock; and banded iron formation. The smallest unit is the banded iron formation, found in one larger outcrop, but also found sporadically throughout the Hamlin Lake area in small (1-2m) lense-like showings. The mineralized pink breccia is the second least abundant unit and is the focus of a currently ongoing drilling project because of its higher grade mineralization.

The second major unit is the mafic volcanic rocks. This unit consists of a fragmental unit and can vary in groundmass from being chlorite rich to magnetite rich in the field. Geochemically the mafic volcanic rocks have SiO₂ values that range from 51.1 to 64.4 wt.%, TiO₂ from 0.08 to 0.61 wt.%, and Fe₂O₃ from 7.0 to 34.3 wt.%. The most abundant rock type and the focus of this study are the felsic volcanic rocks. In the field, the felsic volcanics contain quartz-eyes, amygdules, and fragments with a fine-grained groundmass and overall light grey colour (Fig.1a and b). These rhyolites vary in colour, texture and in geochemistry with preliminary work showing at least two distinct felsic suites when the REE's are plotted (Fig.2b). The major elements in the felsic volcanic rocks show SiO₂ values that range from 76 to 89 wt.%, TiO₂ from 0.2 to 0.8 wt.%, and Fe₂O₃ from 0.9 to 8.1 wt.%. Although the groundmass is different between the felsic and mafic fragmental volcanic rocks, their fragments are both lenticular-shaped and chert-like in appearance. These fragments have yet to be studied to distinguish their origin, but they are likely either pumaceous clasts or fragmented chert layers.

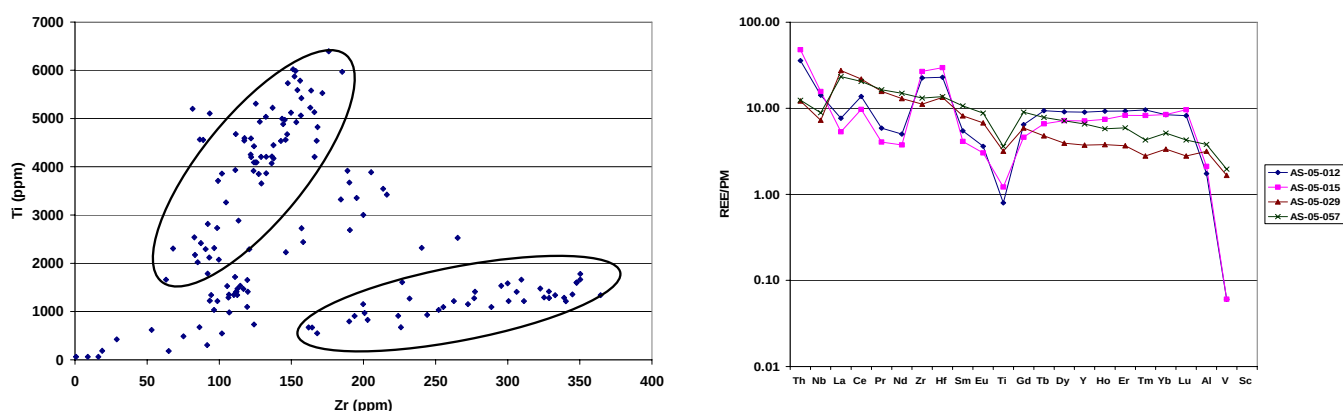


Figure 2. (a) Preliminary Zr vs. Ti (ppm) plot showing two distinct groupings of samples. (b) PM normalized REE plot showing two distinctly different rhyolites suites.

Felsic volcanic rocks associated with VMS systems have been the subject of considerable study over the past two decades. Several classifications have been created in an attempt to characterize felsic volcanic rocks that are associated with VMS deposits, and that are barren of VMS deposits. Leshner et al. (1986) classified felsic volcanic rocks as being FI, FII and FIII's with distinctions between their REE patterns, Zr/Y ratios and abundances in high field strength elements. Preliminary work has shown that there are at least two distinct felsic volcanic suites, suite I having flat REE patterns and positive Zr and Hf anomalies and suite II having more fractionated REE and lacking positive anomalies. When comparing Leshner's classification with the felsic volcanic rocks in the Hamlin Lake area, suite I most closely resembles FII whereas suite II is similar to the FI group.

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PRELIMINARY INVESTIGATIONS OF THE PETROLOGY, GEOCHEMISTRY AND GEOCHRONOLOGY OF THE ST. IGNACE ISLAND COMPLEX, MIDCONTINENT RIFT, NORTHERN LAKE SUPERIOR, ONTARIO

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As part of the Lake Nipigon Region Geoscience Initiative, a helicopter traverse was undertaken in 2005 in northern Lake Superior, in order to sample igneous rocks associated with the Mesoproterozoic Midcontinent Rift (MCR), including the St. Ignace Island Complex (SIC; Fig. 1). The SIC intruded the upper portions of MCR-related, Osler Group volcanic rocks (*ca.*1008 Ma; Davis and Sutcliffe 1985). It consists of a gabbroic to anorthositic ring dyke, which encloses quartz-feldspar porphyritic volcanic rocks (Sutcliffe and Smith 1988; Giguere 1975). Sutcliffe and Smith (1988) described the volcanic component of the SIC as intercalated plagioclase-glomeroporphyritic basaltic rocks, quartz-feldspar-phyric rhyolite flows and fragmental rocks. The pink to grey, rhyolitic rocks in the core of the SIC are dominantly quartz-phyric, with rare pyroxene and feldspar phenocrysts set in a fine-grained to glassy groundmass. They commonly contain wispy to amoeboid, mafic (basaltic?) inclusions, which are typically plagioclase-phyric. Geochemically, the quartz-feldspar-phyric rocks from the core of the SIC are dacites and rhyolites (62 to 74 wt% SiO₂) with elevated K₂O contents (2.3 to 4.8 wt%). The lower silica contents within the core of the complex are apparently associated with small mafic inclusions within the more felsic units. The sampled mafic intrusive rocks from the ring dyke are plagioclase- and pyroxene-phyric, coarse- to fine-grained gabbros to monzogabbros (53 to 58 wt% SiO₂).

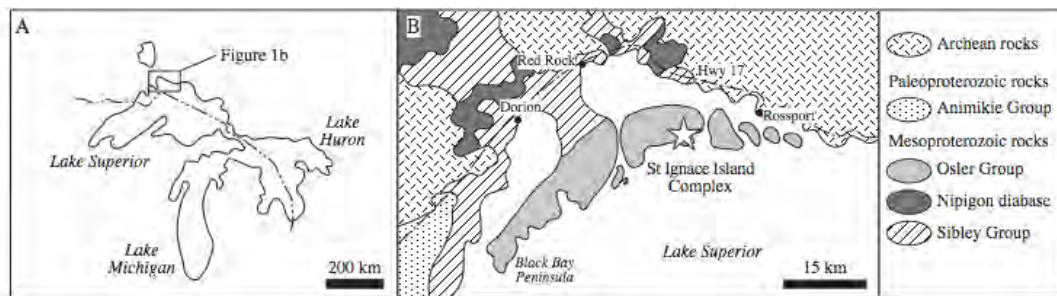


Figure. 1. A) Map of upper Great Lakes showing the location of the study area. B) Regional geology map showing the extent of the exposed portion of the Osler Group and the location of the St. Ignace Island Complex.

The SIC samples yielded both zircon and baddeleyite. Subhedral baddeleyite grains from a rhyolite in the core of the SIC yielded a ²⁰⁷Pb/²⁰⁶Pb age of 1107.2±2.4 Ma, whereas zircons recovered from the rhyolite yielded a ²⁰⁷Pb/²⁰⁶Pb age of 1124 Ma. The zircons are large and show signs of resorption; they are also characterized by high Th/U contents that are typical of zircons derived from a mafic source. The fact that this latter age is much older than that of the Osler Group basalts that the SIC has intruded, combined with a lack

of euhedral zircon and baddeleyite grains, suggests that these grains may be of xenocrystic origin. The presence of baddeleyite in a rhyolite is also somewhat unusual as these are more commonly associated with syenites found in alkalic complexes (e.g. Coldwell Complex).

Gabbro from the margin of the SIC yielded a small number of zircon grains with baddeleyite cores. These grains yielded a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1089.2 ± 3.2 Ma. The growth of euhedral zircon on baddeleyite cores is occasionally observed in mafic rocks and is interpreted to indicate increasing silica activity conditions during magma crystallization. This is consistent with field relationships, which suggest that rhyolitic and gabbroic magmas may have intermingled during emplacement. Consequently, the 1089 Ma age may represent the emplacement age of both the rhyolite and the gabbro and suggests that all dates obtained from the rhyolite are xenocrystic. This is consistent with textures observed by Sutcliffe and Smith (1988) who also reported evidence for localized magma mixing and the presence of vesicular basalt fragments in felsic, welded tuffs. This age is similar to that of other MCR-related intrusions in the area (*e.g.* Crystal Lake, Blake and Moss Lake gabbros; Arrow River dyke) that have intruded Paleoproterozoic rocks, older MCR intrusions and/or Osler Group volcanic rocks during the late stages of MCR magmatism (Heaman and Easton 2006).

Further field, petrographic and geochemical studies will seek to better determine the relationships between the various volcanic and intrusive rocks in order to understand the development of the SIC within the Midcontinent Rift.

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**CHARACTERIZING THE MONAZITE FINGERPRINT OF
PALEOPROTEROZOIC (STATHERIAN) METASEDIMENTARY SEQUENCES
IN CENTRAL WISCONSIN**

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Introduction: Supermature siliciclastic rocks of the 1750-1630 Ma Baraboo Interval are widespread in the southern Lake Superior region and signify a period of crustal stability following the Penokean Orogeny and subsequent geon 17 magmatism (Medaris et al., 2003). Although the chronology and tectonic significance of Baraboo Interval sedimentation has been firmly established, certain quartzite inliers in central Wisconsin remain enigmatic. At Hamilton Mounds Baraboo Interval quartzite is reported to be intruded by geon 17 granite (Greenberg, 1986; Van Wyck and Norman, 2004). This proposed cross-cutting relation conflicts with recent detrital zircon age data showing all Baraboo Interval quartzites to be younger than 1750 Ma (Holm et al., 1998; Medaris et al., 2003). Van Wyck and Norman (2004) propose that early onset of Baraboo Interval quartzite deposition was synchronous with magmatism, an interpretation that is unusual for this rock type and in disagreement with deposition on a recently stabilized craton (Dott, 1983). Instead, Medaris et al. (in review) demonstrate that the metasedimentary rocks at Hamilton Mounds consist of two Paleoproterozoic sedimentary sequences: an older meta-arkose intruded by geon 17 granite, and a younger, overlying supermature quartzite, which is likely correlative with Baraboo Interval quartzite elsewhere. Our purpose here is to characterize and date monazite grains in these two units. Recently, studies of detrital zircons in Baraboo Interval rocks have been invaluable for establishing their maximum age and identifying their source terrane. Assessing the monazite "fingerprint" in these rocks may allow us to differentiate between the two depositional interpretations and to better establish sedimentological aspects of post-Penokean crustal stabilization.

Monazite Textures: The quartzite unit contains only tiny (10-40 micron diameter), rounded to subrounded monazite grains that show simple chemical zonation (rims/cores). Many have cores that are high in both Yttrium and Uranium (Fig. 1a). In contrast, the meta-arkose contains a larger monazite grain-size variance (10-90 micron diameters) and more variable morphology. A few grains are rounded and chemically simple, but many have embayed grain boundaries and are complexly zoned (Fig. 1b). Some grains are irregular and some have a bladed elongate morphology that are concordant to pre-existing textural features (Fig. 1c, d).

Monazite Geochronology: Electron microprobe total-Pb analyses of the fine-grained detrital monazite from the quartzite unit yield spot ages ranging from ~2050 Ma to ~1750 Ma, with dominant peaks at ~1800 Ma and ~1860 Ma (Fig. 2a; composite mean age of 1837 ± 23 Ma). Similar analyses on the meta-arkose unit yields ages ranging from ~1900 Ma to ~1730 Ma, with a single dominant age peak at 1850 Ma (Fig. 2b; composite mean age of 1849 ± 7 Ma).

Interpretation: Both rock units at Hamilton Mounds contain abundant Penokean age

detrital grains, consistent with their having been deposited after the Penokean orogeny. Both rock units also contain some geon 17 ages. The geon 17 ages within the quartzite unit are clearly from detrital grains. However, the geon 17 ages in the meta-arkose are unlikely to be detrital considering that this unit is cut by a ca. 1761 Ma granite dike. We interpret these ages to instead reflect metamorphism associated with dike intrusion. This interpretation is most consistent with the varied monazite morphology in this unit. Our results show that monazite geochronology of metasedimentary units is a powerful tool when combined with detailed in situ textural analysis aided by a comprehensive understanding of the area's geologic context.

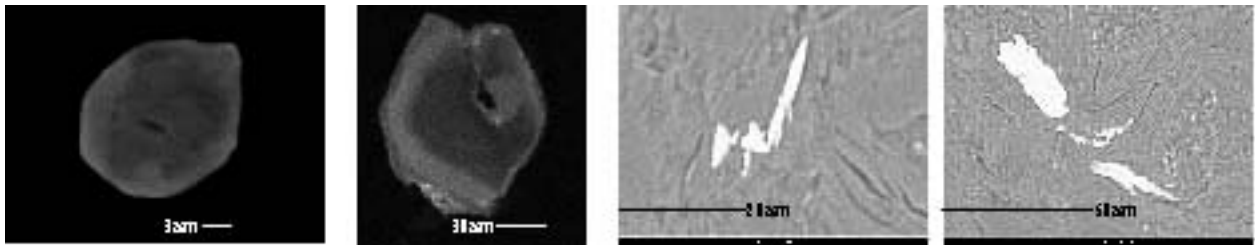


Figure 1a: Figure 1b: Figure 1c & 1d: *In-situ* BSE image of meta-Quartzite monazite grain
In-situ BSE images of meta-arkose monazite grains
 mapped for Y

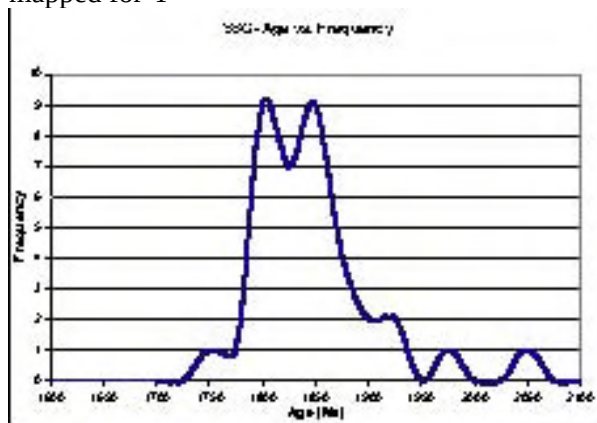


Figure 2a:
 Histogram of meta-quartzite monazite age results

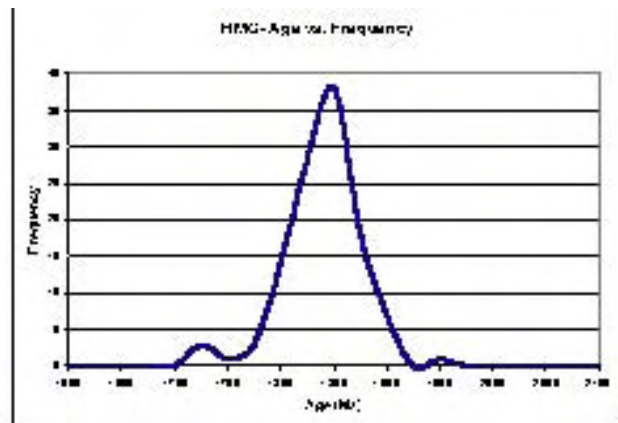


Figure 2b:
 Histogram of meta-arkose monazite age results

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**THE THERMAL HISTORY OF LOW METAMORPHIC GRADE
PALEOPROTEROZOIC METASEDIMENTARY ROCKS OF THE PENOKEAN
OROGEN, LAKE SUPERIOR REGION: RECOGNIZING A WIDESPREAD 1786
MA OVERPRINT USING XENOTIME GEOCHRONOLOGY**

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Paleoproterozoic strata in northern Michigan, Wisconsin, and Minnesota were deposited between 2.3 and 1.75 Ga within the Penokean foreland. These strata were metamorphosed by multiple events, all previously attributed to the Penokean orogeny (1875-1830 Ma). We sampled 10 localities (Fig. 1) in the Marquette Range Supergroup in Michigan and the Animikie, Mille Lacs, and North Range Groups in Minnesota that contain xenotime suitable for *in situ* SHRIMP U-Pb geochronology and where the metamorphic grade is greenschist to sub-greenschist. The units sampled are Enchantment Lake Formation (sample 1), Sunday Quartzite (sample 5), Ajibik Quartzite (sample 7), and Michigamme Formation (samples 8, 9, 10) in Michigan, and the Mille Lacs Group (sample 2, 3), the Mahanomen Formation (sample 4), and Pokegama Quartzite (sample 6) in Minnesota. Thirty-two U-Pb ages of xenotime in these samples give a population at 1786 ± 4 Ma and 9 ages give a population at 1861 ± 10 Ma. Both populations are contained in samples from the Chocoma Group in Michigan and the Mille Lacs and North Range Groups in Minnesota (Fig. 1) and thus record a region-wide 1860 Ma low-temperature thermal event that is slightly older than the basal units of the Baraga Group in Michigan and the Rove Formation in Minnesota and Ontario. This event coincides with regional uplift that led to the unconformity between the Baraga and Menominee Groups in Michigan, hence xenotime growth must have occurred at shallow depths. Younger units, including the Animikie Group in Minnesota and the Baraga Group in Michigan, record only the 1786 Ma event.

Amphibolite-granulite facies rocks within a gneiss dome corridor in the southern part of the foreland, south of our sample sites, show an 1800-1790 Ma monazite population that overprints 1830 Ma Penokean metamorphism (Schneider and others, 2004). These high grade rocks are adjacent to gneiss domes and early to late post-Penokean granite plutons. Our samples are 50 to 150 km away from these features so the 1786 Ma xenotime ages do not appear to reflect local thermal imprints from plutonism and gneiss dome formation. Several sample sites in Michigan are within the low temperature zones of the Republic metamorphic node where metamorphic monazite has been dated at 1760 ± 5 Ma (Rose and others, 2003). Thus, most of our xenotime ages are significantly older than the Republic metamorphism, which does not appear to have been a significant xenotime-forming event at our sample sites. The geographic extent of the 1786 Ma xenotime growth event suggests it was a basin-wide subtle thermal pulse. We suggest two possible causes for this event.

First, all of our age localities lie north of a corridor of gneiss domes and granitic plutons that formed in the interval 1800-1765 Ma, during a period of gravitational collapse of overthickened crust of the Penokean orogen (Schneider and others, 2004). This period of

gravity-driven tectonism and coincident heating may have driven a northward flow of hydrothermal fluids which subtly but pervasively altered the northern parts of the Penokean foreland and resulted in growth of xenotime. Alternatively the xenotime ages may record very distal effects of events within the Yavapai orogen, which truncated the southern part of the Penokean orogen on the south in central Wisconsin and southeastern Minnesota, about 200 km south of our sample sites. This early geon 17 crust-forming event occurred across the central and southwestern U.S. and may, in some as yet poorly understood manner, have caused widespread subtle heating across a broad foreland on its north.

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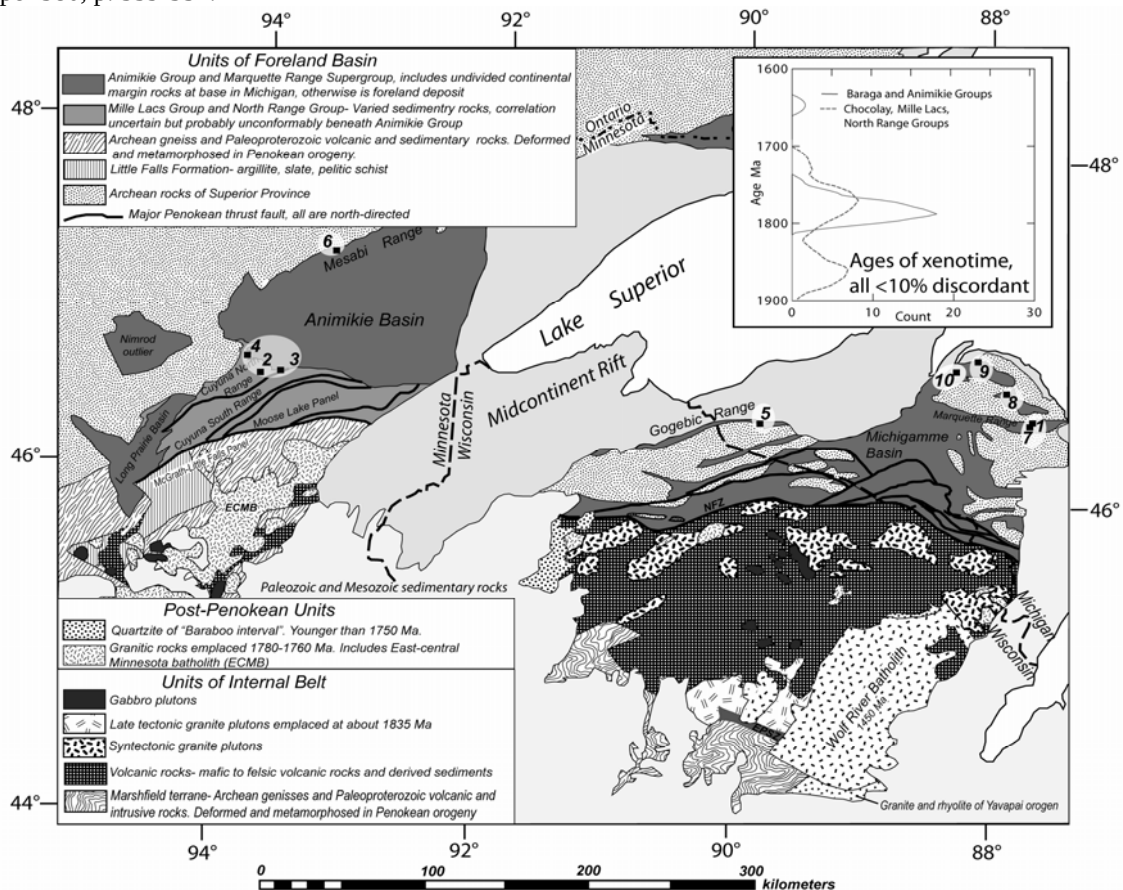


Figure 1. Map of the western Lake Superior region showing sample locations in relation to major tectonic and stratigraphic units. Inset shows density functions of xenotime ages divided into older and younger stratigraphic groups.

SULFUR ISOTOPES FROM PYRITE IN THE NEGAUNEE IRON FORMATION

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In 2003 evidence was presented at the ILSG on hydrothermal venting systems preserved in the sediments older than the Negaunee iron formation. Rare earth elements patterns for the hard ore and vent hematite suggested a commonality for the iron source.

During the study it was noted that within the hard iron oxide deposits on the Marquette Range there are numerous occurrences of veins, disseminated and massive sulfides. Pyrite is the common sulfide but both chalcopyrite and bornite can be present.

Nine pyrite samples associated with hard ores from geographically diverse locations on the Marquette Range were submitted (Geochron Labs) for sulfur isotope analysis. The isotope ratios were determined by using the Canon Diablo troilite (CDT) standard. The physical relation of the oxides to sulfides indicated either a syndeposition or post replacement of the chert and iron oxides by pyrite.

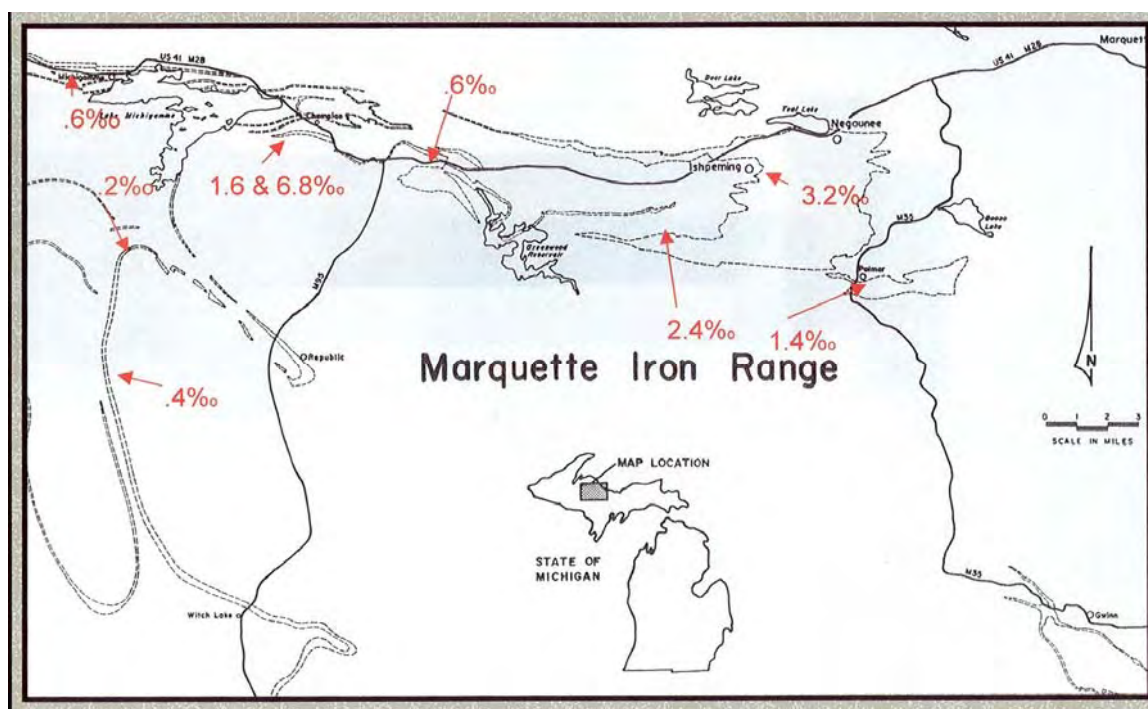


Fig. 1 Location of sulfur isotopes from the Marquette Iron Range

Sulfur associated with sedimentary processes reflect the composition of biogenic sulfide produced by bacterial reduction of marine sulfate and is likely to result in $\delta^{34}\text{S}$ values. Sulfur associated with igneous rocks is isotopically similar to that of meteorites and have $\delta^{34}\text{S}$ values close to 0‰. Further variations are due to complex and interactive chemistry of the fluids and host.

The values obtained range from + 1‰ to +6.8‰ with the mean value of 1.9‰. The narrow low positive values would suggest that the sulfur is attributable to a hydrothermal source thus supporting the earlier conclusion based on the REE data.

Since a hydrothermal component has been shown to exist for portions of the Brockman (Hagemann et al, 1999) Caue (Rosiere et al, 2004) and Carajas (Guedes et al, 2002), it is logical to project an igneous-hydrothermal source be considered for the formation of BIFs in general. It is further suggested that water deposited BIFs could be a natural end product of hydrothermal IOCG type mineralization. Many features (e.g. age, extensional cratonic or continental margin setting, not easily related to igneous activity, mineral assemblage and alteration patterns) common to Iron Oxide deposits (IOCG) are also common to banded iron formations. The existence of end member BIFs in IOCG deposits (e.g. Pilot Knob, MO and Olympic Dam, South Australia) supports the hypothesis.

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SOURCE ROCK AGES AND PATTERNS OF SEDIMENTATION IN THE LAKE SUPERIOR REGION: RESULTS OF PRELIMINARY U-PB DETRITAL ZIRCON STUDIES

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U-Pb age analysis of detrital zircons provides information about source region ages and patterns of sedimentation. Although most commonly applied to orogenic belts and accreted terranes, this technique also has great potential for illuminating the evolution of cratonic regions. Here we report preliminary results of U-Pb analyses of detrital zircons from Paleoproterozoic (Denham Formation, Pokegama Quartzite, Palms Formation, Rove Formation, Thomson Formation), Neoproterozoic (Puckwunge Sandstone, Nopeming Sandstone, Rift Interflow sediments, Fond du Lac Sandstone, and Hinckley Sandstone), and early Paleozoic (St. Peter Sandstone) rocks from Minnesota and Wisconsin.

U-Pb analyses of detrital zircons were conducted using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at Washington State University. Approximately 120 grains were analyzed from each sample. All reported ages are ²⁰⁷Pb/²⁰⁶Pb ages. Only those grains that are <10% discordant, based on comparison of ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb ages, are presented.

Arkosic conglomerate and quartz arenite of the Denham Formation are the oldest rocks that we examined in this study. The Denham samples contain zircons with ages between 3.6 and 2.1 Ga, however most grains fall into two age ranges: 3.5 – 3.4 Ga and 2.8 – 2.5 Ga. The youngest grains observed in the Denham Formation are 2.07 Ga.

Basal Sandstones of the Animikie (Pokegama) and Marquette (Palms) Supergroups in Minnesota and Wisconsin, respectively, contain mostly Neoarchean zircons with similar age distributions (2.9 to 2.6 Ga). Both formations contain scattered grains of Mesoarchean (Pokegama) and Paleoarchean age (Palms), but neither contains grains with ages < 2.6 Ga.

Fine-grained sandstones from upper Rove Formation (NE Minnesota), Thomson Formation (E. Central Minnesota), and Tyler Formation (NW WI) were deposited in a migrating foredeep north of the Penokean orogen. Most zircon grains from these three formations have ages between 2.05 and 1.80 Ga (Fig. 1). All three formations also contain some Paleoproterozoic to Paleoarchean grains, but these ages are relatively few in number. The zircon age histograms also lack the major peak at 2.7 Ga that occurs in

the basal Pokegama and Palms Formations.

Zircons from sandstones immediately below basal volcanics of the Keweenaw Midcontinent Rift (1.1 Ga) of east-central (Nopeming Sandstone) and NE Minnesota (Puckwunge Sandstone) have age distributions that are strikingly different. Zircon ages from the Nopeming Sandstone form three groups: 2.8 – 2.5 Ga, 2.1 - 1.8 Ga, and 1.2 - 1.1 Ga (Fig. 1). A few grains also have ages from 3.3 to 2.8 Ga and 2.4 to 2.2 Ga. Puckwunge zircons have a similar age distribution except that no Mesoproterozoic ages (1.2 – 1.1 Ga) are present.

Zircons from interflow sediments of the SW limb of the North Shore Volcanic Group have a dominant age peak at 1.15 to 1.0 Ga, and scattered ages in the range of 2.7 to 2.3 Ga.

Neoproterozoic Fond du Lac and Hinckley Sandstones were deposited after the main pulse of rift-related magmatism. Fond du Lac zircons have ages that range from 1.5 to 1.0 Ga; a few grains have older ages at 2.9, 2.5, and 1.9 to 1.6 Ga. Hinckley zircons have similar age distributions, but with many more ages from 3.1 – 2.7 Ga and 2.1 – 1.5 Ga (Fig. 1).

Zircons from the Middle Ordovician St. Peter Sandstone have two age populations: 2.8-2.6 Ga and 1.5-1.0 Ga (Fig. 1). Only three grains have ages between 2.5 and 1.5 Ga.

Most of the observed zircon ages can be correlated with known source rock ages in the Lake Superior region (Fig. 1). Some ages, however, have no obvious local sources (e.g., 2.5 – 2.1 Ga, 1.6 – 1.5 Ga, and 1.4 – 1.1 Ga) and must have been derived from more distal sources (Van Wyck and Norman, 2004) or from regional sources with unrecognized multicyclic components. In particular, all Neoproterozoic and Paleozoic sediments that we studied have abundant ages between 1.5 and 1.1 Ga that might have been derived from Grenville sources (e.g., Rainbird et al., 1992; Johnson and Winter, 1999).

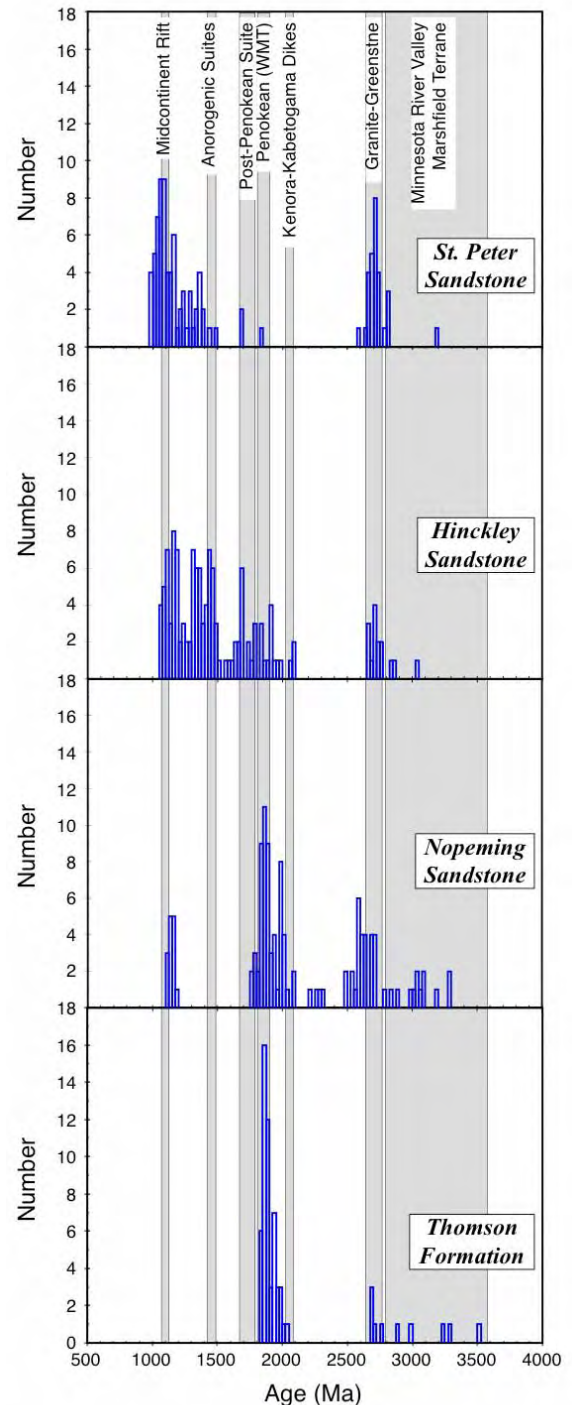


Figure 1. Histograms of $^{207}\text{Pb}/^{206}\text{Pb}$ ages from detrital zircons in Thomson Formation, Nopeming Sandstone, Hinckley Sandstone, and St. Peter Sandstone. Shaded bands indicate possible source region ages in Lake Superior Region.

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